# ATLAS OF SOIL INHABITING, FREE-LIVING NEMATODES OF GOA

A thesis submitted to

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For the award of the degree of

**DOCTOR OF PHILOSOPHY IN ZOOLOGY**

**By**


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# CERTIFICATE

This is to certify that Maria Lizanne A.C. has worked on the thesis entitled, "Atlas of soil inhabiting, free-living nematodes of Goa" under my supervision and guidance.

This thesis being submitted to Goa University, Goa, for the award of degree of Doctor of Philosophy in Zoology, is an original record of the work carried out by the candidate herself and has not been previously submitted for award of any other degree or diploma of this or any other University in India or abroad.

Date: /2015 Prof. I. K. Pai
Place: Goa University (Research Guide)

# DECLARATION

I hereby declare that the thesis entitled, “Atlas of soil inhabiting, free-living nematodes of Goa” is my original contribution and the same has not been submitted on any previous occasion, for any other degree or diploma of this or any other University / Institute. The literature conceiving the problem investigated has been cited and due acknowledgement has been made wherever facilities and suggestions have been availed of.

Date: /2015 Maria Lizanne A.C.

Place: Goa University (Research Scholar)

# PREFACE

The nematodes or roundworms inhabit virtually all ecosystems that include aquatic and terrestrial environments. They form the phylum Nematoda including free living and parasitic forms of all biota as well as predatory ones that consume various microorganisms. Generally, they are small or microscopic, usually less than a millimetre in length, with the exception of some animal parasitic forms, which are large and can be seen with the naked eye. Several nematode genera are important as pests / parasites of crops and animals, while others are beneficial and contribute to nutrient mineralization. Some of them are agents in controlling plant pests and pathogens. Nematodes are also used as bio-indicators, because of the numerous properties they possess. The soil food web is a plethora of soil organisms including bacteria, fungi, nematodes, annelids and arthropods which are dependent primarily on autotrophic input from plants or other external sources including organic matter. Nematodes are the most numerous components of the microfauna and are considered as abundant and diverse invertebrate fauna of the soil.

In the present study, an effort was made to document the diversity, abundance and distribution of soil inhabiting nematodes of the entire state of Goa, of the various vegetation types and of the paddy fields. The sampling sites were chosen opportunistically and soil samples were collected from all the 12 talukas spread across the state, different landscapes and paddy fields of three different ecological types' viz., **khazan, kher** and **morod**. The samples were processed to extract the nematodes for identification. The study was carried on for nearly three years from August 2011 to February 2014 and it resulted in documenting members belonging to nine orders, 24 families, 48 genera and 69 species of the phylum Nematoda.

The first chapter deals with the diversity, abundance and distribution of the nematode species observed in the soil samples of all the talukas. Among the nine orders that were documented, Dorylaimida represented nine families, 23 genera and 33 species followed by the order Tylenchida with four families, eight genera and nine species. Three families, six genera and ten species were reported in Mononchida, followed by three families, five genera and nine species in Rhabditida, while order Alaimida had one family, two genera and three species. In the order Enoplida there was one family, one genus and two species that were reported. The orders Araeolaimida, Aphelenchida and Monhysterida were recorded with only one family, one genus and one species. Samples from all the talukas indicated the presence of atleast 30 species, out of a total of 69 species recorded during the studies.

In the trophic groups, predators represented 14 genera and 24 species while herbivores, 11 genera and 16 species. The omnivores accounted for eight genera and nine species while bactivores for nine genera and 14 species and the fungivores, two genera and three species. Members of Dorylaimida dominated among the predators, omnivores and fungivores.

The second chapter incorporates the data on abundance, diversity and the distribution of the soil nematodes in the various landscapes elements and vegetation types. A maximum of 40 nematode species was recorded from the soil samples collected from the vicinity of roadside weeds / bushes and a minimum of 22 species was recorded from coconut grove area. The other landscapes recorded the species richness in between the above mentioned two extremes.

Maximum abundance of species was observed also from the samples of roadside weeds / bushes, similarly minimum abundance was recorded from the samples of coconut groves. Of the 69 species, that were documented, most of the soil samples of the landscapes / vegetation were represented by more than 20 species.

In abundance, a little high, positive correlation was reported between fungivores / bactivores and a moderate positive correlation was observed between omnivores / herbivores and between omnivores / predator but a very low positive correlation was observed between herbivores / predators. A negative correlation was seen between the remaining trophic groups.

The last chapter includes the documentation of nematodes from the paddy fields. 25 species including some of those recorded in the first chapter were also found to be present in the paddy fields. Of these 25 species, maximum number of species was belonging to order Tylenchida (11), followed by Dorylaimida (8), Mononchida (3), Aphelenchida (2) and minimum species belonging to Araeolaimida (1).

Among the three paddy land types (**khazan, kher** & **morod**) studied, species diversity was maximum (22 species) in the soil samples collected from **morod** land type and minimum (13 species) in **khazan** land type. **Morod** land also has high abundance (299) of individual species. 20% of the species were found to be common to all the three land types.

Among the soil samples collected during the various stages of paddy cultivation, those collected prior to harvesting showed the maximum species abundance. *Aphelenchoides besseyi* reported maximum species abundance in the samples collected before transplanting in the land types, **kher** and **morod** and its absence was obvious in the **khazan** land type. It was found that the species were evenly distributed throughtout the soil ecosystem in the various landscapes / vegetation types including paddy fields that were studied.

The aim of this present investigation was to fill in the lacunae of information on soil nematodes of Goa. The present study provides basic data and information on the soil inhabiting, free living nematodes of Goa. It will form a strong base for further studies and intense research in soil nematology of Goa. The contents of this thesis will be a useful addition to the already existing scanty and scattered literature on the soil nematodes of Goa in particular and India and the world in general. The nature and quantum of the present study is a preliminary one and the first of its kind in the state.

DEDICATED TO

VENERABLE MARY VERONICA OF THE PASSION

FOUNDRESS OF

THE APOSTOLIC CARMEL CONGREGATION

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*Maria Lizanne A.C.*
*Research Scholar*

# TABLE OF CONTENTS

# LIST OF TABLES

# LIST OF FIGURES

# LIST OF PLATES

# INTRODUCTION

*"If all the matter in the universe except the nematodes were swept away,*
*our world would still be faintly recognizable,*
*and if, as disembodied spirits, we could then explore it,*
*we should find its hills, mountains, and valleys; lakes,*
*rivers and oceans characterized by a film of nematodes."*
Cobb, 1915

# INTRODUCTION

## NEMATODES – THE INVISIBLE THREAD WORMS

Nematodes are an ecologically successful group of lower invertebrate animals even though they are placed at a very low level of taxonomic hierarchy in the animal kingdom (Ahmad, 2001). They are usually pseudocoelomate, microscopic, unsegmented, colourless and triploblastic animals. They are structurally very diverse and in numerical superiority they surpass all imaginations. Chew in 1974 remarked that nematode population is one of the most important soil biota groups. They play an important and leading role as regulators of energy. A single acre of soil from a farming land is said to harbour as many as 3,000,000,000 nematodes. At least 500,000 species of nematodes probably inhabits this earth (Jairajpuri, 2002 a).

Nematodes constitute the largest and most ubiquitous group of kingdom Animalia. They are the most common of all the soil fauna, numbering from 1.8 to 120 million per square meter of soil in some cases (Kevan, 1965). Nematodes are biologically diverse and versatile; they occupy various habitats and in number, constitute nearly 90% of all the metazoans in the world (Jairajpuri, 2001). By 2001, Hugot *et al*. had considered about 26,646 species. They are simple animals, often containing only 1000 cells or may be less (Lambert and Bekal, 2002). Most nematodes are microscopic and in size may range from 100 micrometres in length (1 / 10th of a mm or 1 / 250th of an inch) to the female giant nematode, *Dioctophyme renale,* which may grow up to 1 / 2 metre/s or parasites of vertebrates that can reach to several meters (about 8) in length (*Placentonema gigantissima*, a parasite of sperm whale) (Jairajpuri, 2002 b).

Nematodes are basically aquatic animals that adjust naturally to a variety of terrestrial habits provided there is a thin film of water around them. Water or liquid medium is absolutely necessary for their existence as well as for their survival, either parasitic or free-living. Nematode species that are adapted to a terrestrial mode of life survive only because of the moisture holding capacity of the soil particles. Nematofauna like insects occur in all possible kinds of climatic conditions and habitats. One important feature of nematode population is the large number of species present in a given habitat; of an order of magnitude that is higher than any other taxon (Platt and Warwick, 1980). The number of taxa unknown to science is particularly more for the underground biota especially for nematodes. Barker *et al.,* (1994) estimated that only 3% of the world's species have so far been studied and described.

The composition of species, population densities and proportionate dominance vary greatly in relation to food and other biotic and abiotic factors. Nematodes are trophically diverse acting as herbivores, bactivores, fungivores, omnivores and predators as has been classified by Yeates *et al.*, (1993). There are generally two types of body forms in nematodes: the *fusiform* and the *filiform.* The *fusiform* shape is that of an elongated spindle, widest through the middle and tapering toward the blunt or pointed ends; the posterior end is generally more tapering and pointed than the anterior end and in some species is very slender. The *filiform* which is less common has a body which is thread-like and of uniform diameter throughout, not diminishing toward the ends.

**BIONOMIC IMPORTANCE**

One of the reasons why nematodes are useful for biological research is due to their simple anatomy and transparent bodies. Being small and a microscopic life form, *Caenorhabditis elegans* has been regarded as one of the best models for human diseases and it has contributed enormously to our understanding of human neurodegenerative disorders including Alzheimer's (Sherrington *et al*.,1995; Levitan and Greenwald, 1995; Link, 1995), Parkinson's (Lakso *et al*., 2003) and Huntington's (Faber, *et al.*, 1999) diseases; depression (Ranganathan, *et al*., 2001), cancer (Poulin et al., 2004) and aging (Kenyon, 2005); metabolic disorders such as obesity and diabetes (Pierce *et al*., 2001) and genetic diseases such as autosomal dominant polycystic kidney disease (Barr and Sternberg, 1999), muscular dystrophy (Gaud *et al*., 2004) and arrhythmia (Petersen *et al*., 2004).

Nematodes possess several beneficial features that make them useful ecological, bio indicators (Bongers, 1990; Freckman, 1988; Neher, 2001). They are important organisms, in the decomposition of dead and decaying organic matter, mineralization and recycling of plant nutrients and in replenishing soil nutrients in the terrestrial ecosystem (Griffiths, 1994; Boag and Yeates, 1998; Yeates and Bongers, 1999). Many free-living nematode species are bio indicators of pollution levels, mostly of heavy metals and other conditions in the soil or water (Li *et al*, 2011). They are considered as good indicators of a variety of soil properties, as they not only help in soil processes, but also influence these processes eg. transformation of organic matter into mineral and organic nutrients (Bongers, 1990; Freckman and Ettema,1993; Neher *et al*., 1995). Nematodes are known to occupy an important and central position in the soil detritus food chain and food web (Ingham *et al*, 1985; Freckman, 1988; Moore and de Ruiter, 1991). As part of soil organic matter, nematodes are key soil components to enhance soil fertility, thereby crop productivity and balance ecosystem functioning, thus maintaining a balance of the soil ecosystem health.

As primary grazers of saprophytic bacteria and fungi, nematodes are able to make mineral nutrients easily available to higher plants (Freckman and Baldwin, 1990). Although bacteria and fungi are the primary decomposers in the soil food web, these microbes can also immobilize inorganic nutrients in the soil. When the bactivore and fungivore nematodes graze on these microbes, they give off $CO^2$ and $NH_4^+$ and other nitrogenous compounds, which directly affect C and N mineralization (Ingham *et al*, 1985). Besides contributing to C and N mineralization, many free-living nematodes, especially the bactivores, omnivores and predatory nematodes, are also found to correlate with concentrations of many other soil nutrients, suggesting the possibility of nematodes mineralizing many of these nutrients. Nematodes help in capturing and storing carbon that otherwise would contribute to global warming when allowed to overload the atmosphere in the form of carbon dioxide gas.

Soil free-living nematode communities and their structural changes have been found to be one of the best biological tools for assessing soil disturbances, including heavy-metal pollution

(Bongers *et al.*, 2001; Georgieva *et al.*, 2002), in addition to agricultural and extensive grazing activities (Yeates and Bongers, 1999; Kandji *et al.*, 2001; Mills and Adl, 2006) in the terrestrial ecosystems (Gupta and Yeates, 1997; Neher, 1999). Due to their immense sensitivity to various changes in the soil ecosystem and their ability to reflect differences between disturbed, undisturbed and human-impacted environments, the free-living nematodes are considered to be very useful and inexpensive organisms for ecological research (Porazinska *et al.*, 1999).

## SOIL INHABITING NEMATODES

Soil inhabiting nematodes predominate over all other soil animals, both in number and species. Several taxonomically differing groups of nematodes inhabit the soil but members of the order Dorylaimida occur more commonly than others (Ahmad, 2001). Nematodes are ubiquitous inhabitants of soil, subsisting on living organisms of every type and, in turn, contributing their biomass to other soil biota. Soil nematodes are vermiform animals, usually very small, the adults may grow up to 5.0 mm long, are very abundant, about millions / $m^2$ and mostly diverse in all soils (Yeates, 1979). In spite of being small in size and usually with trivial contribution to the total biomass, they have significant functions in soil communities (Bongers, 1986; Ferris and Ferris 1972; Freckman, 1982; Norton, 1978; Yeates, 1979).

Although, nematodes represent a relatively small amount of biomass in the soil, they occur across multiple trophic levels and are essentially very important in the soil environment (Barker and Koenning, 1998). Their feeding habits are clearly related to their oral structure and they are easy to be extracted from the soil using simple extraction procedures (Ritz and Trudgill,

1999) so their trophic roles can be readily inferred. Soil texture (Hunt, 1993), soil temperature (Boag *et al*., 1991) and broad vegetation types (Boag and Orton Williams, 1976) have been found to have a strong influence on the distribution and density of many soil nematode taxa.

The biotic factors of soil environment include roots of living plants and soil microflora and fauna including nematodes. Plant roots and soil microorganisms influence the nematodes and are in turn affected by nematode activity. As nematodes feed on a wide range of soil organisms and are dependent on the continuity of soil water films for movement, their activities are largely controlled by soil biological and physical conditions. Nematodes are influenced by the physico-chemical factors of soil. Interpretation of soil health condition by using nematode community analysis requires a comprehensive study that includes different nematode trophic groups, fungal- to bacterial-feeding nematode ratio, richness, diversity, dominance, maturity index (Bongers, 1990; Neher, *et al.* 1995; Neher and Campbell, 1996; Bongers *et al.*, 1997).

Coarse textured soils (loamy and sandy loam) are ideal for nematode activity. The optimum soil crumb size for movement of nematodes is 150 to 250µm in sandy loam and 250 to 400µm in peat soil. Movement is faster in peat soil because of less friction between nematodes and peat crumbs than in clayey or sandy loam where there is more friction. Maximum multiplication occurs in sandy clay loam with pH 6.4 (laterite soil) (Norton, 1978); while sandy soil alone, supported minimum multiplication. Clayey loam (alluvial soil) and coarse sandy loam also support appreciably high populations. The texture of the soil is of some importance as the nematode population is generally higher in lighter soils than in heavy soils (Thorne, 1927).

Extreme of soil moisture conditions is generally harmful to nematodes. They are killed by flooding either due to rain or irrigation or by drying of soil during hot summer months. The water saturated condition of the soil is unfavourable because the soil pores have only water, no air. Extremely dry soils have only air, no water in the pores. Nematodes attacking wetland crops like rice are well adapted to highly wet conditions (Singh and Sitaramaiah, 1993).

Terrestrial nematodes are classified into three ecological categories: 1) Cosmopolitan species, that live under almost any conditions, 2) Widely distributed species, that are somewhat limited to particular combinations of environmental conditions and 3) Sharply local species, that are found in very special and often in peculiar situations. Moisture, presence of plant roots and the presence of decaying plant and animal matter are the chief factors that favour the abundant occurrence of free-living soil nematodes (Hyman, 1992*).* They feed on dead, decaying or diseased plant materials. In general free-living nematodes show no particular adaptations to terrestrial life (Steiner,1917).

## THE STATE OF GOA

Goa is the smallest, agrarian state, located on the West Coast of India (Figure 4-1). It has rich flora and fauna, owing to its location on the Western Ghats, which forms most of the eastern Goa and has been internationally recognized as one of the Biodiversity Hotspots. Its geographical position is marked by $15^0$48'00"N and $14^0$53'54"N and $74^0$20"13"E and $73^0$40'33"E and has an area of 3,702 $km^2$. Esconed on the slopes of the Western Ghats (Sahyadri ranges), to the north of Goa, is the Sindhudurg district of Maharashtra, to the East is Belagavi, on the south, Goa is bounded by  Uttara Kannada district of the state of Karnataka and on the west, by the Arabian Sea. It is interspersed with extensive paddy fields and fine network of waterways. The agriculture along with the forest cover (1424. 46 sq. km) is instrumental in keeping Goa green and covers nearly 65% of the total area of the State. Paddy is one of the predominant crops of the State which is followed by coconut and cashew.

**PHYSICAL FEATURES OF GOA**

In a broad sense, there are four main physical divisions of Goa: The Eastern Hilly region encompassing areas in the Western Ghats like Satari, Sanguem, Dharbandora and Canacona, the Central Valley lands comprise of Pernem, Ponda, Bicholim and Quepem, the Flood Plains comprise of the coastal plains and undulating uplands and the Coastal Plains with areas of Mormugao, Tiswadi, Salcete and Bardez (i). The height of Goa is from sea-level at the coast to an altitude of about 1,022 metres above sea-level and its highest point is at Sonsogad, 1,167 metres in the Sahyadri Ghats (ii).

**CLIMATE**

The state of Goa, situated well within the tropics and flanked by the Arabian Sea to the west and the Western Ghats to the east, has tropical maritime and monsoon type of climate, with profound orographic influence. Accordingly, the climate is equable and moist throughout the year. Goa is in the path of the southwest monsoon, experiencing a dry period of six to eight months followed by rainfall of four months. It receives regular and sufficient precipitation with uni-modal pattern during the southwest monsoon season mainly from June to October which is about 250 cm (2014) on an average in 100 to 120 days and experiences temperate weather conditions, during the rest of the year, with little or no clear cut demarcation between, what is generally termed as winter and summer seasons. By and large, Goa experiences warm and humid tropical climate, which is generally pleasant. Temperature variations through the seasons are also slight. The month of May is relatively the warmest, when the mean daily temperature is around 39$^{o}$C and the coolest month is January, when the mean daily temperature is around 18$^{o}$C. The state is generally humid, due to its proximity to the sea. The humidity rises during the monsoons, but on an average the humidity is around 76%.

The state of Goa has rich soil, laden with organic matter, along with vast expanse of vegetation (Anonymous, 1979). Soil is an excellent habitat for nematodes; they inhabit the thin film of moisture around the soil particles. Because of their size, nematodes tend to be more common in coarser textured soils. Nematodes move in water films in large pore size. In soil, the nematodes dominate, in number as well as species, over all other soil-inhabiting animals collectively and have occupied all possible habitats, representing a very wide range of biological diversity (Cobb, 1915). Dense vegetation and grass, have contributed to high contents of organic matter (0.5 to 1.5% organic carbon), in several soils of the state. On the whole, the pH of the soils ranges from 4.5 to 6.5. Soils of Goa in general, are productive and respond well to irrigation and fertilizer (N & P) management (xi). The above mentioned conditions such as good rainfall, humid climate, moist soil that is abundant with decaying and decomposing organic matter, can make soils of Goa a very favourable and rich habitat to sustain enormous diversity and abundance of nematodes species.

# REVIEW OF LITERATURE

*"On the ineffaceable trail of the past*
*are built the edifice of the future"*

# REVIEW OF LITERATURE

## HISTORICAL ASPECTS

Members belonging to the phylum Nematoda (round worms), have been surviving for approximately one billion years, thus making them, one of the most ancient and diverse types of animals, on the earth's surface (Wang *et al*., 1999). Perhaps, they might have evolved from simple animals, some 400 million years before the "Cambrian explosion" of invertebrates, were able to be fossilized (Poinar, 1983). Thus, we find that very few nematodes have been fossilized and exactly what ancestral nematodes looked like, remains absolutely unknown. While we do not know the internal as well as the external morphology of the primitive nematodes, it is quite probable, that they were microbial feeders in the primordial oceans.

The oldest known fossils of nematodes are only about 120-135 million years old; by then they might have been already diversified to feed on microbes, animals and plants (Poinar *et al*. 1994, Manum *et al*. 1994). The earliest fossils of nematodes are now found only in the amber. Much of what we know about the evolution of nematodes is the result of the study of the comparative anatomy of existing nematodes, their trophic habits, and by the comparison of the nematode DNA sequences (Thomas *et al*. 1997, Powers *et al*. 1993). It might be that nematodes have evolved their ability to parasitize animals and plants several times during their evolution and this inference is based upon the analyses of molecular phylogeny (Blaxter *et al.* 1998).

It is very clear that nematodes have evolved to occupy almost every conceivable niche on the earth that contains, at least a thin film of water and some organic matter. It is a fact that nematodes are extremely abundant and diverse animals. Most nematode species are free-living, mostly feeding on bacteria, fungi, protozoans and other nematodes (40% of the described species); many are parasites of animals, invertebrates and vertebrates (45% of the described species) and plants (15% of the described species) (Lambert and Bekal, 2002).

**ANCIENT HISTORY**

Occasional references to nematodes are found in the *Rig*, *Yajur* and *Atharv* Vedas (6000-4000 BC) under the Sanskrit name *Krmin* or *Krmi* meaning worm (Ray, 1992). Later, when indigenous medical science, *Ayurveda* (3000 BC) developed, Charaka recognized 20 different microscopic organisms as *krmis* in his *Samhita*, which included nematodes with accurate descriptions of intestinal helminths (*Charak Samhita*, Hoeppli, 1959).

The oldest reference to giant intestinal parasitic nematodes of human beings (*Ascaris*) is found in 'Huang Ti Nei Ching' or 'The Yellow Emperor's Classic of Internal Medicine' from China (ca. 2700 BC). Record of nematodes among the ancient civilizations of the Mediterranean and Middle-east occurs in the Ebers' Papyrus (1553-1550 BC) indicating the presence of *Ascaris lumbricoides* and *Dracunculus medinensis,* even at that time. Old Hebrew writings contain many references of what may be interpreted as parasitic diseases caused by nematodes, Agatharchides, (180 BC). More definite references to roundworms and threadworms can be found in Greek writings of Hippocrates in 400 BC and Aristotle in 350 BC.

## EARLY HISTORY

It was in 1656 AD, that Borellus, first discovered the free-living nematode 'vinegar eels' (*Turbatrix aceti*), which once were present in all types of vinegar. While European workers have contemplated the extinction in the wild of this vinegar eelworm, *Turbatrix aceti* – the first 'free-living nematode' reported, it has recently been recorded from spoiled vinegar in Brazil as is been reported by De Moura *et al*., 2006. Tyson was the first to study the anatomy of nematodes and described a nematode egg in 1683 AD. Turbevill Needham, a Catholic Clergyman, in 1743 AD discovered accidently, the wheat seed gall nematode which was later named as *Vibrio tritici* and now known as *Anguina tritici* by Steinbuch in 1799 AD.

In 1845 AD, Dujardin published one of the major taxonomic works in Nematology where two large genera, Dorylaimus and Rhabditis were described by him. Berkeley in 1855 AD observed for the first time, 'vibrios' (*Meloidogyne*) from galls on the roots of cucumbers in England. In 1857 AD, Kuhn reported *Anguillula dipsaci* (*Ditylenchus dipsaci*) infecting the heads of teasel, *Dipsacus fullonum*. Schacht in 1859 AD found that, the decline in sugarbeet production, in Europe, was due to a cyst nematode which was later named as *Heterodera schachtii* by Schmidt in 1871 AD. Bastian in 1865 AD published a monograph, where over hundred species of free living nematodes were described, for the first time. Ritzema-Bos reported foliar nematode, *Aphelenchoides fragariae* on strawberry in 1891 AD. Later, in 1892 AD, Liebscher discovered Pea cyst nematode, *Heterodera goettingian.* Kuhn (1913-14) from Germany made the discovery of potato cyst nematode, *Heterodera rostochiensis* (*Globodera rostochiensis*).

## MODERN HISTORY

In 1941, the potato cyst nematode was also discovered in Nassau County, Long Islands, New York State, US. Christie & Perry in 1951, demonstrated the pathogenic potential of ectoparasitic nematodes e.g., *Xiphinema, Longidorus, Belonolaimus, Dolichodorus, Hemicycliophora* etc. The year 1953 saw the discovery of a burrowing nematode as causal organism of 'Spreading Decline' of citrus in Florida, USA; and of 'Yellows' disease of pepper in Indonesia. In 1955, lesion nematode, *Pratylenchus penetrans* was discovered, as the causal organism of Peach replant problem in Canada and demonstration of its pathogenicity to the satisfaction of Koch's postulates.

## CONTRIBUTIONS OF PIONEERS IN NEMATOLOGY

Cobb has many outstanding and important contributions to Nematology and from the collections of his writings, '*Contributions to a Science of Nematology*' published in 1913 is the most outstanding. His work is still rated to be of the highest standard till date. He devised many techniques which are routinely used today, sieving nematodes, extracting them from soil, mounting of nematodes for permanent slide preparation etc. He gave the descriptions of minute sensory organs of nematodes like amphids, phasmids, deirids, cephalids etc. He discovered many new species of nematodes and separated the free-living and plant parasitic nematodes from Helminthology to Nematology; a term proposed by him in 1914 and is still in use. He also established the Division of Nematology in the US, Department of Agriculture in early 1900. Bütschli, (1875) produced comprehensive illustrated descriptions of free-living soil nematodes including several species belonging to Order Tylenchida. De Man (1884) published numerous papers on nematode taxonomy. Monograph on free living nematodes of the Netherlands in the year 1884 is considerd as one of the most classical work. The most outstanding account of nematodes is "*An introduction to Nematology*" (1937) by Chitwoods and collaborators, "*A synopsis of the families and genera of nematodes*" by Baylis and Daubney (1926) and "*The nematode parasites of vertebrates*" by Yorke and Maplestone (1926) are useful taxonomic aids. Two outstanding Russian scientists, Paramanov and Fillipjev established philosophies that brought Nematology to maturity as a Zoological Science in 1930s.

Goodey published two exhaustive books on nematodes. The first published in 1933 was "*Plant Parasitic Nematodes and the diseases they cause*" and the second published in 1951 was entitled "*Soil and freshwater nematodes*". Goodey was instrumental in revising and updating his second book in 1963. Filipjev in 1934 wrote two books on nematodes, "*Nematodes harmful and useful in agriculture*" which was later translated by Schuurmans in English and "*A Manual of Agricultural Helminthology*" (1941). Christie (1959) published an excellent book on "*Plant nematodes, their bionomics and control*" that covers major plant parasitic nematodes, their symptoms, life histories, feeding habits, distribution and control. Later, Thorne (1961) wrote a useful book on, "*Principles of Nematology*". Taylor in the USA; Franklin, Fenwick, Pitcher, Jones and Peters in England and Heinrich Micoletzky in Austria, were the other pioneers in the field of Nematology. A more complete outline of historical developments was provided by Ferris and Bongers (2009). Further, noteworthy ecological contributions developed in the 1970s and 1980s (e.g., Nicholas, 1975). Centers of ecological study on nematodes were established in Sweden (e.g., Sohlenius, 1973), Poland (e.g., Prejs, 1970; Wasilewska, 1970), Italy (e.g., Zullini, 1974), Germany (e.g., Sudhaus, 1981), and Russia (e.g., Tsalolikhin, 1976). The study of *C. elegans* has led to far better insights into the facts of animal development and neurobiology and has been of great value in biomedical research as well as in the understanding of nematode biology and also in deciphering the working of the anaesthetic mechanism in human beings (Riddle *et al.* 1997).

## HISTORY OF NEMATOLOGY IN INDIA

The first ever report of a plant parasitic nematode from India, was by Barber in 1901, about the root-knot nematode, *Heterodera radicicola* (the then name of *Meloidogyne*) infesting tea in South India. During the period of 1913-19, Butler reported ‘ufra’ disease of rice from Bengal which was caused by *Ditylenchus angustus*. As the disease was first observed in the rice fields of a farmer named Uftur Rahman from Bengal, it was named after him.

In 1919, Milne reported seed gall nematode (*Anguina tritici*) of wheat. During the period of 1926-34, Ayyar recorded root-knot nematode on vegetables and other crops in South India. In 1936, white tip disease of rice by *Aphelenchoides besseyi* was reported by Dastur. ‘Molya’ disease of wheat and barley was recorded from Rajasthan by Vasudeva in 1958 which was caused by nematode species, *Heterodera avenae*. In 1959-61, Siddiqi discovered Plant Parasitic Nematodes from Uttar Pradesh including citrus nematode (*Tylenchulus semipenetrans*). Cereal cyst nematode was reported for the first time from India by Prasad *et al*., in 1959. In 1961, Jones of Rothamsted Agricultural Experiment Station, UK., visited India and discovered the golden potato cyst nematode, *Heterodera* (*Globodera*) *rostochiensis* from the Nilgiri Hills of Tamil

Nadu in South India. In 1966, Nair and his coworkers recorded the burrowing nematode (*Radopholus similis*) of banana in Kerala. 1966 also saw the Division of Nematology established at the Indian Agricultural Research Institute, New Delhi. In 1967-68, the First South-East Asia Post Graduate Nematology course was held at Aligarh Muslim University and Indian Agricultural Research Institute, New Delhi, in collaboration with the International Agricultural Centre, Wageningen (Netherlands).

In 1971, the publication of Indian Journal of Nematology was started. In 1977, All-India Co-ordinated Research Project (AICRP) on 'Nematode Pests of Crops and their Control' funded by Department of Science and Technology, and later by Indian Council of Agricultural Research (ICAR) started functioning in 14 centres in India. Literature survey also revealed that many new species belonging to different orders and genera were reported for the first time in different states of India **(**Ahmad and Jairajpuri, 1988a). Relationship between the new and known species of genera *Tripylina* Brzeski and *Trischistoma* Cobb, 1913 (Nematoda) has also been studied by Qudsia and Tabinda, 2010.

The studies on soil nematodes collected from the recent survey of Ladakh (July 2008), revealed two new records for India, *Cervidellus vexilliger* (de Man, 1880) Thorne, 1937 and *Chiloplacus demani* (Thorne, 1925) Thorne, 1937, while, *Acrobeloides nanus* (de Man, 1880) Anderson, 1968 was being recorded for the first time from Ladakh region, Jammu & Kashmir, India (Rizvi, 2010a). Review of the literature by Boag and Yeates, (1998) regarding nematode diversity highlighted the crucial lack of information especially in the tropical areas. D. J. Raski contributed immensely towards developing Nematology in India. He gave the first report of virus transmission by Plant Parasitic Nematodes. The outstanding contributions of Siddiqi, Jairajpuri and other co-workers from Aligarh Muslim University, Das from Hyderabad, E. Khan from Delhi and several other young taxonomists has greatly helped in establishing a sound basis for all developmental work in Nematology in India.

**NEMATOLOGY IN GOA**

Ahmad and Jairajpuri in 1984 reported two new species of Dorylaimoidea, *Prodorylaimium goanese* and *Indodorylaimus saccatus* from the soil of Mayem, Goa. Later, in 1988b, they reported for the first time, the presence of *Lenonchium macrodorum* from the soi1 around roots of paddy, *Oryza sativa* L., from Mangeshi, Goa. Koshy *et al.,* (1988) reported the occurrence of a burrowing nematode, *Radopholus similis* in the state of Goa. Ahmad and Ahmad (1992) reported the presence of *Makatinus heynsi* a species of Dorylaimida, from Goa. Pai and Gaur (2010) reported for the first time the occurrence of an economically important spiral nematode (*Helicotylenchus multicinctus,* Cobb.) from Goa. Maria and Pai (2014a) reported 52 nematode species belonging to seven orders for the first time from the South District of Goa. Maria and Pai (2014b) highlighted the importance of soil inhabiting nematofauna in enhancing the fertility of soil.

**CONTRIBUTIONS ON SOIL NEMATODES**

A milestone in the ecology of free-living soil nematodes was the seven-year study in Denmark by Overgaard (1949) on nematode faunae of different soils, their physiological ecology and inference to soil ecosystem services. In the US, there was a huge surge of activity in soil ecology around 1980 (Norton, 1978; Yeates and Coleman, 1982; Stinner and Crossley, 1982) and, in the same time period, a very productive program on the ecology of soil inhabiting nematodes developed in New Zealand (e.g., Yeates, 1979). Nematofauna richness, as indicated by the number of genera (Ekschmitt *et al.*, 2001), reflects biodiversity of soil environment. Future research on soil nematode ecology could also use molecular techniques and stable isotope chemistry (Moens *et al*., 2005) to assist in determining or confirming the trophic groups of some confusing species found in the soil. The studies of Ingham *et al.* (1985) stimulated interest in the positive contributions of free-living soil nematodes in nutrient cycling and agricultural productivity and the extensive review of nematode feeding habits by Yeates *et al*. (1993) provided a necessary foundational basis. Previous investigations showed that density, biomass, trophic structure, species diversity, and sex ratio of soil free-living nematode communities were sensitive to anthropogenic changes in soil ecosystems (Georgieva *et al.*, 2002; Yeates *et al*., 2003; Pen-Mouratov *et al.*, 2008). Gradual reductions of nematode abundance and diversity, and changes in the distribution of genus and trophic group composition have been observed with increasing soil depth (Yeates, 1980; Yeates *et al*., 2000; Lazarova *et al*., 2004).

Maggenti, (1981) and Siddiqi, (1986) gave taxonomic keys for tylenchids identification upto genus level while Nickle, (1991) provided more recent keys for the identification of the same. Keys for plant-feeding dorylaimids and aphelenchids, were given by Hunt, (1993) and to free-living, predacious and plant-feeding dorylaimids were given by Jairajpuri and Ahmad, (1992). Andrássy, (1984) provided keys to most species of terrestrial and freshwater nematodes that have no spear while Bongers, (1988) to all soil and freshwater nematodes from The Netherlands.

# PURPOSE OF STUDY

The review of literature reveals that immense studies on the diversity of nematodes and on related issues have been done in various places round the globe. Closer home the taxonomists during 1960s and 1970s had almost the entire nematofauna of India to discover and made good use of this chance to describe more than 500 species within a short time of about 13 years (Sitaramaih *et al*., 1971). They first concentrated on the identification and descriptions of new species and new records from India. Later on their approach was shifted in building a sound classification and on the study of intraspecific variations.

A lot of work has been done on the fauna of Goa (Anonymous, 2008). But, groups such as nematodes are practically ignored and unrecorded. This could probably be, owing to their microscopic size and hidden life, that they have been totally neglected. Further perusal of the literature reveals that, regardless of the extensive work done on nematodes world over and in various states of our country, India; almost no work, other than a few stray reports as mentioned in the review of literature has been carried out from Goa. There is hardly any literature available on the diversity of nematodes of Goa (iii). Further, no quantitative and qualitative reports on the terrestrial, free living nematodes of Goa are available.

As a solid foundation for understanding nematofauna of the state of Goa, a humble and a preliminary but extensive study was undertaken, to prepare an atlas of the soil inhabiting, free-living nematode fauna of Goa, which happens to be for the first time in the state.

Recognizing the importance of soil inhabiting, free living nematodes, the following objectives were worked out for the thesis:

1) Documentation of the diversity, abundance and distribution of the soil inhabiting, free living nematodes of the entire State of Goa.

2) Recording the description / diagnosis of the documented nematodes species along with their morphometric information.

3) Documentation of the diversity, abundance and distribution of soil nematodes of the various vegetation types and landscape elements of Goa.

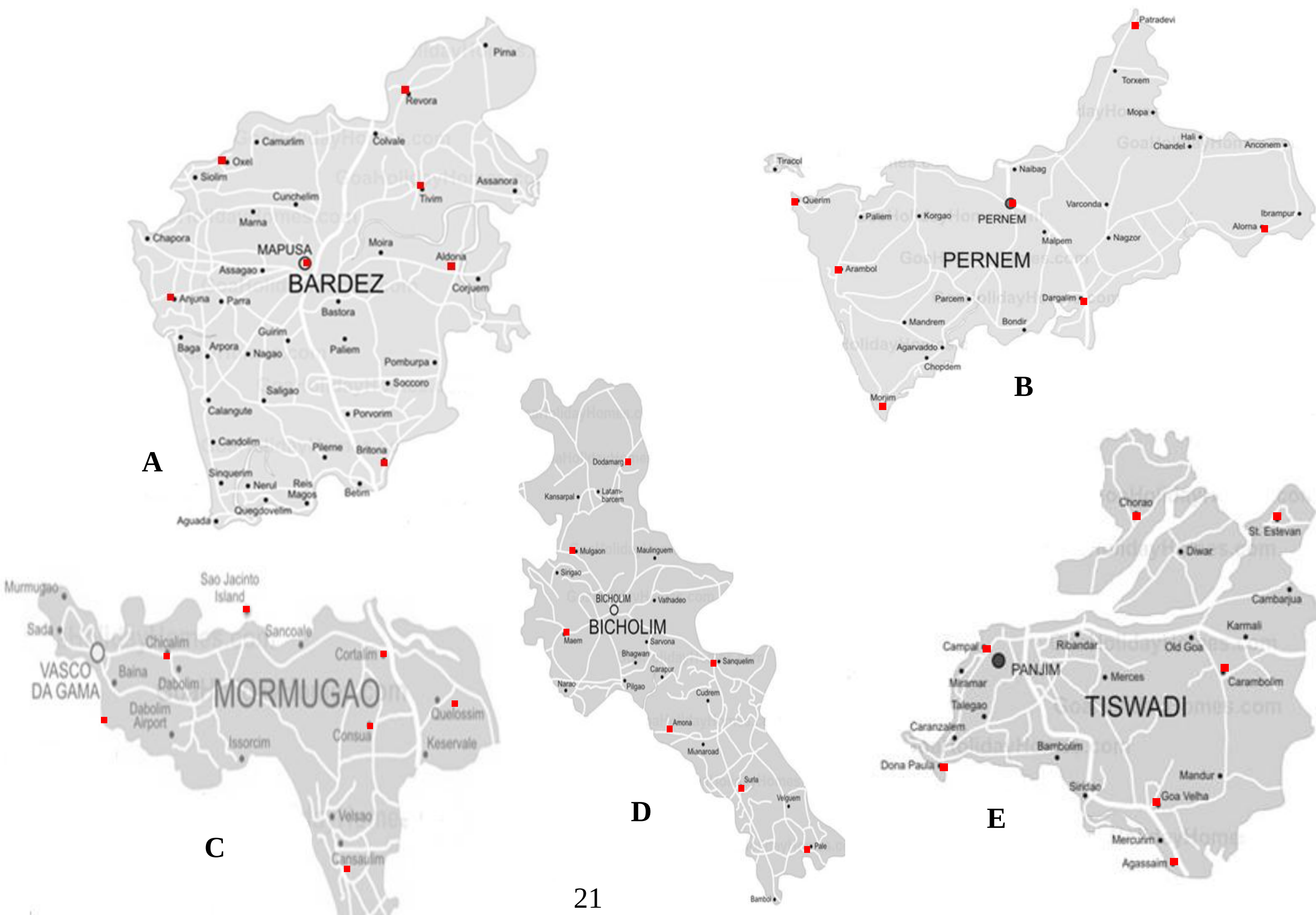
4) Documentation of the specific nematofauna of the paddy fields of Goa.

The study was carried out to fill in the lacuna of the invertebrate fauna of Goa especially of the soil nematodes and to add to the already existing knowledge, on the rich biodiversity of Goa. The observation and results recorded in this thesis provide the basic information and data required on the diversity of soil inhabiting, free living nematodes of Goa.

# STUDY SITE


Figure 4-1: Map of India showing the location of Goa


Figure 4-2: Map of Goa with the 12 talukas

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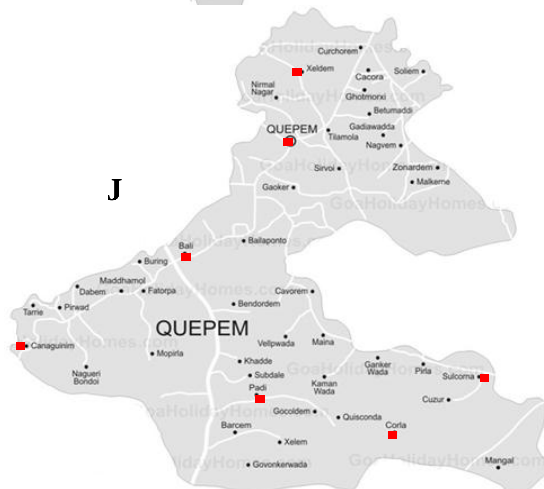


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**Figure 4-3: Maps (A-L) of different talukas of Goa (not to the scale) showing the sites (red squares) of sampling. (xii)**


L

| SR. NO. | SAMPLING SITES TALUKAS VILLAGES | LANDSCAPE |
|---|---|---|
| 1. | Marmagoa: i) Chicalim | Flower gardens, banana grove |
| | ii) Consua | Bushy plants, *Acacia* plantation |
| | iii) Sao Jacinto Island | Gulmohar tree, near the roots of vegetable plants |
| | iv) Cortalim | Cashew plantation, banana plantation |
| | v) Vasco | Coconut plantation, *Terminalia* species |
| | vi) Quelossim | Chikoo plantation, roadside weeds |
| | vii) Cansaulim | Mango plantation, jackfruit plantation |
| 2. | Salcette: i) Verna | Flower gardens, arecanut plantation, avocardo plantation |
| | ii) Nuvem | Cashew plantation, *Acacia* plantation |
| | iii) Carmona | *Casuarina* plantation, near roots of vegetables plants. |
| | iv) Curtorim | Coconut grove, Roadside weeds |
| | v) Paroda | Rubber plantation, chikoo (sapota) plantation |
| | vi) Betul | Casuarina plantation, cashew plantation |
| | vii) Navelim | Cashew plantation, banana plantation |
| 3. | Quepem: i) Canaguinim | Bamboo reeds, *Terminalia* species |
| | ii) Balli | Scrub jungle, roadside weeds |
| | iii) Quepem | Teak plantation, *Acacia* plantation |
| | iv) Corla | Forest area, cashew plantation |
| | v) Xeldem | Mango plantation, jackfruit plantation |
| | vi) Sulcorna | Forest area, bamboo reeds |
| | vii) Padi | Scrub jungle, roadside weeds |
| 4. | Canacona: i) Agonda | Forest area, bamboo reeds, cashew plantation |
| | ii) Loliem | Arecanut plantation, banana plantation |
| | iii) Cabo da Rama | *Casuarina* plantation, roadside weeds |
| | iv) Butpal | Near the roots of vegetable plants |
| | v) Palolem | *Casuarina* plantation, roadside weeds |
| | vi) Gaondongrem | Forest area, wild bamboo reeds |
| | vii) Avem | Cashew plantation, near the roots of vegetable plants, |
| 5. | Sanguem: i) Oxel | Coconut plantation, flower gardens |
| | ii) Cumbaim | Forest area, roadside weeds |
| | iii) Salginim | *Acacia* plantation, bushy plants |
| | iv) Uguem | Forest area, *Casuarina* grove |
| | v) Rivona | *Acacia* plantation, coconut plantation |
| | vi) Bali | Forest area, bamboo reeds, cashew plantation |
| | vii) Vadem | Mango plantation, roadside weeds |
| 6. | Pernem: i) Arambol | *Casuarina* plantation, forest area |
| | ii) Querim | Betelnut plantation, near the roots of vegetable plants |
| | iii) Patradevi | Cashew plantation, gulmohur trees |
| | iv) Pernem | Cashew plantation, mango plantation |
| | v) Morjim | Betelnut plantation, near the roots of vegetable plants |
| | vi) Dargalim | Betelnut plantation, coconut plantation |
| | vii) Alorna | Coconut plantation, near the roots of vegetable plants |
| 7. | Ponda: i) Borim | Roadside weeds, flower garden |
| | ii) Banastari | Betelnut plantation, coconut plantation |
| | iii) Curti | Banyan tree, near the roots of vegetable plants |

| SR. NO. | SAMPLING SITES<br>TALUKAS VILLAGES | LANDSCAPES |
|---|---|---|
| | iv) Dabal | Palmolein plantation, |
| | v) Cundaim | Coconut plantation, near the roots of vegetable plants |
| | vi) Panchvadi | Banyan tree, near the roots of vegetable plants |
| | vii) Verem | Betelnut plantation, coconut plantation |
| 8. | Tiswadi: i) Dona Paula | Bushy plants, *Casuarina* plantation |
| | ii) Agassaim | Sweet potato plantation, chilly plantation |
| | iii) Campal | *Casuarina* grove, wild palm tree plantation |
| | iv) Carambolim | Bushy plants, near the roots of vegetable plants |
| | v) Chorao | Chikoo plantation, brinjal plantation |
| | vi) Goa Velha | Sweet potato plantation, chilly plantation |
| | vii) St. Estevam | Coconut plantation, near the roots of vegetable plants |
| 9. | Bardez: i) Mapusa | Coconut plantation, mango grove |
| | ii) Aldona | *Acacia* plantation, paddy fields |
| | iii) Britona | Coconut plantation |
| | iv) Anjuna | *Casuarina* plantation |
| | v) Tivim | Flower garden, sugarcane cultivation |
| | vi) Revora | Mango plantation, jackfruit plantation |
| | vii) Odxel | Coconut plantation, chikoo (sapota) plantation |
| 10. | Satari: i) Birondem | Banana plantation, chikoo (sapota) plantation |
| | ii) Anjunem | Roadside weeds, |
| | iii) Bondir | Coconut grove, |
| | iv) Salorem | Mango plantation, jackfruit plantation |
| | v) Onda | Near the roots of vegetable plants |
| | vi) Valpoi | Forest area, crocodile bark tree plantation |
| | vii) Carambolim | *Acacia* plantation, |
| 11. | Dharbandora: i) Collem | *Terminalia* species, wild bamboo reeds |
| | ii) Usgao | Roadside plants, bushy plants |
| | iii) Mollem | Forest area, crocodile bark tree plantation |
| | iv) Codli | Teak plantation, watermelon plantation |
| | v) Dharbandora | Cashew grove, wild palm |
| | vi) Anvoldem | Coconut grove, cashew grove, |
| | vii) Toldem | Terminalia species, wild bamboo reeds |
| 12. | Bicholim: i) Amona | Gulmohar tree, crocodile bark tree plantation |
| | ii) Surla | Near the roots of vegetable plants |
| | iii) Sanquelim | Roadside weeds, mango grove |
| | iv) Maem | *Casuarina* plantation, forest area |
| | v) Mulgaon | Coconut grove, cashew grove |
| | vi) Dodamarg | *Terminalia* species, wild bamboo reeds |
| | vii) Pale | Cashew grove, jackfruit grove. |

**Table 4-1: Landscape and sampling sites.**

**Marmagoa (M), Salcette (Sl), Quepem (Q), Canacona (C), Sanguem (Sn), Pernem (P), Ponda (Po), Tiswadi (T), Bardez (Ba), Satari (Sa), Dharbandora (D) and Bicholim (Bi).**

For the purpose of documentation, all the twelve talukas (Figure 4-2) (admininstrative sub divisions) of the state of Goa were considered as study sites. Seven different villages (Figure 4-3) of each of the 12 talukas and five sampling sites of each village were chosen opportunistically, for sampling. Soil samples were also collected from different landscapes elements (Table 4-1) and from the vicinity of the roots of various vegetation types. Collection of soil samples also included from the paddy fields, representing three different ecological land types viz. **khazan, kher** and **morod** at three different points of paddy cultivation; prior to transplantation, pre harvest and post harvest.

Soil of the state can be classified as laterite, alluvial and sandy. The major portion is of laterite type (81%). They are acidic (5.5 to 6.5 pH) in nature, sandy loam to silt-loam in texture and well drained. This type of soil is poor in lime, potash and phosphorus, but rich inorganic carbon and nitrogen. The coastal island comprises a stretch of land with high water table, which can be utilized for irrigation and multiple cropping. These soils are also acidic, sandy to sandy loam, fairly rich in organic matter but deficient in phosphate and potash. They are about 11%. The remaining 8% of the soils are alluvial in nature.

The scenic beauty of Goa, a tiny emerald of our country, is principally attributed to its vegetation cover, consisting of three main categories: the typical tropical monsoonal forest of the Sahyadrian Ghats and their extensions, along the projecting hill ranges; towards the coastlands, the poor cover of grass and shrub on its lateritic plateaus and the fringing belts of vegetation along the estuaries and extensive shore-line. The vegetal growth in marshy areas and sandy shores has undergone very little floristic change.

Paddy field is being recognised as an important place for biodiversity fostering a variety of organisms. However, there are few reports on the ecology of paddy field nematodes. In Goa the paddy is cultivated under three distinct ecologies during **kharif** season (34,278 ha) namely **khazan, kher** and **morod** and during the **rabi** season. While, upland rice cultivation dominates the rice ecosystem in talukas adjacent to Western Ghats, the lowland rice and the salt tolerant rice dominates the coastal ecosystem (Figure 8-1).

**Khazan** lands (about 32% of the area) consist of low - lying areas, often below sea level and along the estuaries. They are mostly used for monsoon paddy crop.

**Kher** lands or Midlands (around 32% of the area) are flat lands at low elevation above sea level and having a high water table. Arable, sandy to sandy loams soils, suitable for multiple cropping through irrigation.

**Morod** land (around 16.4%) refers to lateritic uplands or terraced fields, with single rain fed crop of rice.  These lands contain some amounts of nitrogen and phosphorous.

Remaining 19.6% of the land is used during **rabi** season cultivation.

# METHODOLOGY

# MATERIALS AND METHOD

Methodology consisted of the following techniques:-

**1) SAMPLING**

Sampling was undertaken from the month of August to February for nearly three years (2011-2014). During this period, the adult nematodes can be found and identification becomes relatively easy. Also prior to this period is monsoons in Goa and when moisture becomes excessive, owing to either heavy rainfall or irrigation, nematode number often declines (Hollis and Fielding, 1958). The nematode species get washed off, with the running rain water. This leads in turn, to decrease of nematode density. Further, nematode densities become greatly diluted by flushing or flooding. Apart from the above, the beginning of winter as well as the drying of the soil during summer is harmful for nematodes as they require a film of water for their survival. Running of water also decreases the rate of oxygen diffusing into the soil and this decrease could be lead to decreased oxygen quantity in the soil (Van Gundy *et al.*, 1968). Many nematodes are limited by oxygen during long periods in residual water (Norton, 1978). Sufficient time is required to allow sufficient oxygen to diffuse throughout the top 24 inches of soil. Maximum number of adult nematodes can be extracted from the soil depth of about 5 to 25 cm.

**2) PROCESSING THE SOIL SAMPLES**

Samples were processed by modified Cobb's (1918) Sieving and Decantation (gravity) Method. This method takes the advantage of the difference in size and specific gravity between nematodes and soil components. The minimum equipments required for it are plastic buckets of six to ten litres capacity, a stirring stick about 45cm long and 2.5cm wide, sieves of the type used for soil analysis. These are about 20cm in diameter. One should be a coarse sieve of 20 to 40 mesh size to remove large size soil material and the other a fine sieve of 200 to 250 mesh size, glass beakers holding 300 to 600ml (Figure 5.1).

The step by step protocol is as follows:

i) Place the soil sample of about 1000g in a bucket (No. 1) and add 5 litres of water.

ii) Stir with the stick until all clods and peats are broken up. Then stop stirring for 30 seconds to one minute. The purpose of stirring is to separate the nematodes from the soil particles and to suspend them in the water. Nematodes have a specific gravity of only 1.05. If suspended in water for a long time, they tend to gradually sink to the bottom. When stirring is stopped, heavy soil particles sink to the bottom of the bucket and the nematodes remain suspended in the water.

iii) Pour the water through 20 mesh sieve into the second bucket (No.2) leaving the heavy soil particles in the first bucket (No. 1). Nematodes will pass easily through the coarse sieve.

iv) Add about a litre of water and repeat the above (ii) and (iii) steps. Most of the nematodes will now be in water of the second bucket.

v) Wash the residue on the coarse sieve with more water and it flow into the second bucket. The purpose is to make sure that no nematodes remain in the residue on the coarse sieve.

vi) Discard the residue on the coarse sieve as well as from the first bucket, wash and clean both.

vii) Pour the water from the second bucket gently through the fine sieve of 200 to 250 mesh-BSS (British Standard Specification) and allow the water to run down the drain. If this is carefully done, most of the nematodes will be caught on the fine sieve.

viii) Avoid pouring the fine mud at the bottom of the bucket.

ix) Wash the fine sieve with a gentle stream of water to remove fine soil particles.

x) Then collect the residue on the sieve in a beaker and use for further processing.

**Advantages of Cobb's Method**

i) Since the method is not dependent on nematode movement, sluggish or quiescent nematodes are extracted as effectively as the active ones.

ii) The method allows recovery of most nematodes from large soil samples.

iii) Nematodes are available for direct examination in less than half an hour.

**Disadvantages of Cobb's Method**

i) The method requires expensive sieves, experienced workers and expertise to carry it out.

ii) Nematodes are difficult to find because they get mixed up with the fine soil particles or debris.

iii) Unless it is carefully done more than half the nematodes in the soil sample will not be found.

**3) ISOLATION OF NEMATODES**

The nematodes were then isolated using Modified Baermann's Funnel Technique (Baermann, 1917) (Figure 5.2). This method is used to isolate small nematodes from the soil samples. It is based on the principle that nematodes have the tendency to move downward when the soil is placed in a funnel. The Baermann funnel is a regular glass or plastic funnel, about 7.5 to 15cm in diameter, with a piece of rubber tubing attached to the stem and closed with a clump or a pinchcock. A moulded wire gauge is placed in the funnel. The funnel is filled with fresh tap water. Care should be taken to ensure that there are no air bubbles in the funnel or in the rubber tubing as the nematodes can be caught in the air bubble and die. The wire gauge was lined with tissue paper in the form of a cross (+). The edge of the tissue paper should not protrude out of the funnel otherwise water will flow out.  The residue that was collected in the beaker was poured over the tissue paper. The entire set-up was kept undisturbed for a day or two at room temperature. Fresh water was added to the funnel to compensate for loss by evaporation. The nematodes being active migrate to the bottom through the tissue paper and get accumulated in the stem of the funnel and in the rubber tubing at the bottom (Figure 5.4). At the end of the waiting period, a small amount of water suspension was drawn into a cavity block through the rubber tubing (Figure 5.3). The nematodes thus isolated were collected for counting, fixing and processed for making permanent slides.

**Advantages of Baermann Funnel Technique**

i) Technique is simple and the equipment is inexpensive and can be used in ordinary laboratories.

ii) Recovery of active nematodes from very small sample is fairly good.

iii) This method produces clean and healthy specimen for inoculation purpose.

**Disadvantages of Baermann Funnel Technique**

i) Lack of aeration in the water reduces nematode movement, hindering recovery.

ii) Recovery may be reduced when the tissue and other materials obstruct nematode movement.

iii) Recovery of active and relatively sluggish nematodes from large soil samples is poor.

iv) Because the funnel capacity is small, the sample in it may be too small to be a representation.

**Disadvantages of the combination of both the methods**

i) Although recovery of mobile nematodes is good, sluggish nematodes recovered during the sieving part of the technique may fail to pass through the tissue in the funnel.

ii) Processing takes longer and requires considerably expensive equipment.

**Advantages of the combination of both the methods**

i) The combination method allows recovery of most nematodes from large soil samples.

ii) Resultant samples contain less silt and debris than it does with the gravity screening technique and therefore easier to examine the nematodes under the dissecting microscope.

Therefore in the present work, the candidate has combined both the techniques: Cobb's sieving and decantation method and Baermann funnel method to get the maximum number of nematodes.

**4) KILLING AND FIXATION OF NEMATODES**

The nematodes were allowed to settle down, at the bottom of the cavity block and excess water was removed by using a fine needle syringe (insulin syringe). Fixative (FG) was prepared with 90ml distilled water, 8ml formalin and 2ml glycerol and heated for $60^0$C was poured into the cavity block (Seinhorst, 1959). This simultaneously killed and fixed the nematodes. It is very essential to fix the nematodes to serve the following purpose:

a) Fixative renders hardness to the material to resist further post mortem changes and preserves the tissue as if in live condition.

b) Fixative coagulates and renders the fluid of the material insoluble so that cellular substances remain intact and are not washed away.

c) Fixative alters the refractive index of the material and makes it optically differentiated under the microscope.

**5) MOUNTING, SEALING AND PREPARATION OF PERMANENT SLIDES**

After 24 hours of fixation, the nematodes were transferred to a dehydrating agent of glycerine-alcohol (GA) prepared with 79 parts distilled water, 20 parts 96% ethanol and 1 part glycerol. This block was then kept in a desiccator containing anhydrous calcium chloride. After 4 to 5 weeks, the nematodes were dehydrated and ready for mounting. A tiny drop of anhydrous glycerine was placed in the centre of a clean glass slide (1mm thickness) and one by one the dehydrated nematodes were transferred into this drop using a horse hair mounted on a handle. Care was taken to make sure that the nematodes were gently pressed to the bottom of the glycerine drop as there is possibility that they can move into the molten wax, if they are on the surface of the glycerine drop. Small pieces (4) of wax were kept on four sides of the drop and a cover slip (0.1mm thickness) was gently placed on the pieces. This slide was then heated on a hot plate ($60^0$C) till the wax melted. As the wax melted, it sealed the drop of glycerine with the nematodes in the centre. The permanent slides were then used for further study.

**6) TECHNIQUE TO HANDLE A LIVE NEMATODE**

Using a compound binocular research microscope; select the nematode of your choice from the cavity block containing the nematode suspension (step 3, as mentioned earlier). Loosen the chosen nematode from the bottom of the cavity block with a short twitch of the horse hair mounted on a handle and gently lead it to the surface of the solution, until it is more or less horizontal, whilst simultaneously changing the focus of the microscope, with the fine tuning knob, to make the nematode visible, as it is led to the surface of the solution. Then, tactfully position the tip of the horse hair for the final twitch. The nematode curls round the horse hair, if the tip of the hair is positioned just below them and at right angle to their body axis. Gently lift the handle with the nematode curled round the horse hair and place where needed. The viscosity and the surface tension of the liquid make the nematode to stick to the horse hair instead of pulling it down to the bottom of the cavity.

Mastering this technique is important for any one working with the nematodes, as it is easy to identify them, when they are alive, than when they are killed, since there is a possibility that, some parts of the nematode may be damaged, whilst killing and fixing them.

**Figure 5-1: Sample preparation for the extraction of nematodes**

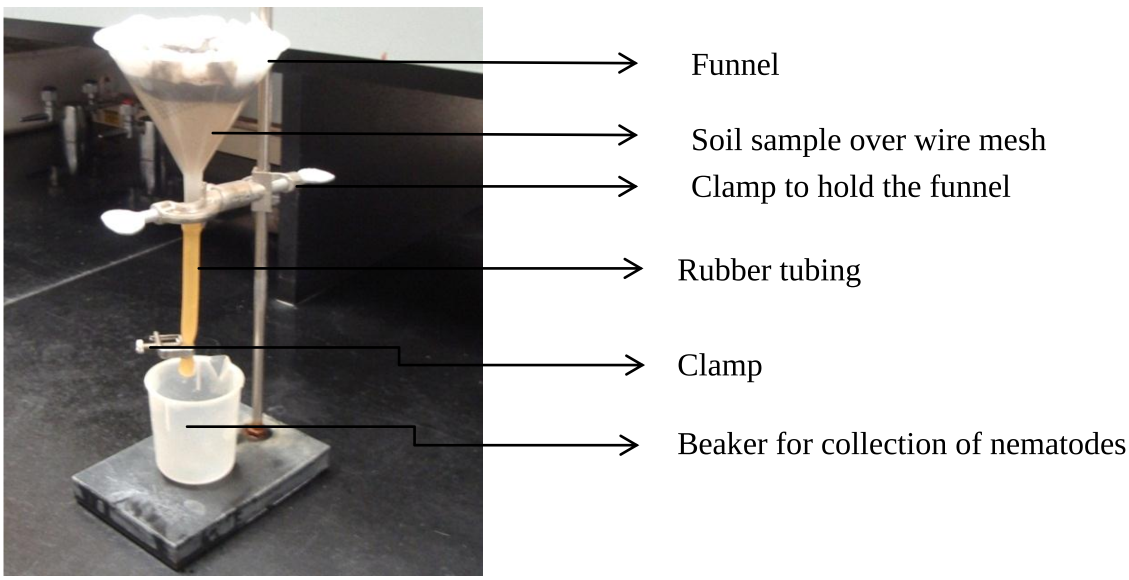



**Figure 5-2: Baermann Funnel set up**

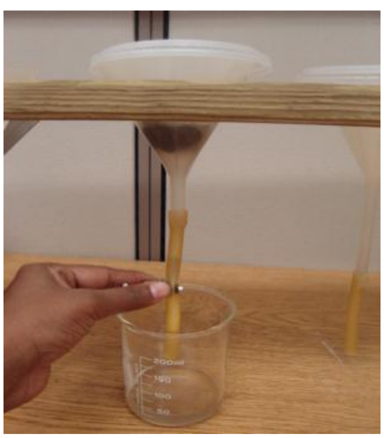


**Figure 5-3: Collection of nematodes**

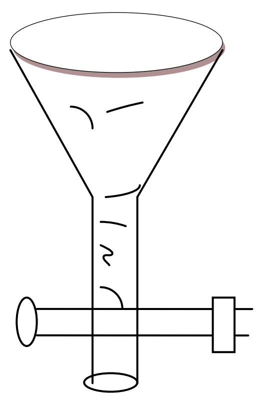


**Figure 5-4: Extraction based on the active movement of the nematodes (motility dependent method)**

# CHAPTER I

*When you walk on soil, swim in the lake or swat a fly;*
*you are rubbing against 'invisible worms' called nematodes".*
Jairajpuri, 2002 a.

# CHAPTER I

## Documentation of the diversity, abundance and distribution of the soil inhabiting, free living nematodes of the entire state of Goa.

### INTRODUCTION

It is a challenging exercise to identify a habitat that is not occupied by a diverse community of nematodes. The dry valleys of Antarctica, having an environment, considered to be extreme providing bare minimum requirements for supporting life, has 74 nematodes species (Maslen, 1979). Soils of high Arctic populated so heavily with nematodes that, it exceeds that of the humid tropics. Temperate grasslands appear to sustain the greatest levels of diversity and abundance in the phylum.

The free living nematodes, zoologically more important, than the parasitic ones, were mostly neglected until the present century, when the knowledge of them was greatly augmented by the studies of Allgen, Cobb, deConinck, Daday, Ditlevsen, Filipjev, deMan, Micoletzky, Schuurmans-Stekhoven and Steiner. Free-living nematodes belong, mostly to the following orders: Enoploidea, dorylaimoidea, mermithoidea, araeolaimoidea, monhysteroidea, rhabditoidea (Hyman, 1992). Each soil sample contains an abundance and diversity of nematodes, consequently, having high value of intrinsic information (Bongers and Ferris, 1999; Yeates *et al.*, 1993). All observers agree that, the soil nematodes are most numerous, around the roots of plants and therefore their distribution in the soil is not uniform. Free living nematodes occupy the interstitial spaces in the soil. They are seldom sedentary, continually moving to feed on a diverse array of food. The type of food available in the different areas appears to be the chief factor in determining the species found.

Generally nematodes belonging to ten orders regularly occur in the soil. The common ones belong to the orders Dorylaimida, Rhabditida, Aphelenchida and Tylenchida. Taxonomically, the orders Tylenchida and Triplonchida constitute plant feeders, fungal feeders and predaceous forms. Aphelenchida comprises of fungal feeders and predators. Order Dorylaimida includes species that are plant feeders, fungal feeders, predaceous and omnivores. Bacterial feeders are found in orders Rhabditida, Diplogasterida, Monhysterida, Alaimida and Araeolaimida, whereas predators occur in various orders like Mononchida, Diplogasterida, Aphelenchida and Dorylaimida. All these types of nematodes have been found to occur in the soil.

Free living nematodes can be divided into five broad groups based on their diet. Bacterial-feeders mostly consume bacteria while fungal-feeders feed by puncturing the cell wall of fungi and sucking out the internal contents. Predatory nematodes prey on all types of nematode species and protozoa. Generally, less disturbed soils contain more predatory nematodes, suggesting that, predatory nematodes are extremely susceptible to a wide array of disturbances. Omnivore nematodes feed upon a variety of organisms or may prefer a different diet at each life stage. Root feeders are mostly plant parasites and some of them are ectoparasites. These remain in the soil and feed at the root surface. Though they are ectoparasites, as they remain outside the plants, are considered as free living nematodes. Over two thousand species of Dorylaims, consisting about 1 / $10^{th}$ of total known nematodes fauna, exhibit considerable diversity in their size, structure of feeding apparatus including pharynx, gonad, copulatory structures and tail shapes and sizes (Bongers, 1999). The Dorylaim nematodes are unique in the sense that within the same group, they exhibit most of the feeding patterns represented by nematodes. This is the reason for their wide occurrence and diversity (Jairajpuri, 2002 a).

It is amazing to know ‘how so many species can coexist in a small soil volume?’ Although in a typical soil-core sample only a few species dominate, while most other species have low abundance (Freckman and Ettema, 1993; Overgaard, 1949). Although the diversity is most often equated with species, it can also be applied at various taxonomic levels of resolution, such as genotype, species, genus, family order and trophic group. For free living nematodes, it is very common to apply diversity indices to taxonomic levels above species because species identification based on general morphology is difficult (Neher and Darby, 2006).

This present chapter presents the data on the abundance, diversity and distribution patterns of the soil inhabiting, free living nematode fauna of the entire state of Goa. It documents the various orders, families, genera and the species of the soil nematofauna, of Goa as well as the percentage of the trophic and ordinal diversity. It also records the description / diagnosis of the documented nematodes species along with their morphometric information.

## MATERIALS AND METHOD

The nematodes collection was carried out with major emphasis on the diversity of nematode fauna. Soil samples were collected from (1) August 2011 to February 2012, (2) August 2012 to February 2013 and (3) August 2013 to February 2014, from all the twelve talukas of

Goa, namely Canacona, Marmagoa, Quepem, Salcette and Sanguem in South Goa and Bardez, Bicholim, Dharbandora, Pernem, Ponda, Satari and Tiswadi in North Goa (Figure 4.2). Seven different villages of each taluka (Figure 4.3 A-L) and five sampling sites from each village were chosen opportunistically (Table 4-1). Also different soil types were selected for the collection of the samples. 425 soil samples of 1000g from near the vicinity of the roots of the plants were collected for assessment from about 5 to 15cms depth. Each sample was collected in a self-sealing plastic bag with a label containing necessary field details. They were either processed straight away or stored in the refrigerator at $4^{o}$C and were processed later. Nematodes were isolated using standard techniques as mentioned above and identification upto species and counting was done in the laboratory. 600 permanent slides were prepared. The work was carried out in the laboratories of the Departments of Zoology of Carmel College of Arts, Science & Commerce for Nuvem, Salcete Goa and of Goa University, Taleigao Plateau, Goa.

For identification and classification the nematodes were listed according to the following literature (Ahmad and Jairajpuri, 1987, 1989; Ahmad, 1996; Andrássy, 1982 (a & b), 1984, 1993, 1999; Bajaj and Jairajpuri, 1979; Choudhary *et al*., 2010; Esquivel, 2003; Goodey, 1951, 1963; Jairajpuri and Ahmad, 1992; Jairajpuri and Khan, 1982; Mai *et al*., 1996; Ravat and Ahmad, 2000 Rizvi, 2010b and Siddiqi, 1986, 2000). Information was also collected from the websites of NEMAPLEX (iv), Animal Diversity Web (v) and Nema Species Masterlist A-Z (vi). Most of the species were identified to the species level using a Stereozoom LABOMED CZM4 and MOTIC B SERIES B1 – 220 ASC. Images were taken using Olympus BX51 JENOPTIX which was attached with ProgRes CT1 camera. Measurements were recorded using Ocular Micrometer.

## RESULTS

**Diversity and abundance***:* In the present study, a total of sixty nine nematode species including forty eight genera, twenty four families and nine orders (Table 6.1) were identified. The order Dorylaimida had the highest number of families (9), genera (23) and species (33); followed by Tylenchida with four families, eight genera and nine species. Mononchids were represented by three families, six genera and ten species, followed by the order Rhabditida having three families, five genera and nine species, while order Alaimida was represented by one family, two genera and three species. Order Enoplida was represented by one family, one genus and two species. Araeolaimida, Aphelenchida, and Monhysterida were represented by only one family, one genus and one species each (Figure 6.1). In terms of cumulative total of individuals, Dorylaimida was the most abundant, followed by Mononchida, Tylenchida, Rhabditida, Alaimida, Enoplida, Araeolaimida, Monhysterida and Aphelenchida.

**Trophic and ordinal diversity***:* Among the trophic groups, in genera as well as in abundance, Dorylaim species dominated among predators (14), omnivores (9) and fungivores (2) while herbivores had eight species of Dorylaims and nine of Tylenchids (Table 6.2). Bactivores were represented by 14 species. The predators dominated in the trophic genera (37.50%) as well as in abundance (37.68%) followed by herbivore (22.19% and 24.63%), bactivore (18.75% and 20.28%), omnivores (16.66% and 13.04%) and fungivores (4.16% and 4.34%) (Figure 6.2).

In the ordinal diversity of genera as well as abundance, the order Dorylaimida dominated, (47.91%% and 49.27% %) followed by Tylenchida (16.66% and 13.04%), Mononchida (12.50% and 14.49%), Rhabditida (10.41% and 11.59%), Alaimida (4.16% and 4.34%), Enoplida (2.08%

and 2.89%), Aphelenchida (2.08% and 1.44%), Araeolaimida (2.08% and 1.44%) and Monhysterida (2.08% and 1.44%) (Figure 6.3). Maximum numbers of orders (9) were reported from the soils samples of Dharbandora and minimum (5) were reported from those of Tiswadi taluka (Figure 6.4).

**Species Diversity and Abundance:** Maximum numbers of 50 nematode species and 38 genera were recorded from the soil samples collected from Bicholim taluka and minimum number of 36 species was observed from those of Ponda taluka (Table 6.3). Soil samples from Dharbandora taluka recorded the minimum number (21) of genera. Among the families, minimum number 16 was observed from the soil samples of Tiswadi taluka and maximum (20) was recorded from the soil samples of Pernem (Figure 6.4). Above 50% of species identified were observed in most of the soil samples collected from Goa (Table 6.3). The most common species recorded, in most of the soil samples were *Lenonchium macrodorum*, *Lenonchium oryzae, Ottolenchus parvus, Psilenchus minor*, *Radopholus similis*, *Panagrolaimus rigidus*, *Panagrellus dorsobidentata and Criconemoides (Mesocriconema) xenoplax*. Species *Prodorylaimium goanese* was observed in few samples (Figure 6.4). Most of the species belonged to predator (26) trophic group followed by herbivore (17), bactivore (14), omnivore (09) and fungivore (03) (Table 6.2). Species abundance per 100 gm of dry soil ranged from 98 individuals to 540 individuals with *Psilenchus minor* having the maximum species abundance (540), while *Prodorylaimium goanese* had the minimum (98) abundance.

**Diversity Indices**: In individual abundance as well as species richness, the soil samples collected from Bicholim taluka showed maximum results and those from Ponda taluka showed minimum results. Simpson's Dominance showed highest results in the samples of Ponda taluka and lowest in the samples of Bicholim taluka whereas Shannon's Diversity values were more in the soil samples of Bicholim taluka and less in the samples of Ponda taluka. The species were more or less evenly distributed in all the soil samples with the values ranging from 0.834 (Bicholim) to 0.875 (Ponda). Equitability values too were almost the same for all the taluka with a difference of just 0.04. The values of Fisher's Alpha diversity index were less (8.09) for the soil samples of Ponda taluka and more (8.72) for the soil samples of Bicholim taluka (Table 6.5).

The dendrogram of the cluster analysis of species diversity of nematodes of soil samples collected different talukas, showed that there was close similarity between the samples of the Pernem and Satari with similarity index of 79.12, Bicholim and Quepem - 75, Bicholim and Tiswadi – 73.33 while a wide difference between the samples of Pernem and Canacona with similarity index of 65.42 and between Pernem and Salcette with 66.66 (Figure 6.5). The dendrogram of the cluster analysis of diversity indices showed close similarity between Bardez and Marmagoa, Dharbandora and Canacona, and Sanguem and Pernem sampling sites while a wide difference between Salcete and Ponda, Pernem and Bicholim, and Canacona and Quepem sampling sites (Figure 6.7).

Various nematode morphometric parameters (deMan formula) were used to record the measurements of the nematode species (Table 6.4). The presence of individual species in total number of talukas was also recorded. Most of the species that were recorded were present in the soil samples of about seven to nine talukas except *Prodorylaimium goanese* which was present in only four talukas (Figure 6.6).

| ORDERS | FAMILIES | GENUS SPECIES |
|---|---|---|
| DORYLAIMIDA | Dorylaimidae | 1. *Dorylaimus stagnalis* Dujardin, 1845 |
| | | 2. *Mesodorylaimus chamoliensis,* Ahmad 1995 |
| | | 3. *Mesodorylaimus mesonyctius* (Kries, 1930) Andrassy, 1959 |
| | | 4. *Thornenema lissum* (Thorne, 1939) Andrassy, 1959 |
| | | 5. *Coomansinema dimorphicauda* Ahmad & Jairajpuri, 1989 |
| | | 6. *Discolaimus major* Thorne, 1939 |
| | | 7. *Discolaimus texanus* Cobb, 1913 |
| | | 8. *Prodorylaimium goanese* n. sp reported by Ahmad & Jairajpuri, 1984 |
| | | 9. *Indodorylaimus saccatus* Ahmad & Jairajpuri, 1984 |
| | | 10. *Longidorylaimoides longicaudatus* (Imamura,1931) Thorne & Swanger, 1936 |
| | Qudsianematidae | 11. *Ecumenicus monohystera* (De Man, 1880) Thorne, 1974 |
| | | 12. *Labronemella labiata* Andrassy, 1985 |
| | | 13. *Labronema ferox* Thorne, 1939 |
| | Belondiridae | 14. *Axonchium ampicolle* Cobb, 1920 |
| | | 15. *Axonchium vulvulatum* Nair & Coomans, 1974 |
| | Nordiidae | 16. *Lenonchium macrodorus* Ahmad & Jairajpuri, 1988 |
| | | 17. *Lenonchium oryzae* Siddiqi, 1965 |
| | Leptonchidae | 18. *Timmus tenerhastus* Goseco, Ferris & Ferris, 1976 |
| | Aporcelaimidae | 19. *Aporcelaimellus obscurus* (Thorne and Swanger, 1936) Heyns, 1965 |
| | | 20. *Aporcelaimus regius* Thorne, 1974 |
| | | 21. *Aporcelaimus americanus* Thorne & Swanger, 1936 |
| | | 22. *Aporcelaimium labiatum* (De Man, 1880) Loof & Coomans, 1970 |
| | | 23. *Akortonus vigor* Thorne, 1974 |
| | | 24. *Makatinus heynsi* n. sp. Reported by W. Ahmad & I.Ahmad, 1992 |
| | Actinolaimidae | 25. *Neoactinolaimus agilis* Thorne, 1967 |
| | | 26. *Neoactinolaimus attenuates* n. sp reported by Khan, Ahmad & Jairajpuri, 1994 |
| | | 27. *Hexactinolaimus aneityi* Yeates, 1973 |
| | Longidoridae | 28. *Longidorus* elongatus (De Man, 1876) Thorne & Swanger, 1936 |
| | Xiphinematidae | 29. *Xiphinema brevicolle* Lordello & da Costa, 1961 |
| | | 30. *Xiphinema americanum* Cobb, 1913 |
| | | 31. *Xiphinema elongatum* Sch.-Stekhoven & Teunissen, 1938 |
| | | 32. *Xiphinema orbum* Siddiqi, 1964 |
| | | 33. *Xiphinema insigne* Loos 1949 |
| MONONCHIDA | Mononchidae | 34. *Mononchus tunbridgensis* Bastian, 1865 |
| | | 35. *Coomansus indicus* Jairajpuri & Khan 1977 |
| | | 36. *Coomansus parvus* (De Man, 1880) Jairajpuri & Khan, 1977 |
| | | 37. *Clarkus elongatus* Jairajpuri & Khan, 1977 |
| | Iotonchidae | 38. *Iotonchus trichurus* (Cobb, 1917) Altherr, 1958 |
| | | 39. *Iotonchus indicus* Jairajpuri, 1969 |
| | | 40. *Iotonchus basidontus* Clark, 1960 |
| | | 41. *Parahadronchus shakili* (Jairajpuri, 1969) Mulvey, 1978 |
| | | 42. *Parahadronchus andamanicus* (Jairajpuri, 1969) Mulvey, 1978 |
| | Mylonchulidae | 43. *Mylonchulus subsimilis* (Cobb, 1917)Meyl, 1957 |
| TYLENCHIDA | Belonolaimidae | 44. *Tylenchorhynchus annulatus* (Cassidy, 1930) Golden, 1971 |

| ORDERS | FAMILIES | GENUS SPECIES |
|---|---|---|
| | Tylenchidae | 45. *Tylenchus indicus* Khan et al, 1969 |
| | | 46. *Ottolenchus parvus* (Siddiqi, 1963) Siddiqi, 1979 |
| | | 47. *Psilenchus minor*, Siddiqi, 1963 |
| | | 48. *Radopholus similis* (Cobb, 1893) Thorne, 1949 |
| | Hoplolaimidae | 49. *Rotylenchoides brevis*, Whitehead, 1958 |
| | | 50. *Hoplolaimus galeatus* (Cobb, 1913) Thorne, 1935 |
| | | 51. *Hoplomaimus indicus*, Sher, 1963 |
| | Criconematidae | 52. *Criconemoides xenoplax* (Raski, 1952) Luc & Raski, 1981 |
| ALAIMIDA | Alaimidae | 53. *Alaimus indicus*, Choudhary & Jairajpuri, 1983 |
| | | 54. *Alaimus manipuriensis*, Choudhary & Jairajpuri, 1983 |
| | | 55. *Amphidelus novus*, Baqri & Jairajpuri, 1968 |
| RHABDITIDA | Rhabditidae | 56. *Mesorhabditis spiculigera* (Steiner, 1936) Dougherty, 1953 |
| | | 57. *Mesorhabditis cranganorensis* (Khera, 1968) Andrassy, 1983 |
| | Cephalobidae | 58. *Cephalobus persegnis* Bastian, 1865 |
| | | 59. *Acrobeles ciliatus* Linstow, 1877 |
| | | 60. *Acrobeles cephalatus*(Cobb, 1901)Thorne, 1925 (Thorne, 1937) |
| | | 61. *Acrobeles timmi* Chaturvedi & Khera, 1979 |
| | Panagrolaimidae | 62. *Panagrolaimus fuchsi* Ruhm, 1956 |
| | | 63. *Panagrolaimus rigidus*, (Schneider, 1866) Thorne, 1937 |
| | | 64. *Panagrellus dorsobidentata* (Rühm, 1956) |
| ENOPLIDA | Ironidae | 65. *Ironus ignavus* Bastian, 1865 |
| | | 66. *Ironus longicaudatus* de Man, 1884 |
| ARAEOLAIMIDA | Plectidae | 67. *Plectus cirratus* Bastian, 1865 |
| APHELENCHIDA | Aphelenchidae | 68. *Aphelenchus avenae* Bastian, 1865 |
| MONHYSTERIDA | Monhysteridae | 69. *Prismatolaimus andrassyi* Khera & Chaturvedi, 1977 |

**Table 6.1: Taxonomic status of soil nematodes of Goa.**

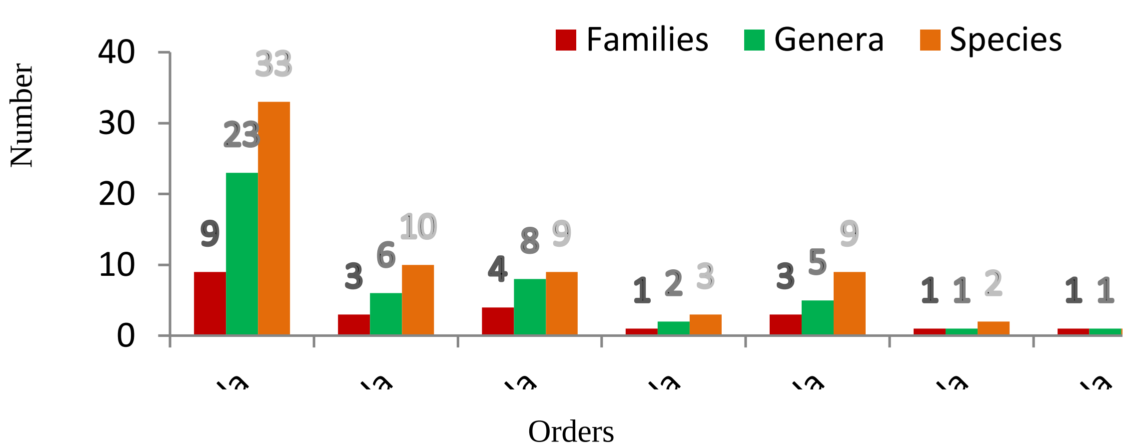



**Figure 6.1:Order-wise soil nematode diversity of Goa.**

| Sr.No. | Trophic Groups | Order | Species | Ind. species abundance / 100gm of dry soil (m) |
|---|---|---|---|---|
| I | Omnivores | Dorylaimida | *Dorylaimus stagnalis* | 451 |
| | (O) | | *Mesodorylaimus chamoliensis* | 302 |
| | | | *Mesodorylaimus mesonyctius* | 334 |
| | | | *Thornenema lissum* | 205 |
| | | | *Prodorylaimium goanese* | 98 |
| | | | *Indodorylaimus saccatus* | 276 |
| | | | *Longidorylaimoides longicaudatus* | 264 |
| | | | *Ecumenicus monohystera* | 282 |
| | | | *Timmus tenerhastus* | 476 |
| II | Predators | Dorylaimida | *Coomansinema dimorphicauda* | 442 |
| | (P) | | *Discolaimus major* | 295 |
| | | | *Discolaimus texanus* | 312 |
| | | | *Labronemella labiata* | 300 |
| | | | *Labronema ferox* | 404 |
| | | | *Aporcelaimellus obscurus* | 411 |
| | | | *Aporcelaimus regius* | 375 |
| | | | *Aporcelaimus americanus* | 364 |
| | | | *Aporcelaimium labiatum* | 343 |
| | | | *Akortonus vigor* | 382 |
| | | | *Makatinus heynsi* | 335 |
| | | | *Neoactinolaimus agilis* | 425 |
| | | | *Neoactinolaimus attenuates* | 377 |
| | | | *Hexactinolaimus aneityi* | 382 |
| | | Mononchida | *Mononchus tunbridgensis* | 378 |
| | | | *Coomansus indicus* | 453 |
| | | | *Coomansus parvus* | 424 |
| | | | *Clarkus elongatus* | 395 |
| | | | *Iotonchus trichurus* | 435 |
| | | | *Iotonchus indicus* | 461 |
| | | | *Iotonchus basidontus* | 384 |
| | | | *Parahadronchus shakili* | 457 |
| | | | *Parahadronchus andamanicus* | 483 |
| | | | *Mylonchulus subsimilis* | 448 |
| | | Enoplida | *Ironus ignavus* | 390 |
| | | | *Ironus longicaudatus* | 280 |
| III | Herbivores | Dorylaimida | *Lenonchium macrodorus* | 512 |
| | (H) | | *Lenonchium oryzae* | 520 |
| | | | *Longidorus* elongatus | 375 |
| | | | *Xiphinema brevicolle* | 384 |
| | | | *Xiphinema americanum* | 486 |
| | | | *Xiphinema elongatum* | 477 |
| | | | *Xiphinema orbum* | 378 |
| | | | *Xiphinema insigne* | 387 |

| Sr.No. | Trophic Groups | Order | Species | Ind. species abundance / 100gm of dry soil (m) |
|---|---|---|---|---|
| | | Tylenchida | *Tylenchorhynchus annulatus* | 360 |
| | | | *Tylenchus indicus* | 378 |
| | | | *Ottolenchus parvus* | 535 |
| | | | *Psilenchus minor* | 540 |
| | | | *Radopholus similis* | 525 |
| | | | *Rotylenchoides brevis* | 394 |
| | | | *Hoplolaimus galeatus* | 420 |
| | | | *Hoplomaimus indicus* | 477 |
| | | | *Criconemoides xenoplax* | 502 |
| IV | Bactivores | Alaimida | *Alaimus indicus* | 442 |
| | (B) | | *Alaimus manipuriensis* | 270 |
| | | | *Amphidelus novus* | 295 |
| | | Rhabditida | *Mesorhabditis spiculigera* | 225 |
| | | | *Mesorhabditis cranganorensis* | 378 |
| | | | *Cephalobus persegnis* | 386 |
| | | | *Acrobeles cephalatus* | 372 |
| | | | *Acrobeles ciliatus* | 290 |
| | | | *Acrobeles timmi* | 335 |
| | | | *Panagrolaimus fuchsi* | 374 |
| | | | *Panagrolaimus rigidus* | 435 |
| | | | *Panagrellusdorsobidentata* | 464 |
| | | Araeolaimida | *Plectus cirratus* | 256 |
| | | Monhysterida | *Prismatolaimus andrassyi* | 270 |
| V | Fungivores | Dorylaimida | *Axonchium ampicolle* | 285 |
| | (F) | | *Axonchium vulvulatum* | 324 |
| | | Aphelenchida | *Aphelenchus avenae* | 245 |

**m=mean values, n=425, range= 98-540**

**Table 6.2: Diversity and abundance (no. of ind. / 100gm of dry soil) of different trophic Groups**

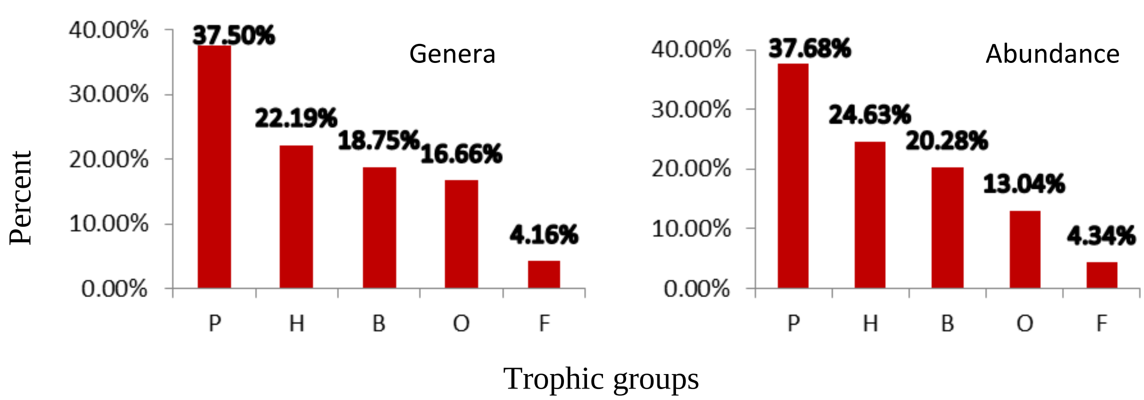



**Figure 6.2: Community structure - Trophic diversity (Genera & Abundance)**

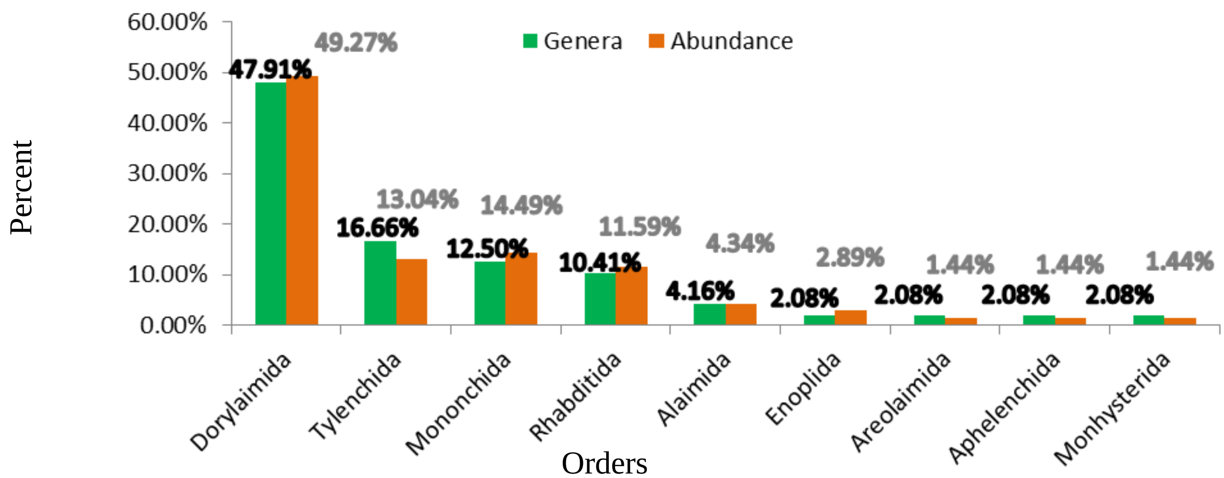



**Figure 6.3: Community structure - Ordinal diversity (Genera &Abundance)**

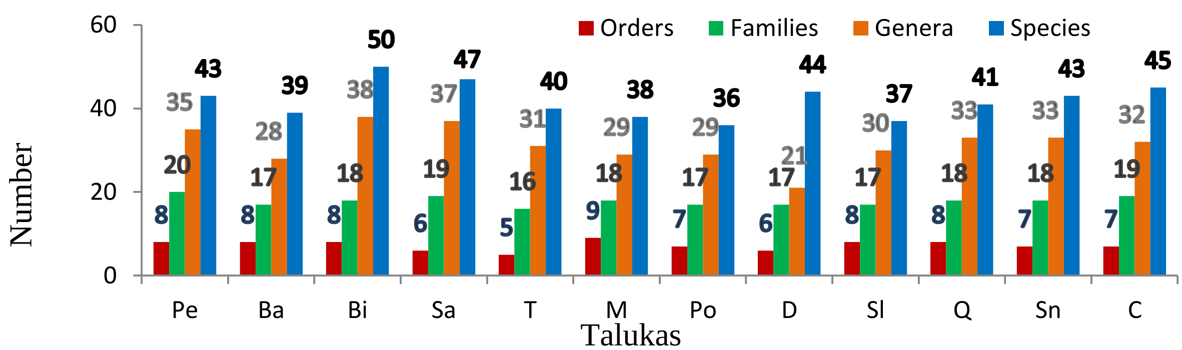



**Figure 6.4: Taxonomic status of the presence of nematodes in different talukas**

**Pe=Pernem, Ba=Bardez, Bi=Bicholim, Sa=Satari, T=Tiswadi, M=Marmagoa, Po=Ponda, D=Dharbandora, Sl=Salcette, Q=Quepem, Sn=sanguem, C=Canacona**

| | | TALUKAS | | | | | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sr. No.** | **SPECIES** | **Pe** | **Ba** | **Bi** | **Sa** | **T** | **M** | **Po** | **D** | **Sl** | **Q** | **Sn** | **C** | **12** |
| 1 | *Dorylaimus stagnalis* | + | - | + | + | - | - | + | + | - | - | + | + | **7** |
| 2 | *Mesodorylaimus chamoliensis* | - | + | + | - | + | + | - | + | - | + | + | + | **8** |
| 3 | *Mesodorylaimus mesonyctius* | - | - | - | + | + | - | + | - | + | + | - | - | **5** |
| 4 | *Thornenema lissum* | + | - | - | + | - | - | + | + | - | + | - | - | **5** |
| 5 | *Coomansinema dimorphicauda* | + | - | + | + | + | + | - | + | + | - | - | + | **8** |
| 6 | *Discolaimus major* | + | + | + | - | + | - | - | + | - | + | - | - | **6** |
| 7 | *Discolaimus texanus* | + | + | + | - | - | + | - | - | + | + | - | + | **7** |
| 8 | *Prodorylaimium goanese* | - | + | - | + | + | - | - | - | - | + | - | - | **4** |
| 9 | *Indodorylaimus saccatus* | + | - | + | - | - | - | + | + | + | - | + | + | **7** |
| 10 | *Longidorylaimoides longicaudatus* | + | + | + | + | - | + | - | + | - | - | + | - | **7** |
| 11 | *Ecumenicus monohystera* | - | - | + | + | + | - | + | - | + | + | - | + | **7** |
| 12 | *Labronemella labiata* | + | - | + | + | - | + | - | + | - | + | - | + | **7** |
| 13 | *Labronema ferox* | + | - | + | + | - | + | - | + | - | + | + | + | **8** |
| 14 | *Axonchium ampicolle* | - | + | - | + | - | - | + | - | + | - | + | + | **6** |
| 15 | *Axonchium vulvulatum* | - | + | - | + | + | - | + | - | + | - | + | + | **7** |
| 16 | *Lenonchium macrodorus* | + | + | + | - | + | - | + | + | - | + | + | + | **9** |
| 17 | *Lenonchium oryzae* | - | + | + | + | + | - | + | + | - | + | + | + | **9** |
| 18 | *Timmus tenerhastus* | + | - | + | + | + | - | + | + | + | - | - | + | **8** |
| 19 | *Aporcelaimellus obscurus* | + | - | + | + | + | - | + | + | + | - | - | + | **8** |
| 20 | *Aporcelaimus regius* | - | + | + | - | + | + | - | + | - | + | + | - | **7** |
| 21 | *Aporcelaimus americanus* | - | + | + | - | + | + | - | + | - | + | + | - | **7** |
| 22 | *Aporcelaimium labiatum* | + | - | - | + | - | + | + | - | + | + | + | - | **7** |
| 23 | *Akortonus vigor* | + | - | - | + | - | + | + | - | + | + | + | - | **7** |
| 24 | *Makatinus heynsi* | + | - | + | + | - | + | + | - | + | + | + | - | **8** |
| 25 | *Neoactinolaimus agilis* | - | + | + | - | + | + | - | + | - | + | + | + | **8** |
| 26 | *Neoactinolaimus attenuates* | + | - | + | + | + | - | - | + | - | + | - | + | **7** |
| 27 | *Hexactinolaimus aneityi* | + | - | + | + | + | - | - | + | - | + | - | + | **7** |
| 28 | *Longidorus* elongatus | + | + | - | + | - | + | - | + | - | - | + | + | **7** |
| 29 | *Xiphinema brevicolle* | + | + | - | + | - | + | - | + | - | - | + | + | **7** |
| 30 | *Xiphinema americanum* | - | + | + | - | + | + | + | + | + | - | + | - | **8** |
| 31 | *Xiphinema elongatum* | - | + | + | - | + | + | + | + | + | - | + | - | **8** |
| 32 | *Xiphinema orbum* | + | - | + | + | - | - | - | + | + | + | - | + | **7** |
| 33 | *Xiphinema insigne* | + | - | + | + | - | - | - | + | + | + | - | + | **7** |
| 34 | *Mononchus tunbridgensis* | - | + | + | - | + | + | - | - | + | + | - | + | **7** |
| 35 | *Coomansus indicus* | - | + | + | + | + | + | - | - | + | + | - | + | **8** |
| 36 | *Coomansus parvus* | + | + | - | + | + | + | - | - | + | + | - | + | **8** |

| | | TALUKAS | | | | | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sr. No.** | **SPECIES** | **Pe** | **Ba** | **Bi** | **Sa** | **T** | **M** | **Po** | **D** | **Sl** | **Q** | **Sn** | **C** | **12** |
| 37 | *Iotonchus trichurus* | + | - | + | + | + | - | + | + | - | + | + | - | **8** |
| 38 | *Iotonchus indicus* | + | - | + | + | + | - | + | + | - | + | + | - | **8** |
| 39 | *Iotonchus basidontus* | + | - | + | + | + | - | - | + | - | + | + | - | **7** |
| 40 | *Clarkus elongatus* | + | - | + | + | + | - | - | + | - | + | + | - | **7** |
| 41 | *Parahadronchus shakili* | + | + | + | - | + | + | - | - | + | + | + | - | **8** |
| 42 | *Parahadronchus andamanicus* | + | - | + | + | - | + | + | + | - | + | - | + | **8** |
| 43 | *Mylonchulus subsimilis* | + | - | + | + | - | + | + | + | - | + | - | + | **8** |
| 44 | *Tylenchorhynchus annulatus* | - | + | + | - | + | - | + | - | + | - | + | + | **7** |
| 45 | *Tylenchus indicus* | - | + | + | - | + | - | + | - | + | - | + | + | **7** |
| 46 | *Ottolenchus parvus* | + | - | + | + | + | - | + | + | - | + | + | + | **9** |
| 47 | *Psilenchus minor* | + | - | + | + | + | - | + | + | - | + | + | + | **9** |
| 48 | *Radopholus similis* | + | + | - | + | + | + | - | + | + | - | + | + | **9** |
| 49 | *Rotylenchoides brevis* | + | + | - | + | - | + | - | + | + | - | + | - | **7** |
| 50 | *Hoplolaimus galeatus* | - | + | + | - | + | + | + | - | + | + | + | - | **8** |
| 51 | *Hoplomaimus indicus* | - | + | + | - | + | + | + | - | + | + | + | - | **8** |
| 52 | *Criconemoides xenoplax* | + | + | - | + | + | + | + | - | + | + | + | - | **9** |
| 53 | *Alaimus indicus* | + | - | + | + | - | + | + | + | - | + | + | - | **8** |
| 54 | *Alaimus manipuriensis* | - | + | - | + | - | + | - | + | + | - | - | + | **6** |
| 55 | *Amphidelus novus* | - | + | + | + | - | + | - | + | + | - | - | + | **7** |
| 56 | *Mesorhabditis spiculigera* | + | - | + | + | - | + | - | + | + | - | - | + | **7** |
| 57 | *Mesorhabditis cranganorensis* | - | - | + | + | + | - | + | + | - | + | + | + | **8** |
| 58 | *Cephalobus persegnis* | - | + | + | + | + | - | + | - | - | + | + | + | **8** |
| 59 | *Acrobeles ciliatus* | + | + | - | + | - | - | + | - | + | - | + | + | **7** |
| 60 | *Acrobeles cephalatus* | + | - | + | + | + | - | + | - | + | - | + | + | **8** |
| 61 | *Acrobeles timmi* | + | + | - | + | - | - | + | + | - | + | + | + | **8** |
| 62 | *Panagrolaimus fuchsi* | + | + | - | + | - | - | + | + | - | + | + | + | **8** |
| 63 | *Panagrolaimus rigidus* | - | + | + | - | + | + | - | + | + | + | + | + | **9** |
| 64 | *Panagrellusdorsobidentata* | - | + | + | - | + | + | - | + | + | + | + | + | **9** |
| 65 | *Ironus ignavus* | - | + | - | - | + | + | - | + | - | + | + | + | **7** |
| 66 | *Ironus longicaudatus* | + | + | - | + | - | - | + | - | - | - | - | + | **5** |
| 67 | *Plectus cirratus* | + | - | + | - | - | + | - | - | + | + | - | + | **6** |
| 68 | *Aphelenchus avenae* | + | + | + | - | - | + | - | - | + | + | - | - | **6** |
| 69 | *Prismatolaimus andrassyi* | - | + | + | - | - | + | + | - | + | - | + | - | **6** |
| | **TOTAL** | **43** | **39** | **50** | **47** | **40** | **38** | **36** | **44** | **37** | **41** | **43** | **45** | |

**Table 6.3: Nematode diversity in different talukas: + =present, - =absent**

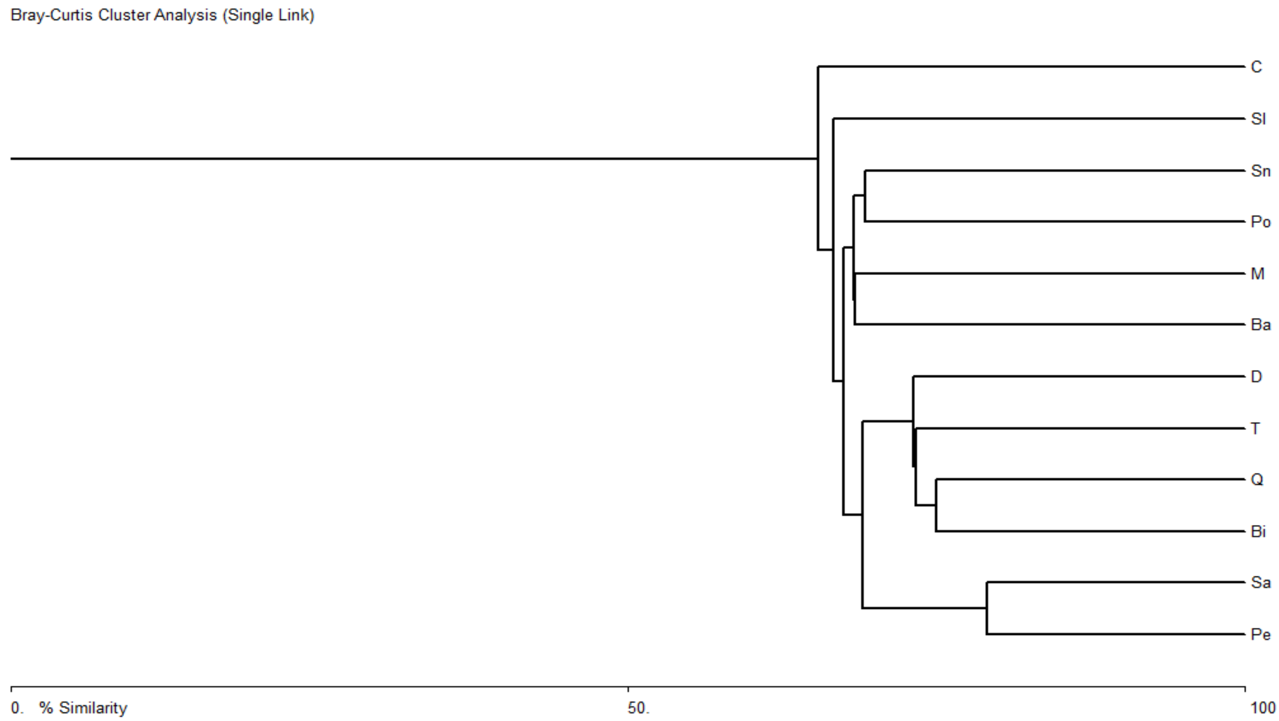



**Figure 6.5: Dendrogram of the cluster analysis of the diversity (presence / absence) of nematode species of the 12 talukas**

| Symbols | Description for measurements |
|---|---|
| L | overall body length |
| V | distance of vulva from anterior |
| a | body length / greatest body diameter (width) |
| b | body length / distance from anterior to esophago-intestinal valve (Pharynx l) |
| b' | body length / distance from anterior to base of esophageal glands |
| c | body length / tail length |
| c' | tail length / tail diameter at anus or cloaca (ABD) |
| s | stylet length / body diameter at base of stylet |
| T | % length of mail gonad relative to body length |
| o | % distance of dorsal esophageal gland opening from stylet knobs in relation to stylet length |
| P | % distance of phasmid from anus in relation to length of tail |
| $P^a$ | % distance of anterior phasmid from anterior of nematode in relation to bodylength |
| $P_p$ | % distance of posterior phasmid from anterior of nematode in relation to body length |
| $G_1$ | % length of anterior female gonad in relation to body length |
| $G_2$ | % length of posterior female gonad in relation to body length |
| Tail | portion of body from anus or cloaca to posterior terminus |

**Table 6.4: Nematode morphometric parameters (de Man formula).**


**Figure 6.6: Presence of individual species in the total number of talukas**

| Diversity indices | Talukas | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Pe | Ba | Bi | Sa | T | M | Po | D | Sl | Q | Sn | C |
| Species Richness_S | 43 | 39 | 50 | 47 | 40 | 38 | 36 | 44 | 37 | 41 | 43 | 45 |
| Abundance_A | 525 | 501 | 603 | 567 | 513 | 497 | 474 | 544 | 495 | 517 | 536 | 548 |
| Simpson's Dominance_D | 0.032 | 0.033 | 0.030 | 0.031 | 0.033 | 0.033 | 0.034 | 0.031 | 0.033 | 0.032 | 0.032 | 0.031 |
| Shannon_H | 3.41 | 3.39 | 3.47 | 3.46 | 3.40 | 3.38 | 3.37 | 3.41 | 3.38 | 3.40 | 3.41 | 3.42 |
| Evenness_e^H/S | 0.855 | 0.869 | 0.834 | 0.839 | 0.867 | 0.869 | 0.875 | 0.855 | 0.871 | 0.859 | 0.856 | 0.844 |
| Equitability_J | 0.95 | 0.94 | 0.96 | 0.96 | 0.94 | 0.93 | 0.92 | 0.95 | 0.93 | 0.94 | 0.95 | 0.96 |
| Fisher_α | 8.48 | 8.34 | 8.72 | 8.59 | 8.38 | 8.33 | 8.09 | 8.56 | 8.24 | 8.44 | 8.50 | 8.58 |

**Table 6.5: Diversity indices of nemafauna for different talukas**

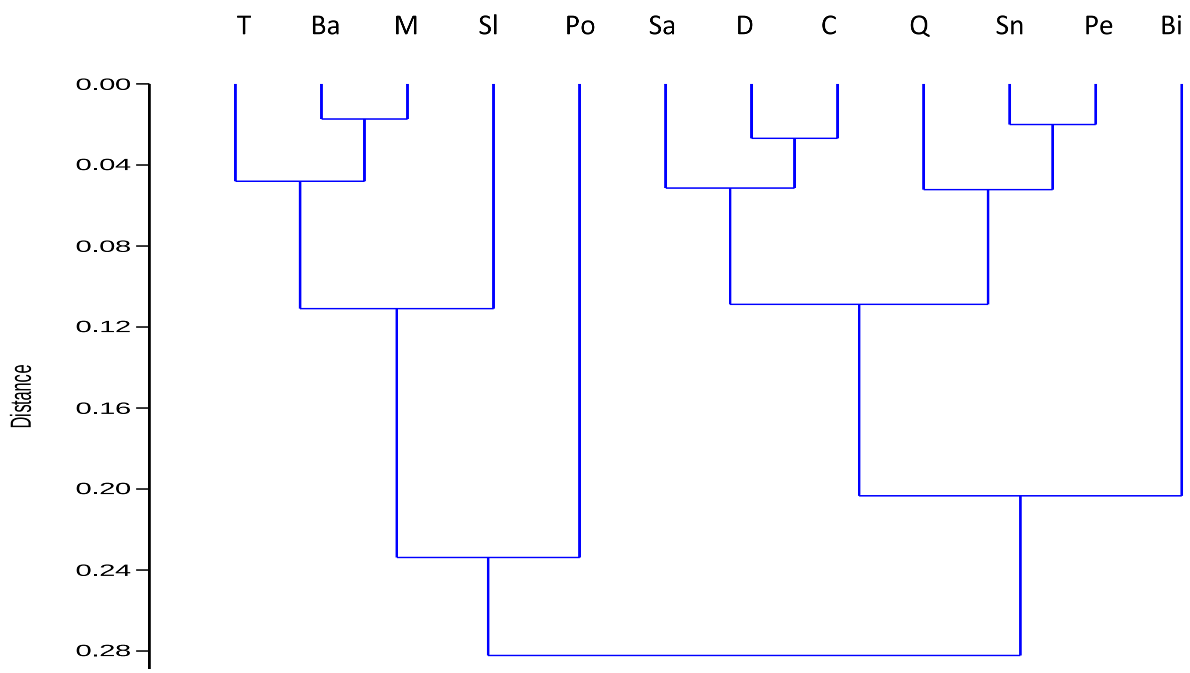



**Figure 6.7: Dendrogram of the cluster analysis of the diversity indices of nematode species of the 12 talukas (UPGMA, Euclidean distance).**

# DISCUSSION

Studies on belowground life forms make up merely a small amount (less than 3%) of papers published in the main ecological journals (Wardle, 2002). The maintenance of high nematode species diversity, in light of their presumably low degree of diet and habitat specialization, appears to be an enigma (Anderson, 1975; Ghilarov, 1977; Giller, 1996). Even though the number of species known today is a little above 20,000, this could be just the tip of an iceberg (Jairajpuri, 2002a).

In the present investigation, forty eight nematode genera were recorded with dorylaims constituting the most dominant group. The order also has the highest number of families and species which is in full agreement with Jairajpuri (2002 a) that the abundance of dorylaims in terms of genera, species and individuals confirms their wide occurrence and diversity in the soil ecosystem. Individual representation of dorylaims also was very high in this study as this order forms a very large and important group of soil inhabiting nematodes (Jairajpuri and Ahmad, 1992). Again dorylaims can be easily recognized at lower magnification.

Next dominant orders were Tylenchida and Rhabditida. This agrees well with Freckman, 1982 where he reports that only about ten of the 20 orders of phylum Nematoda regularly occur in soil, and four orders out of the ten (Rhabditida, Tylenchida, Aphelenchida, and Dorylaimida) are particularly common in soil. Occurrence of Aphelenchids was very poor.

It was also observed that species belonging to order Dorylaimida were found to be abundant among the trophic groups such as omnivores, predators, herbivores and fungivores. Species abundance was highest among the predators, which mostly consisted of members belonging to order Dorylaimida. Dorylaims are unique, because, within the same group, they exhibit most of the feeding patterns represented by nematodes and this is one of the reasons for their diversity and wide occurrence in the soil ecosystem (Jairajpuri, 2002a).

Generally less disturbed soils contain more predatory nematodes, indicating that, predatory nematodes are sensitive to a wide range of instability. Fungivores were represented with minimum species density. Ambiguity in trophic classification of nematodes usually occurs because it is inferred by morphology rather than actual experiments on feeding preferences (Yeates *et al.,* 1993). Furthermore, feeding-habit grouping may be ambiguous and / or not mutually exclusive in some cases (Sohlenius *et al*., 1977).

Among the soil samples that were collected throughout the state, samples collected from Bicholim taluka recorded the maximum diversity of nematode species. Bicholim is one of the talukas, where mining was carried on, but had been stopped for nearly two years. Initially there might have been decrease in nematode community, but probably the community was able to recover and get stabilized quickly, so maximum number of nematode species was recorded during the time of collection. This is in agreement with the reports of Háněl (2002) and Sikora *et al.,* (2014) that, nematodes communities develop more abundantly with diverse communities and a high proportion of omnivores and plant parasites after reclamation practices in the mining areas. The soil samples collected from Ponda taluka, showed minimum diversity. This could probably be because of the fact that Ponda consists mostly of soils that are poorly drained and less permeable. They are mostly saline, high in pH and contain less humus (vii). Most of the soil samples recorded above 55% of the species identified. Lateritic soil is the major type of soil in the state, along with alluvial soil. Lateritic soil is highly porous and permeable, slightly acidic; with low pH values whereas alluvial soil in addition to above has high organic content and is well drained (vii).

Maximum multiplication of nematodes occurs in sandy clay loam with pH 6.4 (laterite soil) (Norton, 1978). Clayey loam (alluvial soil) and coarse sandy loam also support appreciably high populations. The texture of the soil is of importance, as the nematode population is generally higher, in lighter soils, than in heavy soils (Thorne, 1927). This could be the reason for high occurrence of nematode diversity in most of the samples.

Predators formed the major group of the species identified. This could be because almost half the number of species identified belonged to the order Dorylaimida and species belonging to the order Dorylaimida commonly occur in soil ecosystem (Jairajpuri, 2002 a) and of this maximum were predators. Also order Dorylaimida includes species that are plant feeders, fungal feeders, predaceous; omnivores in general.

Shannon's and Fisher's diversity indices confirm the presence of more diverse species and high abundance in the soil samples of Bicholim taluka. It can be also inferred, based on the same indices that, the soil samples collected from Ponda taluka had less abundance and less diversity of species. Simpson's dominance values were high for the soil samples of Ponda taluka; while they were less for the soil samples of Bicholim taluka. Since the diversity is less, dominance of the species present is more. Soil samples from Bicholim study sites have exhibited more number of species, comparaed to those from Ponda which has less number of species.

Minute difference was observed in the distribution of species in the samples of Bicholim taluka when comparaed with the distribution values of other talukas. It was also revealed that Ponda taluka supports the high number of dominant species.

The dendrogram of the cluster analyses of species diversity showed, either values close to each other or a wide range from the highest to the lowest. This probably explains either a close similarity of the species diversity between the soil samples of Pernem and Satari taluka and a wide difference of the species diversity between the soil samples of Pernem and Canacona talukas.

## SUMMARY

From this study, it can be concluded that 69 species were recorded from the soil ecosystem of Goa. Of these 69, maximum number of species belonged to order Dorylaimida, followed by Tylenchida, Mononchida, Rhabditida, Enoplida, Alaimida and minimum to Aphelenchida, Araeolaimida and Monhysterida. Soil ecosystem favours dorylaims.

Species diversity was maximum (50 species) in the soil samples collected from Bicholim taluka and minimum (36 species) in Ponda taluka. Reclamation practices after mining helps in the establishment of highly diverse nematode communities. Soils of Ponda taluka are mostly saline and have high pH; hence they do not favour the presence of nematodes.

Soil samples from Bicholim taluka also had high abundance (603) of individual species while those from Ponda taluka had less abundance (474) of individual species. Mostly the species were evenly distributed. Of the 69 species recorded, soil samples collected from seven talukas had more than forty species.

Nematodes are ubiquitous inhabitants of soil and can survive on a variety of food and hence high diversity. The study shows that since the soils of Goa are rich in organic matter it favours the growth and population of soil inhabiting nematodes.

Predators were more among the species that were recorded followed by herbivores and bactivores. Many predator species belonged to order Dorylaimida and dorylaim occurrence in the soil ecosystem is the highest.

# CHAPTER II

*"They occur in arid deserts and at the bottoms of lakes and rivers,*
*in the waters of hot springs and in polar seas where*
*the temperature is constantly below the freezing point of freshwater.*
*They were thawed out alive from Antarctic ice in the far south*
*by members of the Shackelton expedition.*
*They occur at enormous depths in Alpine lakes and in the ocean."*
Cobb, 1915.

# CHAPTER II

## Comparision of the diversity, abundance and distribution of the soil nematode fauna from the various landscapes of Goa

### INTRODUCTION

There is a greater diversity of nematode genera and species in subtropical and tropical regions, than in the temperate zone, yet a few large scale and long-term surveys on nematode diversity have been undertaken in tropics. For example, only 10 out of 134 sites situated for nematode diversity have been located in tropical zones (Rosa and David, 2004).

Baird and Bernard (1984) reported 100 species, in just two soya-bean fields in Tennessee. Increasing interest in the biodiversity and the interpretation of a growing knowledge of the contribution of nematodes to soil ecosystem processes have resulted in a wider use of ecological indices (Bongers, 1990; Ferris *et al.*, 2001; Ferris and Matute, 2003) and so on. Nematode distributions are usually clustered around food sources and so food source could profoundly affect densities and detectability (Johnson *et al.*, 1972).

While literature dealing with nematode fauna, as soil health indicators, in different farming and natural systems, is abundant, few studies deal with regional / landscape / distribution pattern of nematode faunae. Most studies on nematode groups in soil are centred on field plots or single crop farm fields (Wardle *et al*., 1995; Berkelmans *et al*., 2003; Ferris and Matute, 2003).

Soil nematodes offer great potential for use as indicator of biodiversity and ecological stability, and for assessing the impact of changing land use on soil condition. The assemblage of plant and soil nematode species occurring in a natural or managed ecosystem constitutes nematode community. Grasslands may possibly contain 50 to 500 nematodes, and forest soils normally hold several hundreds per teaspoon. The proportion of bactivore and fungivore nematodes is related to the amount of bacteria and fungi in the soil.

It has been demonstrated that, various plant species have great influence on the abundance of nematodes (Wardle *et al.*, 2003; De Deyn *et al*., 2004; Viketoft *et al*., 2005). If there are a great number of specific connections between particular plant and nematode species, an increased diversity of plant species, should be relateded to an increase in number of nematodes species. However, so far, current studies indicate, only a weak association between number of plant species and number of nematode species (De Deyn *et al*., 2004; Viketoft *et al.*, 2009).

Theoretically, aboveground plant diversity generally promotes belowground diversity by increasing the variety of food resources (litter quality and composition), the range of environmental conditions like temperature, humidity; or the structural intricacies of the habitat (Anderson, 1995). Traditionally, not only have some nematode species been associated with particular soil textures (Jones *et al.,* 1969; Bongers, 1988), but also known that, populations of some of the larger nematodes are markedly reduced by soil cultivation (Oostenbrink, 1964; Jones *et al.*, 1969). While the litter or organic horizons normally contain the greatest concentrations of nematodes and a 10 or 15 cm deep sample including the organic horizon is appropriate, in some situations (e.g., woody horticultural crops) samples to 30 cm soil depth may be preferred. In some conditions specific populations may be untraceable in superficial samples, but may be present in significant numbers at depth (e.g., *Paratylenchus)* only below 40 cm in an Italian field (Geraert, 1965).

This chapter presents an assessment of abundance, diversity and the distribution patterns of the soil inhabiting, free living nematode fauna of different vegetation types, so that, it adds to the already existing rich knowledge on invertebrate biodiversity of Goa. It documents, the presence or absence of the different species of nematodes in the landscapes, as well as the diversity in each landscape. In this study, diversity is taken to imply not only H'-type statistics, but also its separate components of richness, dominance, and evenness. The study emphasizes the desirability of using species diversity, rather than tropic diversity, to draw the importance of nematodes in soil communities of different landscapes.

**MATERIALS AND METHODS**

Soil samples were collected from (1) August 2011 to February 2012, (2) August 2012 to February 2013 and (3) August 2013 to February 2014 from different landscapes (Table 4.1). The landscapes represented most of the vegetation type commonly found in Goa. Soil samples were also collected from some Khulaghars and farms maintained for specific plantation, eg. sugarcane, palmolein etc. From each type of landscape, soil samples of 1kg near the vicinity of the roots of the plants were collected from about 10 to 15cms depth. In some places soil samples were collected from deeper depth depending upon the season.

Each sample was collected in a self-sealing plastic bag with a label containing necessary field information. They were either processed immediately or stored in the refrigerator at $4^{o}C$ and were processed later. Nematodes were isolated using standard techniques as mentioned above; identification to species level and counting were done in the laboratory. Statistical analyses were made to analyze the distribution, dominance and abundance of different taxonomic groups and the relationships between the groups. Diversity Indices such as the Shannon-Weaver index, Simpson index etc. were also calculated using PAST statistical software Version 2.7 (viii) and Biodiversity Pro statistical software Version 2 (xiii).

**RESULTS**

Maximum number of species (40), genera (32), abundance (557) and orders (seven) were recorded, from the sites near the roadside weeds / bushes. Majority of the landscapes had 30 and more of the recorded species, except coconut plantation, which had a minimum number of species (22), minimum number of families (11) and minimum abundance (399). This was followed by less number of species in teak plantation area (26), forest area (27) and acacia (28) plantation. Sugarcane plantation, acacia plantation and forest area had 21 genera (Figure 7.2). Betelnut plantation recorded five orders, flower garden and forest area seven orders each, while the rest of the landscapes recorded members from six orders (Figure 7.3). Three species, *Cephalobus persegnis, Plectus cirratus and Prismatolaimus andrassyi* were present only in three landscpaes whereas the other species were present in more than four landscapes (Table 7.1 & Figure 7.5).

In all the landscapes, highest number of families (9), genera (23) and species (33) was recorded from the the order Dorylaimida, followed by the order Mononchida with three families, six genera and 10 species. Tylenchida was represented by three families, eight genera and nine species; while orders Araeolaimida, Aphelenchida and Monhysterida had just one family, one genus and one species (Figure 7.2).

Simpson's Dominance showed highest results in the soil samples collected from coconut grove (0.04) and lowest in the samples from vegetable plots and roadside weeds / bushes (0.03). Shannon's Diversity value was more in the soil samples from roadside weeds / bushes (3.44) and less in the samples from coconut groves (3.21). The Species were more or less evenly distributed in all the soil samples with the values ranging from 0.70 (roadside weeds / bushes) to 0.89 (coconut grove). Equitability values ranged from 0.90 (coconut grove) to 0.96 (roadside weeds / bushes) with a difference of almost 0.06. The values of Fisher's Alpha diversity index were less (8.28) for the soil samples from coconut groves and more (9.23) for the soil samples roadside weeds / bushes (Table 7.2).

Maximum percent occurrence of the omnivores was observed in sugarcane plantation (23%) and minimum was recorded in palmolein farms (11%), whereas sugarcane had minimum percentage of predators (27%) and maximum percent occurrence of the trophic group predators was in forest areas (44%). Among the fungivores, maximum was found in palmolein farms, whereas there were no fungivores observed in flower gardens, coconut groves and betelnut plantation. Flower gardens had maximum percent of herbivores (34%), while forest areas and coconut groves had minimum (19%). Bactivores had high percent occurrence in coconut groves (31%) and low in orchards and roadside weeds / bushes (Figure 7.4).

In abundance, a moderate positive correlation was noticed between omnivores / herbivores (r=0.58) and between omnivores / predators (r=0.54). Similarly, a little high, positive correlation, was observed between fungivores / bactivores (r=0.68) and a very low positive correlation was observed between herbivores / predators (r=0.11). The rest of the trophic groups showed negative correlation (Figure 7.6).

The dendrogram of the cluster analysis of species diversity of nematodes of soil samples collected different landscapes, showed that, there is close similarity between the samples of flower gardens and teak plantation with similarity index of 64.28 between roadside weeds / bushes and palmolein farms (62.33), orchards and roadside weeds / bushes (61.76); while a wide difference between the samples of orchards and flower gardens with similarity index of 52; between orchards and acacia plantation with similarity index of 50 and between orchards and sugarcane plantation with similarity index, 45.90 (Figure 7.1).

The dendrogram of the cluster analysis of diversity indices shows, close similarity between forest area and acacia plantation, betelnut plantation and orchards, and flower gardens and wasteland areas sampling sites, while a wide difference between teak plantation and roadside weeds / bushes, and between wasteland areas and vegetable plots sampling sites (Figure 7.5).

| Sr. No. | SPECIES | VEGETATION TYPES | | | | | | | | | | | | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **O** | **FG** | **VP** | **FA** | **RWB** | **WA** | **CG** | **AP** | **SP** | **TP** | **BP** | **PF** | **12** |
| 1 | *Dorylaimus stagnalis* | + | - | + | - | + | - | + | - | + | - | + | + | **7** |
| 2 | *Mesodorylaimus chamoliensis* | - | - | + | + | - | - | - | + | + | - | - | + | **5** |
| 3 | *Mesodorylaimus mesonyctius* | - | + | - | - | + | + | - | - | + | + | + | - | **6** |
| 4 | *Thornenema lissum* | + | + | + | - | + | + | - | + | + | - | - | - | **7** |
| 5 | *Coomansinema dimorphicauda* | + | - | - | + | - | + | + | - | - | - | - | + | **5** |
| 6 | *Discolaimus major* | - | - | + | + | + | - | - | - | - | + | - | - | **4** |
| 7 | *Discolaimus texanus* | + | - | - | - | + | + | + | - | - | - | + | + | **6** |
| 8 | *Prodorylaimium goanese* | - | - | - | + | - | + | - | + | + | - | - | - | **4** |
| 9 | *Indodorylaimus saccatus* | - | + | + | - | + | - | - | - | + | + | - | + | **6** |
| 10 | *Longidorylaimoides longicaudatus* | + | + | - | - | + | - | + | - | + | + | + | - | **7** |
| 11 | *Ecumenicus monohystera* | + | - | + | + | - | + | + | + | - | + | - | + | **8** |
| 12 | *Labronemella labiata* | + | + | + | - | - | + | - | - | + | - | - | - | **5** |
| 13 | *Labronema ferox* | + | - | - | - | + | - | - | + | - | - | - | + | **4** |
| 14 | *Axonchium ampicolle* | - | - | + | - | + | - | - | + | - | + | - | + | **5** |
| 15 | *Axonchium vulvulatum* | + | - | - | + | + | + | - | - | + | - | - | + | **6** |
| 16 | *Lenonchium macrodorus* | + | - | - | - | + | + | - | - | + | - | - | + | **5** |
| 17 | *Lenonchium oryzae* | + | + | + | - | + | - | + | + | - | - | + | + | **8** |
| 18 | *Timmus tenerhastus* | - | + | + | + | + | + | - | - | - | + | + | - | **7** |
| 19 | *Aporcelaimellus obscurus* | - | + | + | + | - | - | - | - | - | + | + | - | **5** |
| 20 | *Aporcelaimus regius* | - | + | + | + | - | + | - | - | - | + | + | - | **6** |
| 21 | *Aporcelaimus americanus* | - | + | + | + | - | - | - | - | - | + | + | - | **5** |
| 22 | *Aporcemaimium labiatum* | + | - | - | - | - | + | + | - | + | - | + | - | **5** |
| 23 | *Akrotonus vigor* | + | - | + | - | + | - | - | + | - | + | + | + | **7** |
| 24 | *Makatinus heynsi* | - | - | + | + | + | + | - | + | - | - | + | + | **7** |
| 25 | *Neoactinolaimus agilis* | - | + | - | - | + | - | + | - | + | - | - | + | **5** |
| 26 | *Neoactinolaimus attenuates* | + | - | + | - | + | - | + | - | - | + | - | + | **6** |
| 27 | *Hexactinolaimus aneityi* | + | - | + | - | + | - | + | - | - | + | - | + | **6** |
| 28 | *Longidorus elongatus* | - | + | + | - | - | - | - | + | + | - | - | + | **5** |
| 29 | *Xiphinema brevicolle* | - | + | + | - | - | - | - | + | + | - | - | + | **5** |
| 30 | *Xiphinema americanum* | + | - | + | - | + | + | - | - | - | - | + | + | **6** |
| 31 | *Xiphinema elongatum* | + | - | + | - | + | + | + | - | - | - | + | + | **7** |
| 32 | *Xiphinema orbum* | - | + | + | + | - | - | - | + | - | + | - | + | **6** |
| 33 | *Xiphinema insigne* | + | + | + | - | + | + | - | + | - | + | - | - | **7** |
| 34 | *Mononchus tunbridgensis* | - | + | - | + | + | + | - | + | - | - | - | + | **6** |
| 35 | *Coomansus indicus* | + | - | + | - | - | + | - | + | - | - | + | - | **5** |
| 36 | *Coomansus parvus* | + | + | - | - | + | - | - | + | - | - | + | + | **6** |
| 37 | *Clarkus elongatus* | - | - | + | + | + | - | - | - | - | + | - | + | **5** |
| 38 | *Iotonchus trichurus* | - | + | - | - | - | + | + | + | + | - | + | - | **6** |
| 39 | *Iotonchus indicus* | + | - | - | + | + | - | - | - | + | - | + | + | **6** |

| Sr. No. | SPECIES | VEGETATION TYPES | | | | | | | | | | | | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **O** | **FG** | **VP** | **FA** | **RWB** | **WA** | **CG** | **AP** | **SP** | **TP** | **BP** | **PF** | **12** |
| 40 | *Iotonchus basidontus* | - | - | + | - | + | + | - | - | + | - | - | + | **5** |
| 41 | *Parahadronchus shakili* | + | - | + | + | - | - | + | - | + | - | - | + | **6** |
| 42 | *Parahadronchus andamanicus* | + | - | + | - | + | - | - | - | + | - | + | - | **5** |
| 43 | *Mylonchulus subsimilis* | - | + | + | - | - | + | - | - | - | + | - | - | **4** |
| 44 | *Tylenchorhynchus annulatus* | - | + | - | + | + | - | - | - | + | + | + | - | **6** |
| 45 | *Tylenchus indicus* | - | + | - | + | + | - | - | - | + | + | - | - | **5** |
| 46 | *Ottolenchus parvus* | + | - | + | - | + | - | - | - | - | - | - | + | **4** |
| 47 | *Psilenchus minor* | - | + | - | - | + | + | - | - | - | - | + | - | **4** |
| 48 | *Radopholus similis* | + | - | - | - | + | + | - | - | + | - | + | - | **5** |
| 49 | *Rotylenchoides brevis* | - | + | - | + | - | + | - | - | + | + | - | - | **5** |
| 50 | *Hoplolaimus* galeatus | + | - | - | - | + | - | + | + | - | - | + | - | **4** |
| 51 | *Hoplolaimus indicus* | + | - | - | - | - | - | + | + | - | - | + | - | **4** |
| 52 | *Criconemella xenoplax* | - | - | + | + | - | - | - | + | + | - | + | + | **6** |
| 53 | *Alaimus indicus* | - | + | + | - | + | + | - | - | - | + | - | - | **5** |
| 54 | *Alaimus manipuriensis* | + | - | - | + | - | - | + | + | - | - | - | + | **5** |
| 55 | *Amphidelus novus* | + | - | - | + | - | - | + | + | - | + | - | + | **6** |
| 56 | *Mesorhabditis spiculigera* | + | + | - | - | - | - | - | - | - | + | + | + | **5** |
| 57 | *Mesorhabditis cranganorensis* | - | - | + | - | + | + | - | + | - | - | - | - | **4** |
| 58 | *Cephalobus persegnis* | - | - | + | - | + | - | + | - | - | - | - | - | **3** |
| 59 | *Acrobeles ciliatus* | - | - | + | - | - | - | + | - | + | - | + | + | **5** |
| 60 | *Acrobeles cephalatus* | + | + | - | + | - | + | - | + | + | - | + | - | **7** |
| 61 | *Acrobeles timmi* | - | - | + | - | + | - | + | + | - | - | - | - | **4** |
| 62 | *Panagrolaimus fuchsia* | - | + | - | - | + | + | - | - | - | + | + | + | **6** |
| 63 | *Panagrolaimus rigidus* | - | - | + | - | - | - | + | - | + | - | + | - | **4** |
| 64 | *Panagrellus dorsobidentata* | - | - | - | + | - | + | - | + | + | - | - | + | **5** |
| 65 | *Ironus longicaudatus* | - | + | - | + | + | + | - | + | - | + | - | - | **6** |
| 66 | *Ironus ignavus* | - | + | - | + | - | + | - | + | - | + | - | - | **5** |
| 67 | *Plectus cirratus* | - | - | + | - | - | - | - | - | + | - | + | - | **3** |
| 68 | *Aphelenchus avenae* | + | - | - | - | + | - | - | - | + | - | - | + | **4** |
| 69 | *Prismatolaimus andrassyi* | - | + | - | + | - | - | + | - | - | - | - | - | **3** |
| | **TOTAL** | **32** | **30** | **38** | **27** | **40** | **31** | **22** | **28** | **30** | **26** | **31** | **36** | |

**Table 7.1: Nematode diversity in different vegetation types of Goa: + =present, - =absent**

O= Orchards, FG= Flower Gardens, VP= Vegetable Plots, FA= Forest Area, RW&B= Roadside Weeds / Bushes, WA= Wasteland Area, CG= Coconut Grove, AP= Acacia Plantation, SP= Sugarcane Plantation, TP= Teak Plantation, BP= Betelnut Plantation (Khulaghars) & PF= Palmolein Farms.

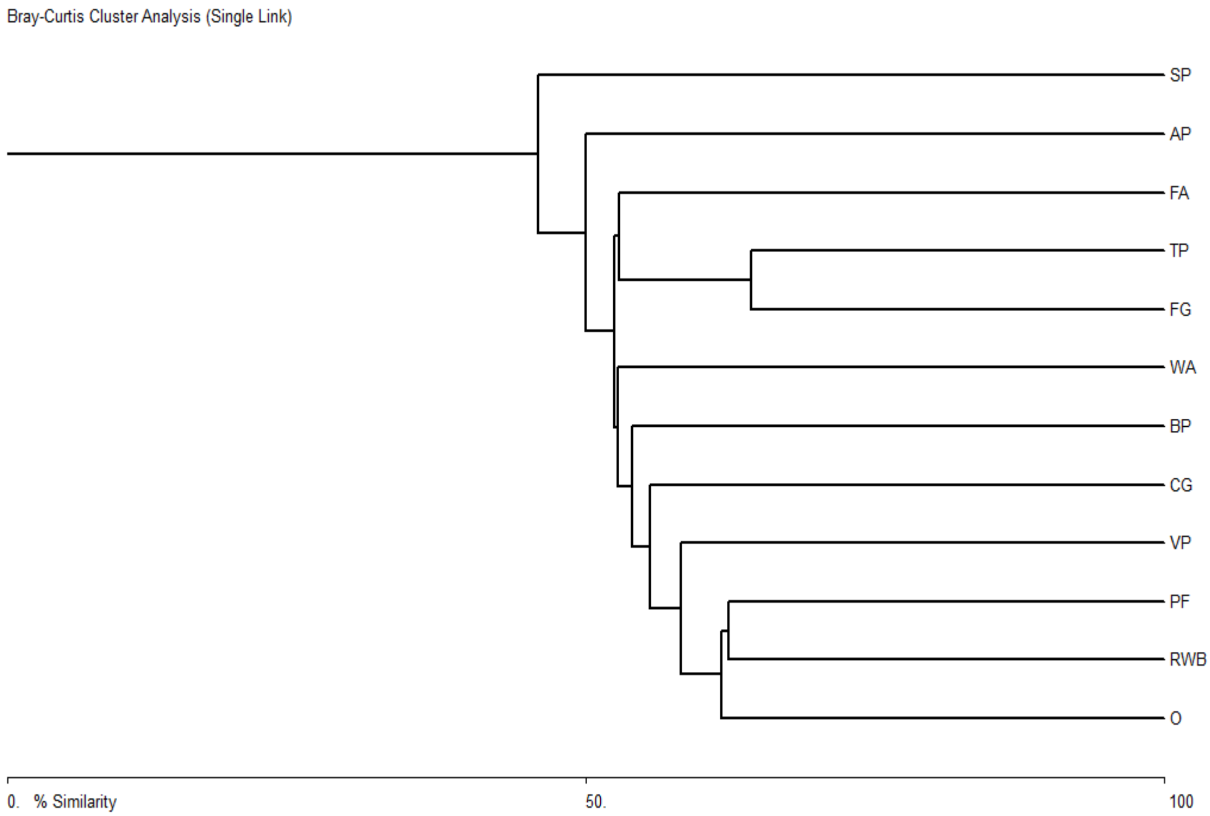



**Figure 7.1: Dendrogram of the cluster analysis of the diversity of nematode species of the vegetation types.**

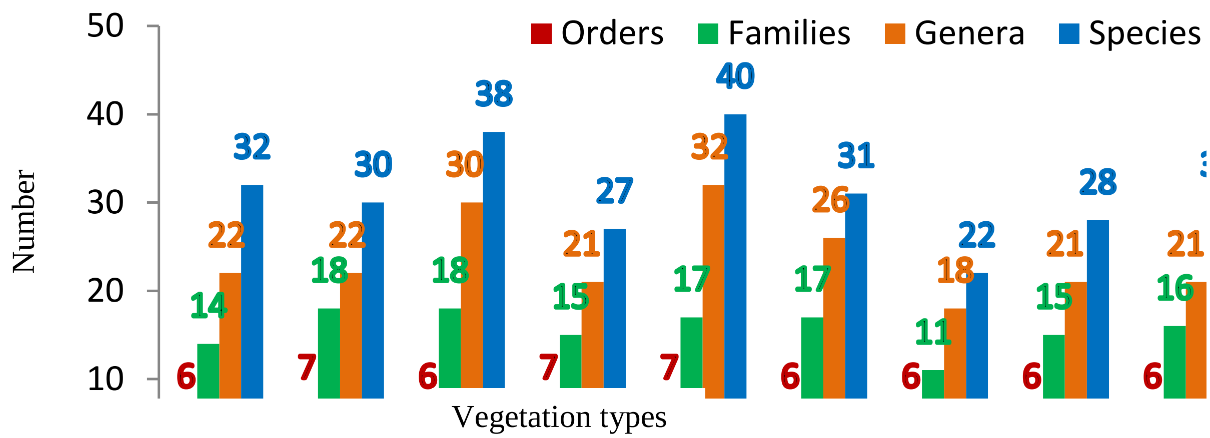



**Figure 7.2: Taxonomic status of the nematodes present in different vegetation types.**

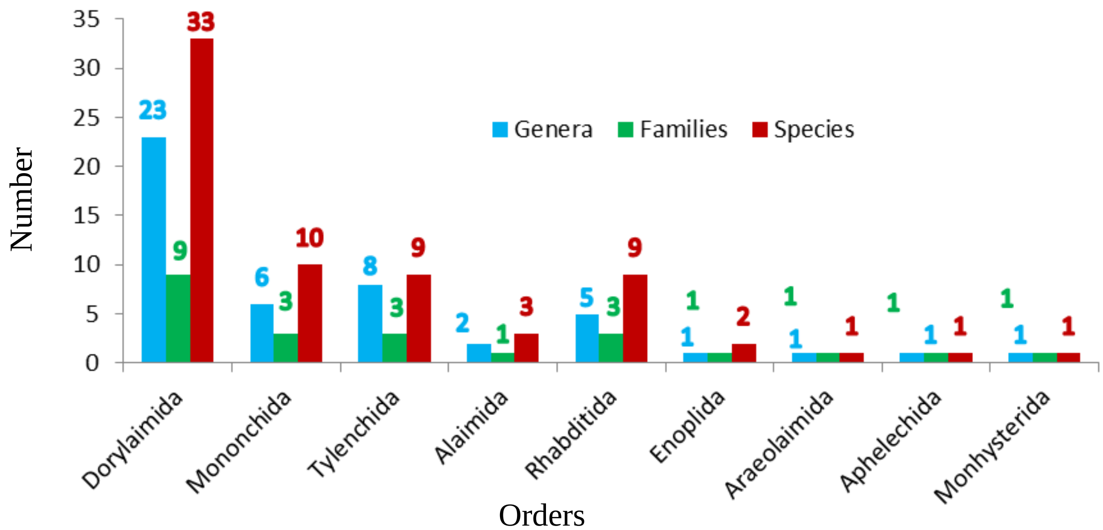
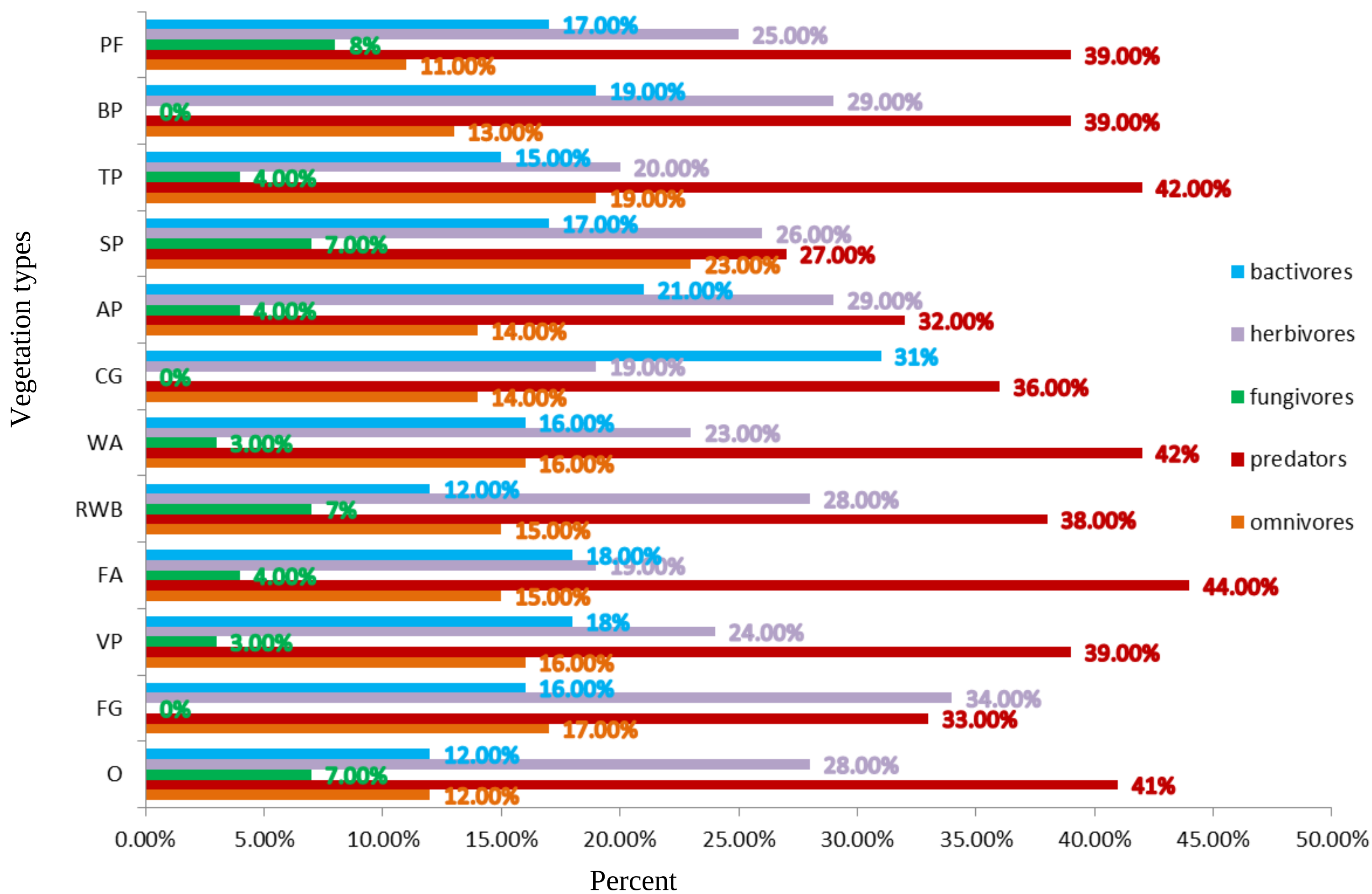



**Figure 7.3: Order-wise soil nematode diversity of the vegetation types of Goa**




**7.4: Percent occurrence of trophic groups in different vegetation types.**

| Diversity Indices | Vegetation types | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | O | FG | VP | FA | RWB | WA | CG | AP | SP | TP | BP | PF |
| Species Richness_S | 32 | 30 | 38 | 27 | 40 | 31 | 22 | 28 | 30 | 26 | 31 | 36 |
| Abundance_A | 481 | 456 | 519 | 432 | 557 | 463 | 399 | 450 | 451 | 427 | 456 | 482 |
| Simpson's Dominance_D | 0.032 | 0.033 | 0.031 | 0.033 | 0.031 | 0.032 | 0.047 | 0.033 | 0.032 | 0.033 | 0.032 | 0.032 |
| Shannon_H | 3.41 | 3.39 | 3.43 | 3.39 | 3.44 | 3.40 | 3.21 | 3.40 | 3.39 | 3.39 | 3.40 | 3.42 |
| Evenness_e^H/S | 0.851 | 0.863 | 0.848 | 0.879 | 0.709 | 0.854 | 0.890 | 0.864 | 0.861 | 0.872 | 0.860 | 0.850 |
| Equitability_J | 0.959 | 0.957 | 0.963 | 0.954 | 0.967 | 0.958 | 0.903 | 0.954 | 0.955 | 0.953 | 0.958 | 0.961 |
| Fisher_α | 8.869 | 8.831 | 9.026 | 8.673 | 9.239 | 8.831 | 8.289 | 8.679 | 8.787 | 8.472 | 8.863 | 8.991 |

**Table 7.2: Diversity indices of nemafauna for different vegetation types of Goa.**

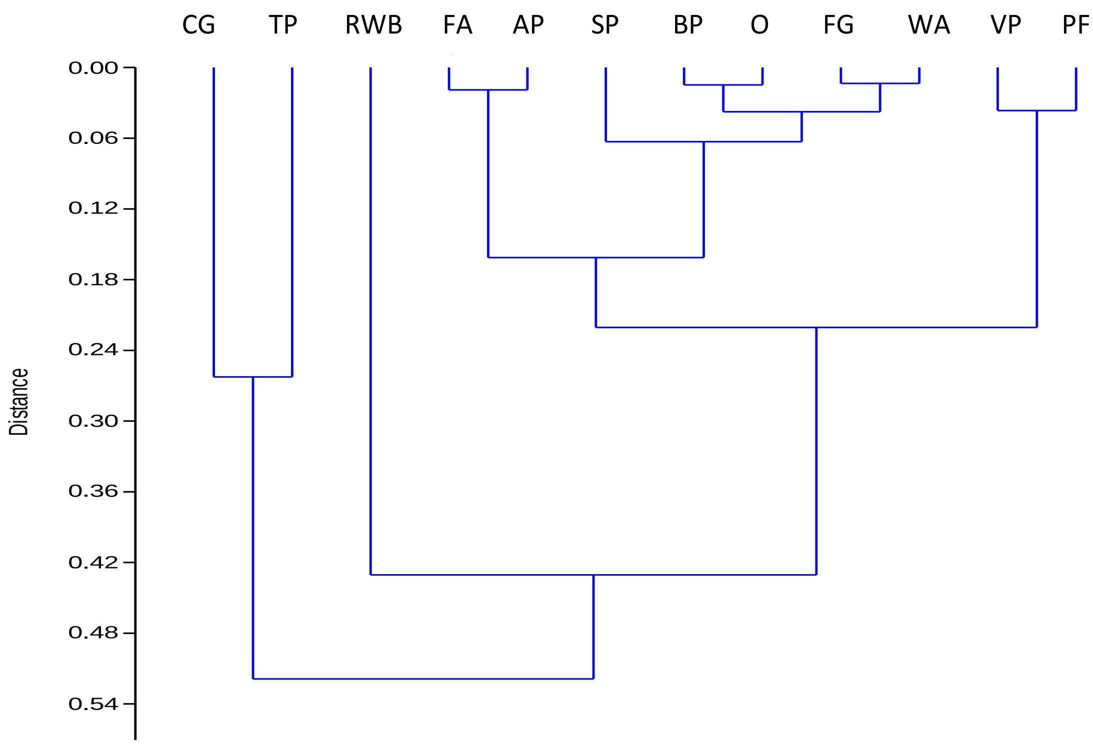
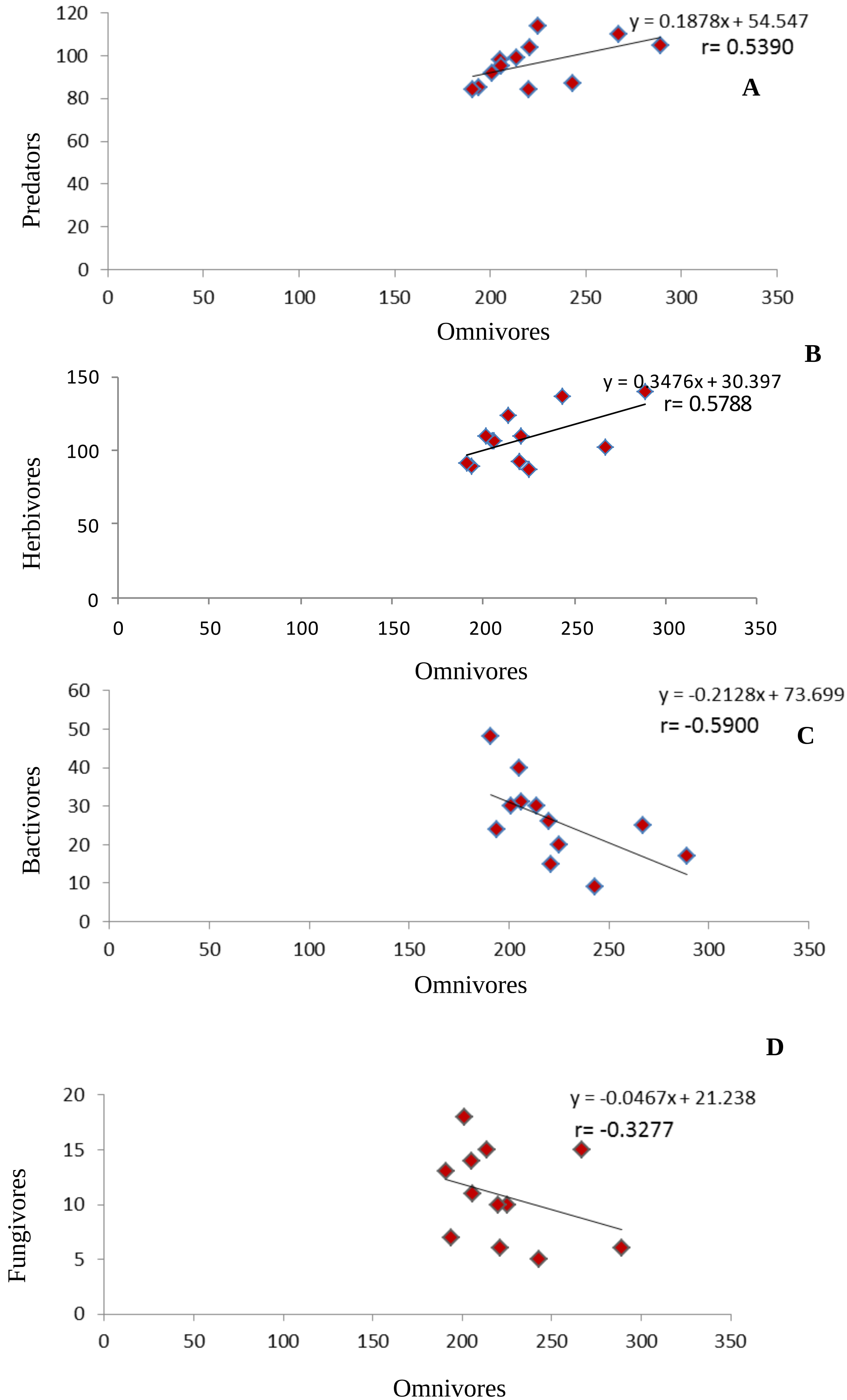



**Figure 7.5: Dendrogram of the cluster analysis of the diversity indices of nematode species of the vegetation types (UPGMA, Euclidean distance).**


A
y = 0.1878x + 54.547
r= 0.5390
Predators
Omnivores
B
y = 0.3476x + 30.397
r= 0.5788
Herbivores
Omnivores
C
y = -0.2128x + 73.699
r= -0.5900
Bactivores
Omnivores
D
y = -0.0467x + 21.238
r= -0.3277
Fungivores
Omnivores

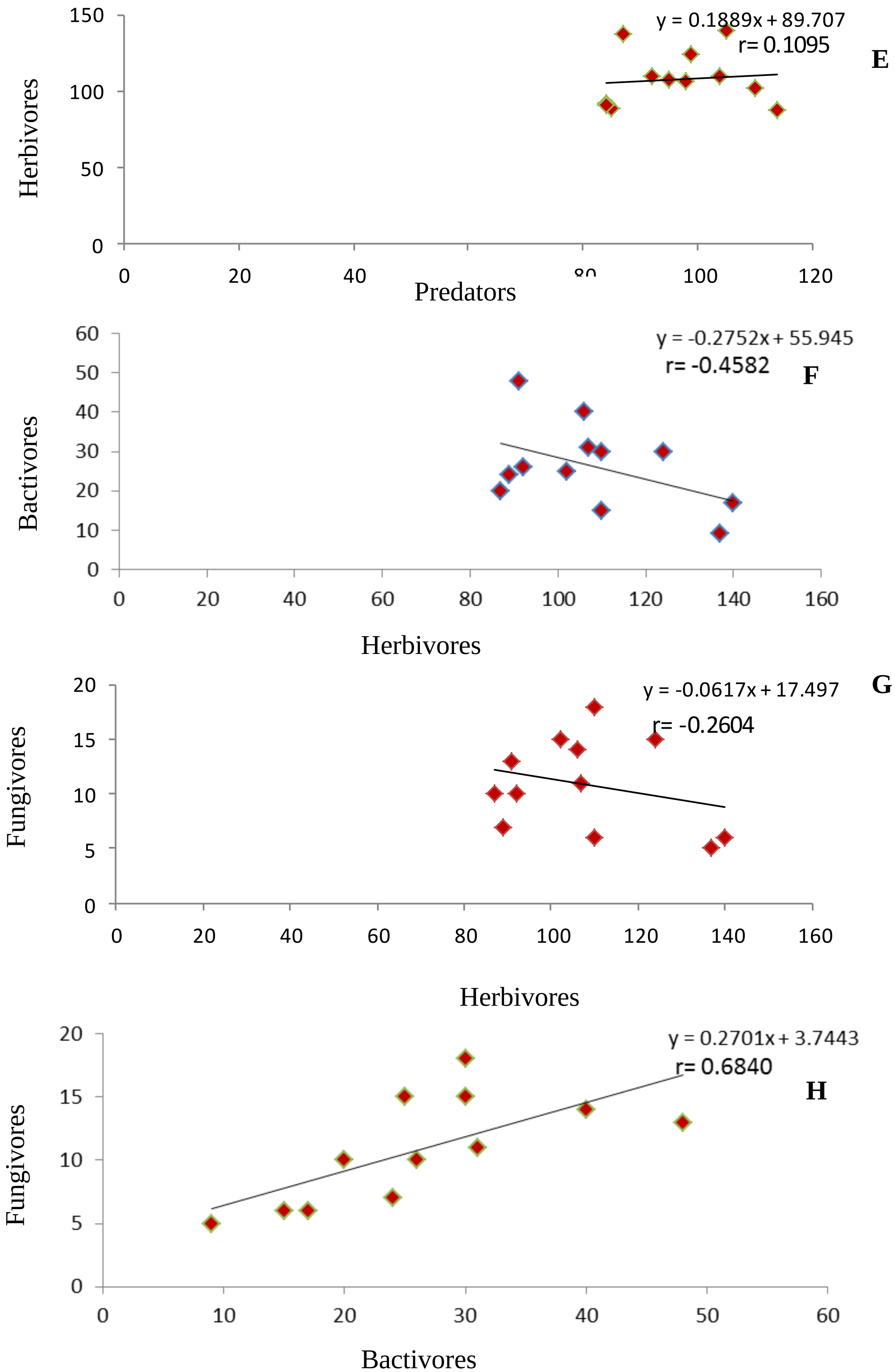



**Figure 7.6: Correlation between the trophic groups (Abundance)**

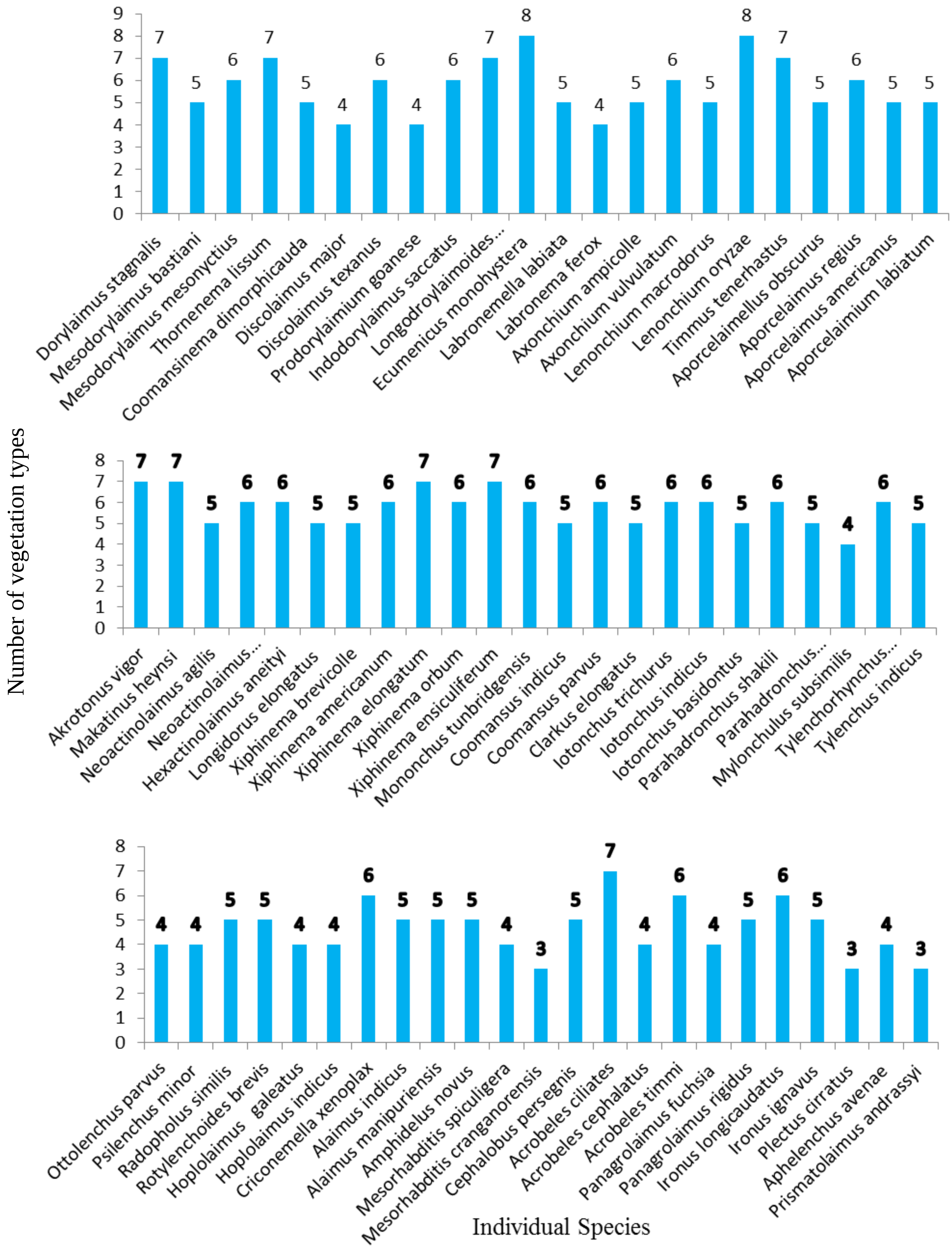



**Figure 7.7: Presence of individual species in the total number of vegetation types**

**DISCUSSIONS**

Vegetable growing plots and roadside weeds / bushes had maximum number of species, as these areas have diverse vegetation. Increasing litter diversity may increase the diversity of microhabitats and therefore decomposer faunal diversity (Wardle, 2006). Nematode distribution is usually clustered about food sources and so food source profoundly affect densities and detectability (Johnson *et al.*, 1972). One habitat in which the diversity of decomposer organisms may significantly influence ecosystem functioning is in plant debris rather than in mineral soil (Wardle, 2006). Soil samples from roadside weeds / bushes study sites have more abundance of individuals whilst those from coconut grove have less number of species. Various plant species have great influence on the abundance of nematodes (Wardle *et al*., 2003; De Deyn *et al.*, 2004; Viketoft *et al.*, 2005).

It is difficult to get moist soil sample from acacia plantation after November. Within two to three weeks after rainy season, the water table declines to 10-15cm depth and below. Hence, topsoil does not remain moist for a longer period in acacia plantation (De Boever *et al.*, 2012). Nematodes tend to move vertically downwards into the soil ecosystem, when water column recedes, into the deeper layers and so it is difficult to trap them in the topsoil layer.

The teak plants are mostly grown in the dry-tropical zones (ix), while coconut prefers areas with abundant sunlight and does not require overhead canopy, as even a small coconut trees require direct sun (ix) and this might be the reason for minimum diversity of nematofauna in the teak and coconut plantations as nematodes need a water film for survival and thrive well in moist soil (Jairajpuri and Baqri, 1991).

Shannon's and Fisher's Diversity indices confirms, the presence of more diverse species and high abundance in the soil samples from roadside weeds / bushes which is in agreement with the reportof Yeates (1996), which says that high Shannon's diversity values could be due the occurrence of abundance of dorylaims. It can be also inferred based on the same indices that the soil samples collected from coconut grove had less abundance and less diversity of species. Simpson's Dominance values were high for the soil samples from coconut grove whilst they were less for the soil samples roadside weeds / bushes.

The difference observed in the distribution of species in the samples of roadside weeds / bushes compared to the distribution values of other landscapes and of coconut grove supports the high number of dominant species in the coconut groves.

In abundance, a moderate correlation between omnivores / herbivores, between fungivores / bactivores, could be attributed to the rapid colonizing activity of bactivores, having high rate of reproduction and metabolic activity. Omnivores, on the other hand have low reproductive rate and low colonizing ability (Bongers, 1990; Bongers and Ferris, 1999). Bactivores might be acting as a suitable food source for omnivores. A positive correlation between omnivores / herbivores could be due to the fact that, omnivores feed on multiple food items, which is in agreement with the findings of Yeates *et al*., (1993) and Yeates, (1999). On the contrary, herbivores depend on plant roots, for their food and so increase in their population. As reported by Háněl, (2003) that, omnivores being versatile feeders intervene in the food web and create a lot of free space, which might be utilized by herbivores, thus increasing their population.

The dendrogram of the cluster analyses of species diversity, showed either values close to each other, or a wide range from the highest to the lowest. This explain, either a close similarity of the species diversity between the soil samples of flower gardens and teak plantation, roadside weeds / bushes and palmolein farms or a wide difference of the species diversity between the soil samples of orchards and sugarcane plantation, and orchards and acacia plantation.

The presence of individual species in total number of talukas was also recorded. Most of the species that were recorded were present in the soil samples of about five to seven landscapes except for *Mesorhabditis cranganorensis*, *Plectus cirratus* and *Prismatolaimus andrassyi* that were present only in three landscapes (Figure 7.7)

**SUMMARY**

From the present chapter, it can be concluded that, though diversity in landscapes or vegetation type may not directly influence the nematode species diversity, yet it may indirectly have an effect on the trophic groups' diversity, as different nematode species feed on different vegetation.

In this investigation, maximum number of species, genera, order and abundance was reported from the soil samples, collected from near the roadside weeds / bushes. As the diversity of weeds / bushes was more, it is probable that, aboveground plant diversity may promote belowground diversity, by increasing the variety of food resources, as well as litter quality and composition.

Minimum diversity of nematode species was found in teak, coconut and acacia plantations. This could be because of these vegetation types require direct sunlight and less water. Nematodes species cannot survive without a thin film of water, even in the terrestrial ecosystem.

A lot of variation was found in the maximum occurrence of the different trophic groups in the vegetation types. It could be probably because, among the Dorylaims itself, various feeding groups exist and Dorylaims diversity is more in soil ecosystem.

A positive correlation between omnivores / predators and omnivores / herbivores could be reasoned because of the omnivores are multiple feeders and soils of Goa are rich in organic matter, with verdant vegetation. A moderately high correlation between fungivore / bactivore could be because bactivores have high reproductive rate and ability to colonize rapidly.

# CHAPTER III

*As a result of my investigations,*
*I am inclined to believe that these free nematodes*
*will be found to constitute one of the most*
*widely diffused and abundant groups in the*
*whole animal kingdom………..*
*Thus, beginning with the land and freshwater species,*
*I have found them in all specimens of soil examined,*
*in moss, various species of lichens…….*
*between the sheaths of leaves…..and on submerged aquatic plants.*

(Bastian, 1865)

# CHAPTER III

## Studies on the diversity, abundance and distribution of soil nematode fauna from paddy fields of Goa.

### INTRODUCTION

There is a tendency amongst the world's conservationists, to focus on large charismatic species, often failing to recognize the agroecosystem, and the species they contain, as part of world's biodiversity (Vandermeer and Perfecto, 1997). The loss of inconspicuous species is the very base of biodiversity crisis. Diversity of soil fauna is one of the important factors, influencing the sustainability of agroecosystem. Species richness of the nematode fauna of agricultural soil may be high (Frechman and Ettema, 1993) and this could be due to dominance of only a few species. They are the most abundant, components of the mesofauna in agronomic soils. Freckman and Ettema, (1993), compared nematode communities, in agroecosystems, varying in level of human involvement. While Yeates and Bird, (1994) compared agroecosystems, with shrubs in Australia, both demonstrating the possibility of nematode communities as bioindicators for monitoring the state of agricultural soils (Bongers *et al.*, 1997; Bongers and Ferris, 1999; Lenz and Eisenbeis, 2000).

The paddy crop environment provides a specialized habitat, for soil nematodes in which the soil particles have a high water holding capacity (Jairajpuri and Baqri, 1991). In paddy, the roots are virtually under water most of the time. Hence, knowledge on nematodes parasitizing paddy is poor. This is due to the fact that paddy is grown mostly in the developing or underdeveloped countries and in these countries appropriate facilities and scientific personnel who could tackle the problem are lacking. In Asian countries in general and Indian subcontinent in particular, more precisely the eastern region of India, rice is grown widely and a large mass of human population depends on it for its livelihood.

Nematodes are considered as important pests of rice (Butler, 1913). Several groups of nematodes can be found in the paddy fields, including those which are specific parasites of the roots, stem, and leaves of rice plants. The plant-parasitic nematodes, that are associated with paddy, belong to several groups with different kinds, characteristics, feeding habits, behaviour and pathogenecity. Agriculture does seem to have produced a dynamic habitat, in which a wide range of soil nematode species can survive and multiply (McNeely *et al.*,1995). At the same time, because of difficulties in identification, many nematode pests of rice have gone unnoticed.

In agroecosystems, soil texture, moisture and the availability of suitable food are critical in determining the diversity of the nematode fauna. The nematode fauna comprises native species, which have survived agricultural management; species which may have been introduced by human activity and species which have arrived by natural dispersion. Not only the climate-driven annual cycles of agriculture, but also longer term cycles of land use, influence the proportion of various nematode taxa, which make up the nematode fauna at a particular time. A sample from an agroecosystem may contain in around 50 nematode taxa, in varying proportion. Agricultural soils by and large sustain, less than 100 nematodes, in each teaspoon (dry gram) of soil. The nematode population of the soil is highest in fertilized agricultural lands with animal faeces. In undisturbed soils, covered with grass and sod, or not grown to crops, the count runs very high, 7 to 9 hundred millions.

Rice is the main cereal crop which is grown and consumed all over the world. The rice plant variety, *Oryza sativa* L., is cultivated in plains under flooded conditions, well drained upland fields or on the mounts. The total area under rice cultivation in the world is about 140 million hectares. In India alone, rice is grown on 37 million hectares and the total production is approximately 65 million tons, which accounts for nearly one third of our total grain production.

About 300 nematode species, belonging to 35 genera, have been reported, to be pests rice. Among them, nematode species from about ten genera are economically important, in rice production (x). Rice grown in different environments is attacked by different nematode species. Ufra (*Ditylenchus angustus*) and root-knot (*Meloidogyne spp*.) are major nematode pests of deep water rice. In the irrigated rice fields, infections by *Hirschmanniella spp*. and *Aphelenchoides besseyi* are common; whereas, upland rice is invariably infested by *Meloidogyne* and *Pratylenchus* species. Among the important nematode species, that attack rice are Ufra and white-tip nematodes which finds a place as major pests of deep water rice in several countries (Varaprasad *et al.,* 2006).

The entire state of Goa falls under 12$^{th}$ agro ecological zone of India viz., West Coast Plains and Ghats region. Rice is the predominant staple food crop of the region as rice-fish curry being the main diet of the bulk of the population. Total area under rice cultivation in the year 2008-09 was around 49,966 ha (Figure 8.1) in the two districts of Goa comprising of 12 talukas (Korikanthmath *et al.*, 2011).

## METHODOLOGY

**Kharif** crops or **Sorod** crops (monsoon crops) are sown during the period from the first week of June to early July and harvesting is done in September-October. So, the study was carried out in July, September and November 2013. In July, the samples were collected before transplanting, in September, during the pre harvest period and in November; the samples were collected, during the post harvest period. Soil samples were collected from five different paddy fields, of each land type, from both the districts of the state of Goa viz., North Goa and South Goa. The fields were chosen opportunistically, and the samples were taken from three different land types, namely **khazan** (coastal saline soils), **kher** (arable, sandy to sandy loams soils, rain fed low lands) and **morod** (lateritic rain fed uplands), where paddy is grown.

Altogether, 30 soil samples were collected, when the seedlings were about 25cms, in length i.e. before transplanting (10 samples), then at pre-paddy harvest period when the plants were about 60-65cms tall (10 samples) and after the post-harvest period (10 samples), from near the vicinity of the roots of the plants, from about 10–15 cm depth. 100 permanent slides were prepared, following the standard procedure (as mentioned earlier) and nematode species were identified.

## RESULTS

### 1) Diversity, abundance and distribution of nemafauna of paddy fields of Goa.

In the present investigation, a total of 25 nematode species were identified, including five orders, 15 families and 19 genera (Table 8-1). The order Tylenchida had the highest number of families (5), genera (8) and species (11) followed by the order Dorylaimida with four families, six genera and 8 species. Mononchida was represented by three families, three genera and three species; while Araeolaimida had just one family, one genus and one species (Figure 8- 2). Among the trophic groups, the herbivores dominated with 47.36% genera diversity and 60% abundance diversity, followed by the other three groups, omnivores, predators and fungivores and the least was observed in bactivores. In the Ordinal diversity of genera as well as abundance, Tylenchids dominated, (36.84% and 44 %), followed by Dorylaims (31.40% and 32%), Mononchids (15.78% and 12%), Aphelenchids (10.52% and 8%) and Araeolaimids (5.26% and 4%) respectively (Figure 8-3). Species abundance per 100 gm of dry soil ranged from 96 individuals to 116 individuals (Table 8-2). *Oionchus obtuses* and *Aphelenchoides besseyi* had the maximum species abundance while *Laimydorus uterinus* and *Lenonchium oryzae* the minimum (Table 8-2).

### 2) Nematofauna diversity of Khazan, Kher and Morod land types.

**Morod** land type represented the maximum diversity of species (22) whereas **khazan** land type minimum with 13 species and 20 species were observed in **kher** land type (Table 8-3). In the families, as well as in genera, similar results were obtained, maximum in **kher** and **morod** land type and minimum in **khazan** land type (Figure 8-4). Five species namely *Lenonchium oryzae, Lenonchium macrodoum, Meloidogyne oryzae, Criconemella (Criconemoides) onoesis* and *Plectus cirratus* were present, in all the three land types, **khazan / kher / morod** (Table 8-3) i.e. 20% of the observed species were common to all the three land types, 32% were common to **khazan** and **kher** land types, 68% were common to **kher** and **morod** land type and 40 % were common to **khazan** and **morod** land types (Figure 8-5). Four of the five common species, belonged to the trophic group herbivores, while *Plectus cirratus*, belonged to trophic group bactivores. Among the trophic groups, herbivores were more in genera, as well as in abundance, in all the three land types, above 50% (Figure 8-6 A, B & C). Fungivores were absent in **khazan** land type, whereas they were quite predominant, in the other two land types recording above 10% abundance. Predators were more in the number of genera and in abundance in **kher** land type compared to **khazan** and **morod** land type (Fig. 8-6 A, B & C). From Table 8-4, it can be deduced that, maximum number of species was found in **morod** land (22) and minimum in **khazan** land (13), while **kher** land recorded for 20 species. It also shows that, the species abundance was highest in **morod** land (299) and lowest in **khazan** land (163). Simpson's Dominance showed, highest results in **khazan** land and lowest in **morod** land; whereas Shannon's Diversity values were more in **morod** land and less in **khazan** land. The species were more or less evenly distributed, in all the three lands with a very minute difference (0.984). The values of Fisher's Alpha diversity index are more for **morod** land when compard with **khazan** land (Table 8-4).

**3) Soil nematofauna diversity at different stages of paddy cultivation.**

In all the three land types, nematode species were found to be abundant prior to harvesting and was lowest before transplanting and post harvesting season (Figure 8.7). *Hirschmanniella oryzae* was not observed in **khazan** land type, while *Hirschmanniella* *mucronata* was not found in **kher** land type (Table 8-3) but, both the Species of *Hirschmanniella* showed maximum species abundance in the **morod** land type, when the samples were collected prior to harvesting (Figure 8-7). *Dorylaimus stagnalis* and *Lenonchium oryzae* had maximum species abundance, while *Laimydorus uterinus*, *Helicotylenchus abunaamai* and *Criconemella onoesis* (aka *Mesocriconema)* had the minimum species abundance in **khazan** land type. *Laimydorus uterinus and Dorylaimoides constrictus* had minimum species abundance in the **kher** land type in the soil samples that were collected, prior to harvesting. *Aphelenchoides besseyi* was the only species, that reported maximum species abundance in the samples collected, before transplanting in both the land types, **kher** and **morod** whereas it was absent in the **khazan** land type (Figure 8-7). *Mylonchulus minor* (8 ind. / 100gm of dry soil) reported minimum species abundance in the samples collected after harvesting while *Laimydorus uterinus* showed minimum species abundance before transplanting in the **kher** land type


Figure 8.1: Agricultural map of Goa

Paddy fields of Goa

| Sr. No. | ORDERS | FAMILIES | GENUS SPECIES |
|---|---|---|---|
| 1 | Dorylaimida | Xiphinematidae | *Xiphinema insigne* Loos, 1949 |
| 2 | | | *Xiphinema brevicolle* Lordello & da Costa, 1961 |
| 3 | | Dorylaimidae | *Dorylaimus stagnalis* Dujardin, 1845 |
| 4 | | | *Laimydorus uterinus* Loof, 1995 |
| 5 | | | *Thornenema mauritianum* (Williams, 1959)Baqri & Jairajpuri, 1969 |
| 6 | | Nordiidae | *Lenonchium oryzae* Siddiqi, 1965 |
| 7 | | | *Lenonchium macrodorus* Ahmad & Jairajpuri, 1988 |
| 8 | | Qudsianematidae | *Ecumenicus monohystera* (De Man, 1880) Thorne, 1974 |
| 9 | Tylenchida | Hoplolaimidae | *Hoplolaimus indicus* Sher, 1963 |
| 10 | | | *Helicotylenchus dihystera* (Cobb, 1893) Sher, 1961 |
| 11 | | | *Helicotylenchus abunaamai* Siddiqi, 1972 |
| 12 | | | *Helicotylenchus indicus* Siddiqi, 1963 |
| 13 | | Meloidogynidae | *Meloidogyne graminicola* Golden & Birchfield, 1965 |
| 14 | | Criconematidae | *Criconemoides onoesis* ( Luc, 1959) Luc & Raski, 1981 |
| 15 | | | *Criconemoides xenoplax* (Raski, 1952) Luc & Raski, 1981 |
| 16 | | | *Ditylenchus angustus* (Butler, 1913) Filipjev, 1934 |
| 17 | | Belonolaimidae | *Tylenchorhynchus annulatus* (Cassidy, 1930) Golden, 1971 |
| 18 | | Pratylenchidae | *Hirschmanniella oryzae* (Van Breda de Haan,1902) Luc & Goodey, 1963 |
| 19 | | | *Hirschmanniella mucronata* (Das 1889,1960) Luc & Goodey, 1963 |
| 20 | Araeolaimida | Plectidae | *Plectus cirratus* Bastian, 1865 |
| 21 | Aphelenchida | Aphelenchoididae | *Aphelenchoides besseyi* (Christie, 1942) Allen, 1952 |
| 22 | | Aphelenchidae | *Aphelenchus avenae* Bastian, 1865 |
| 23 | Mononchida | Mylonchulidae | *Mylonchulus minor* (Cobb, 1893),Andrássy, 1958 |
| 24 | | Iotonchidae | *Iotonchus trichurus* (Cobb, 1916),Andrássy, 1958 |
| 25 | | Mononchulidae | *Oionchus obtuses* Cobb, 1913 |

**Table 8.1: Taxonomic status of soil nematodes of paddy fields of Goa**

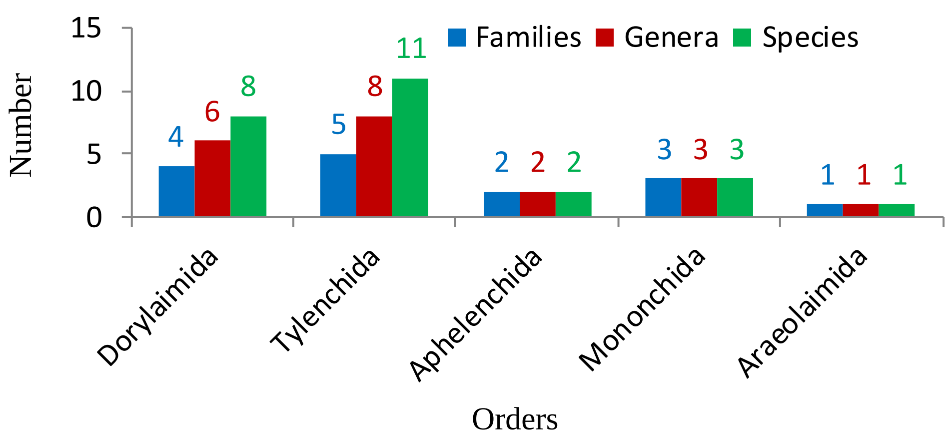



**Figure 8.2: Order-wise soil nematode diversity of paddy fields of Goa**

| Sr. No | Trophic Group | Order | Genera | Species | Species Abundance/ 100gm of dry soil (m) |
|---|---|---|---|---|---|
| I | Omnivores | Dorylaimida | *Dorylaimus* | *stagnalis* | 103 |
| | | | *Ecumenicus* | *monohystera* | 108 |
| II | | | *Laimydorus* | *uterinus* | 96 |
| | Predators | Mononchida | *Mylonchulus* | *minor* | 112 |
| | | | *Iotonchus* | *trichurus* | 105 |
| | | | *Oionchus* | *obtuses* | 116 |
| III | Fungivores | Dorylaimida | *Thornenema* | *mauritianum* | 102 |
| | | Aphelenchida | *Aphelenchus* | *avenae* | 97 |
| | | | *Aphelenchoides* | *besseyi* | 116 |
| IV | Herbivores | Dorylaimida | *Xiphinema* | *brevicolle* | 109 |
| | | | *Xiphinema* | *insigne* | 115 |
| | | | *Lenonchium* | *oryzae* | 96 |
| | | | *Lenonchium* | *macrodorum* | 101 |
| | | Tylenchida | *Hoplolaimu*s | *indicus* | 98 |
| | | | *Helicotylenchus* | *dihystera* | 114 |
| | | | *Helicotylenchus* | *abunaamai* | 106 |
| | | | *Helicotylenchus* | *indicus* | 97 |
| | | | *Meloidogyne* | *graminicola* | 108 |
| | | | *Criconemella* | *onoesis* | 98 |
| | | | *Criconemella* | *xenoplax* | 111 |
| | | | *Ditylenchus* | *angustus* | 107 |
| | | | *Tylenchorhynchus* | *annulatus* | 99 |
| | | | *Hirschmanniella* | *oryzae* | 104 |
| | | | *Hirschmanniella* | *mucronata* | 112 |
| V | Bactivores | Araeolaimida | *Plectus* | *cirratus* | 100 |

m=mean values, n=30, range= 90-120

**Table 8.2: Species diversity and abundance (no. of individuals / 100gm of dry soil) of different trophic groups of soil nematodes of paddy fields of Goa**

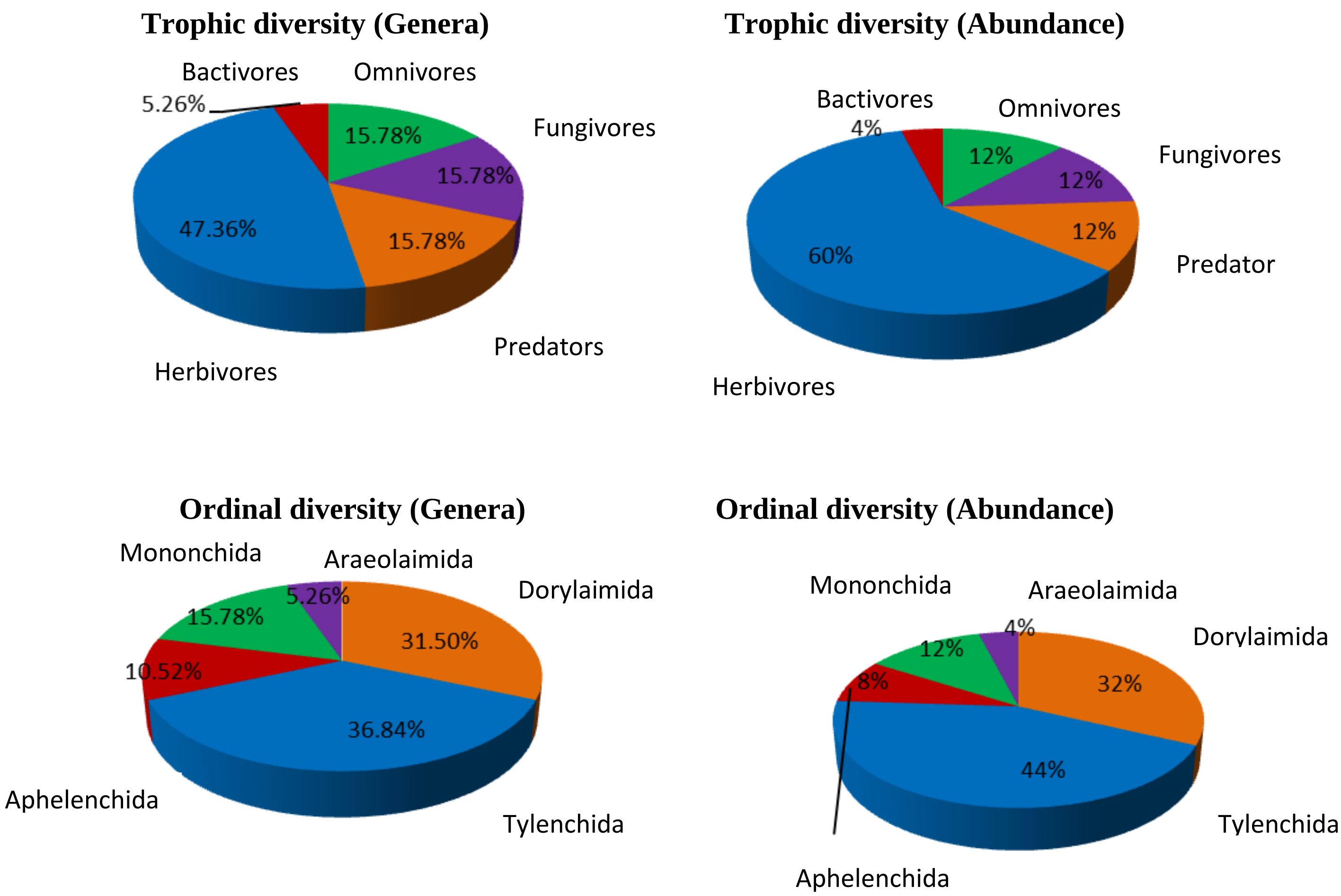



**Figure 8.3: Community Structure of soil nematodes of paddy fields**

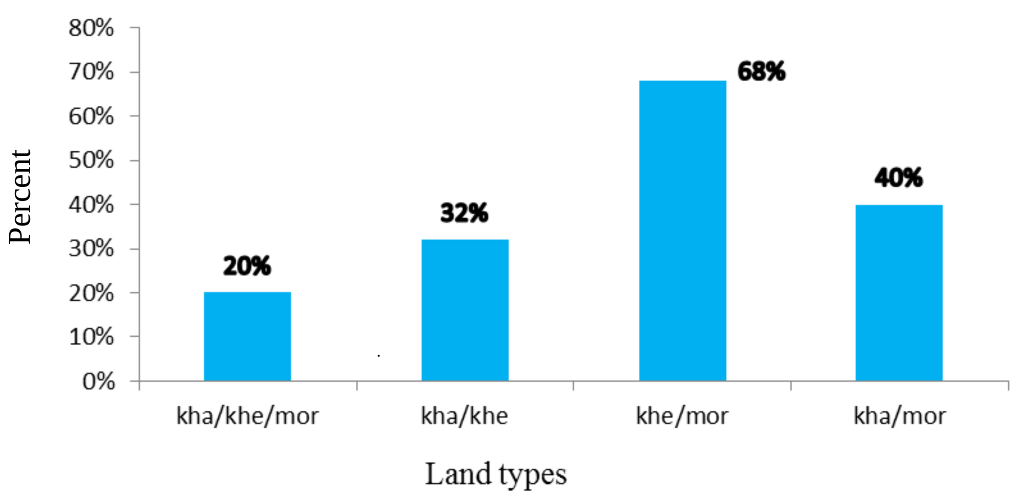



**Figure 8.4: Percent occurrence of common species in different land type**

| | | Presence or absence of species in the different land types | | | | |
|---|---|---|---|---|---|---|
| **ORDERS** | **FAMILIES** | **GENERA** | **SPECIES** | **KHAZAN** Saline land | **KHER** Lowland | **MOROD** Upland |
| Dorylaimida | Dorylaimidae | *Dorylaimus* | *stagnalis* | + | + | - |
| | Qudsianematidae | *Ecumenicus* | *monohystera* | - | + | + |
| | Dorylaimidae | *Laimydorus* | *uterinus* | + | - | + |
| | Dorylaimidae | *Thornenema* | *mauritianum* | - | + | + |
| | Xiphinematidae | *Xiphinema* | *brevicolle* | + | - | + |
| | Xiphinematidae | *Xiphinema* | *insigne* | - | + | + |
| | Nordiidae | *Lenonchium* | *oryzae* | + | + | + |
| | Nordiidae | *Lenonchium* | *macrodorum* | + | + | + |
| Mononchida | Iotonchidae | *Iotonchus* | *trichurus* | - | + | + |
| | Mononchulidae | *Oionchus* | *obtuses* | + | + | - |
| | Mylonchulidae | *Mylonchulus* | *minor* | - | + | + |
| Aphelenchida | Aphelenchidae | *Aphelenchus* | *avenae* | - | + | + |
| | Aphelenchoididae | *Aphelenchoides* | *besseyi* | - | + | + |
| Tylenchida | Hoplolaimidae | *Hoplolaimus* | *indicus* | + | - | + |
| | Hoplolaimidae | *Helicotylenchus* | *dihystera* | - | + | + |
| | Hoplolaimidae | *Helicotylenchus* | *abunaamai* | + | + | - |
| | Hoplolaimidae | *Helicotylenchus* | *indicus* | - | + | + |
| | Meloidogynidae | *Meloidogyne* | *graminicola* | + | + | + |
| | Criconematidae | *Criconemella* | *onoesis* | + | + | + |
| | Criconematidae | *Criconemella* | *xenoplax* | - | + | + |
| | Criconematidae | *Ditylenchus* | *angustus* | - | + | + |
| | Belonolaimidae | *Tylenchorhynchus* | *annulatus* | + | - | + |
| | Pratylenchidae | *Hirschmanniella* | *oryzae* | - | + | + |
| | Pratylenchidae | *Hirschmanniella* | *mucronata* | + | - | + |
| Araeolaimida | Plectidae | *Plectus* | *cirratus* | + | + | + |
| | | | Total | 13 | 20 | 22 |

**Table 8.3: Nematode diversity in different land types: + =present, - =absent**

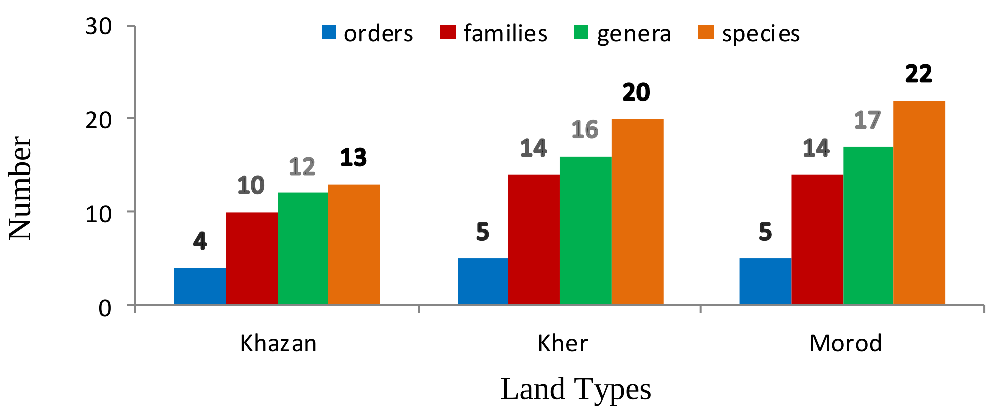
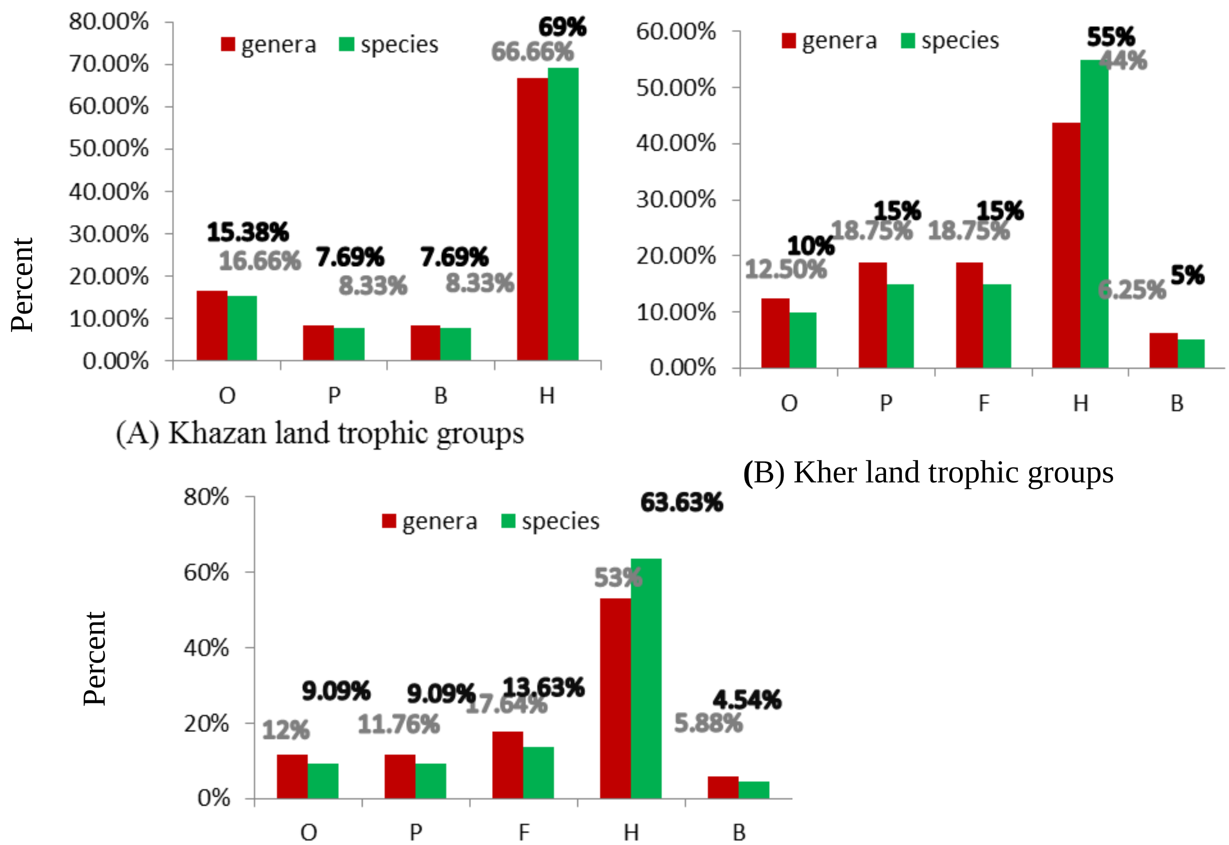



**Figure 8.5: Taxonomic status of the nematodes present in different land types**




(A) Khazan land trophic groups

(B) Kher land trophic groups

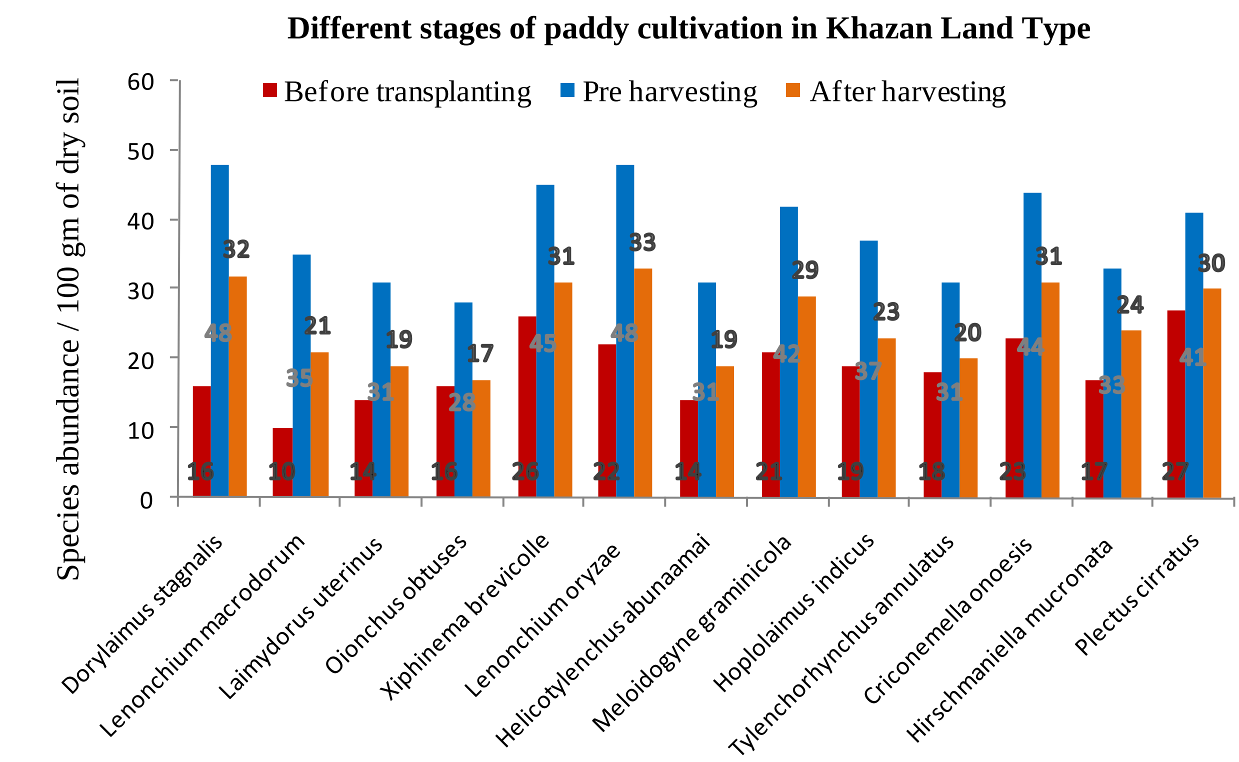
(C) Morod land trophic groups

**Figure 8.6 (A, B, & C): Percent occurrence of trophic groups (genera and species) in different land types**

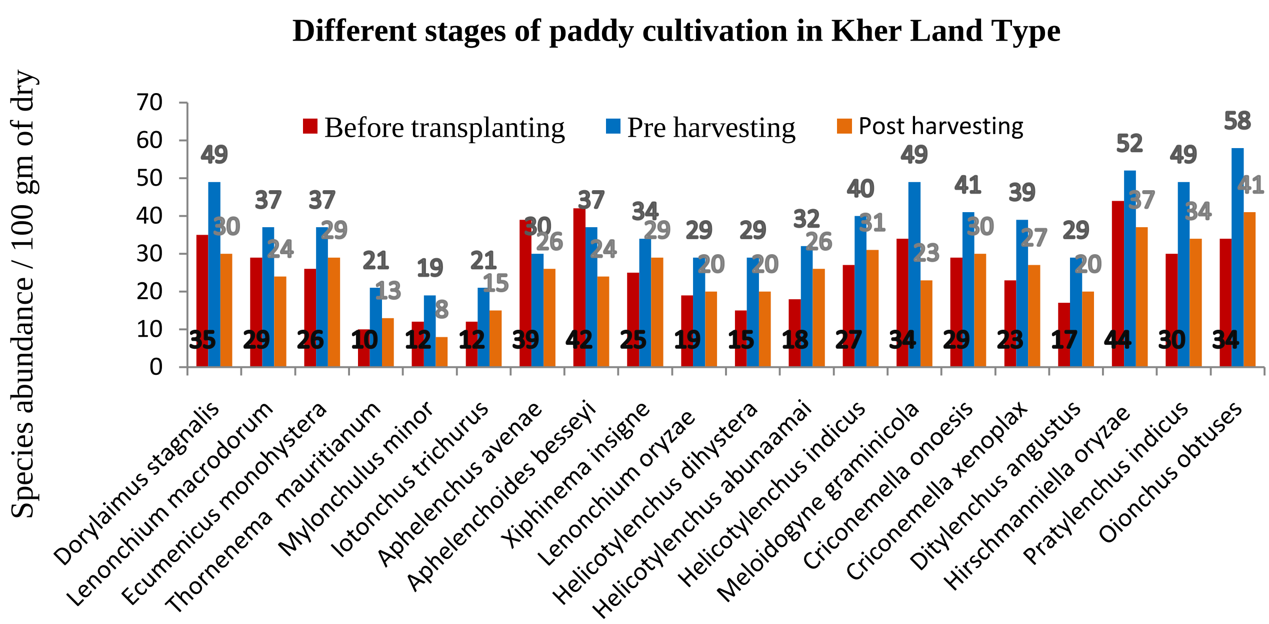
**O=Omnivores, P=Predators, F=Fungivores, H=herbivores, B=Bactivores**

| Diversity indices | Khazan | Kher | Morod |
|---|---|---|---|
| Species Richness | 13 | 20 | 22 |
| Abundance | 163 | 265 | 299 |
| Simpson's Dominance_D | 0.07915 | 0.05148 | 0.04683 |
| Shannon_H | 2.55 | 2.981 | 3.076 |
| Evenness_e^H/S | 0.9854 | 0.9853 | 0.9847 |
| Equitability_J | 0.9943 | 0.9951 | 0.995 |
| Fisher_alpha | 3.322 | 5.018 | 5.475 |

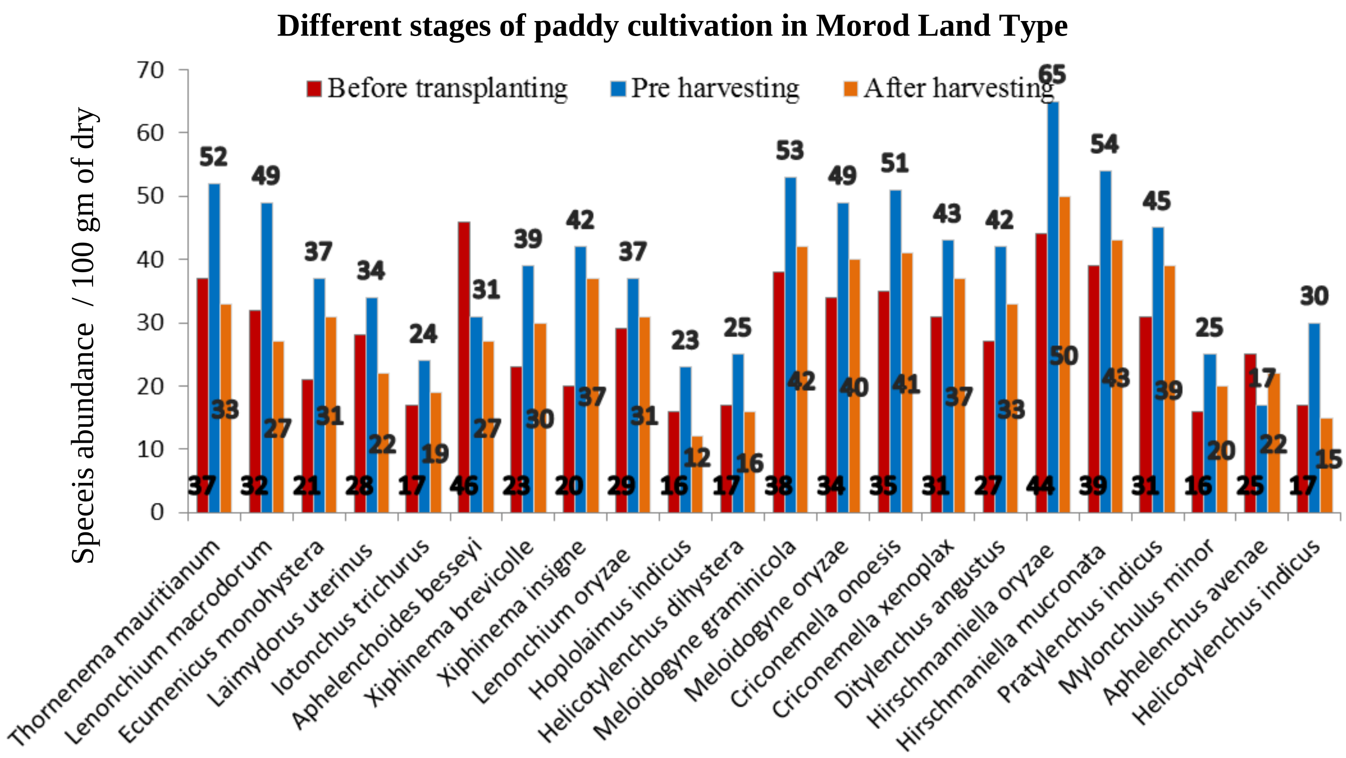
**Table 8.4: Diversity indices of nematofauna for different land type**




**(A) Nematode Species of Khazan Land Type**




**(B) Nematode Species of Kher Land Type**




**(C) Nematode Species of Morod Land Type**

**Figure 8.7 (A, B & C): Species abundance of in all the three land types at three Different points of paddy cultivation**

## DISCUSSION

Frechman and Ettema (1993) observed that, species richness of the nematode fauna of agricultural soils may be high due to dominance of only a few species. Species belonging to the order Tylenchida which mostly represents plant feeders were more. The present investigation also has similar results. This is confirmed by the reports of McNeely *et al.*, 1995, that agriculture produces a dynamic habitat in which a wide range of soil nematode species can survive and multiply. Also plant feeders depend on plant roots for their nutrition rather than soil microorganisms. Háněl (2003) reported that, omnivore nematodes with their versatile feeding habits would intervene in the soil food web, resulting in the absence of the species that are dependent on undisturbed habitats. The free space, that is created, might be utilized by the herbivores and their population increases. So the species abundance, among the herbivores was more. Species belonging to omnivores had maximum abundance; as these are omnivores, increase in the population of hyphae, bacteria, microfaunal prey might result in the increase in the growth of their population. The genera and the abundance in the ordinal diversity were dominated by the order Tylenchida (McNeely *et al*., 1995). In the present study, a total of 25 species is reported. Herbivores showed high value of H' (2.74), which almost agrees with the values recorded by Háněl (1995), with the following successional variation of H': in the agricultural fields 2.66 (1986), 2.83 (1987). This might be due to the presence of plants belonging to other Graminae family besides paddy plants.

In the present study, **khazan** lands reported less number of species. The reason may be, as the conditions in the **khazans** pose special problems for agriculture, since **khazan** soils are poorly drained, have an acidic pH, relatively high organic carbon, salinity and iron and low calcium. Salinity does not favour nematofauna growth and population (Malhotra and Chaubey, 1993; Jairajpuri *et al.,* 1974). Also these are alluvial soils with high water tables and are subject to inundation by saline water. The salinity varies during monsoon (2–3ºBé) and non-monsoon (4–5ºBé) times (Mani *et al*., 2012). Also Burns (1971) reported that, pH 6 was the best for maintenance of several species of nematodes. **Khazan** lands have pH from 4.8-5.3 and so this could be another reason why in the present study the nematodes diversity was found to be less in **khazan** lands. **Morod** and **kher** ecologies showed maximum abundance of nematodes than **khazan**. **Kher** lands possess arable sandy loam soil and **morod** lands are upland or terraced fields suitable for horticulture crops as well as agricultural crops. Of the 5 species, that were common in all the three land types, 4 belonged to trophic group herbivores. The results are in agreement with the reporting of Jairajpuri and Baqri, (1991) as nematodes are the most numerous components of the mesofauna in agricultural soils. In genera and in abundance, in all the three land types, herbivores dominated and were above 50%. These mostly depend on plant roots for their food and not on soil microfauna. Predators were characteristics of **morod** land type. Though this is uncommon in most ecosystems but may be related to rich food web of the site (Baniyamuddin *et al*., 2007), which is the characteristics also of the **morod** land. **Kher** and **Morod** land type showing highest number in genera and abundance of fungivores represents that since these lands are used for multiple cropping through irrigation fungal diversity could be more and so fungivores. Shannon's and Fisher's Diversity indices confirm the presence of more dominant species and high abundance in the **morod** land. It can be also inferred, based on the same indices that, **khazan** land has less abundance and less dominant species in the **khazan** land. **Morod** land has more number of Species whilst **khazan** land has less number of species. The minute difference observed in the distribution of species in **morod** land compared to the other two land types supports the high number of dominant species.

Maximum species abundance, prior to harvesting, was reported in all the three land types. This is in agreement with Tikhinova (1966), who suggests that, at late tilling stage, nematode numbers may increase rapidly, and may reach a peak during the reproductive stage of the plant. Nematodes tend to remain active at a temperature range of 13-42°C with ideal relative humidity above 70%. Also most nematodes do best at temperatures between 25 and 30$^{o}$C. This could be the reason, why maximum species abundance was recorded during pre-harvesting period, as the soil temperature of paddy fields, during this period ranges from 25 to 30$^{o}$C (months of September / October). It has been reported that, low recovery of nematodes species occur, when the crop is not in lush green condition (Norton, 1978). Similar was the observation in the present study too. Minimum species abundance was recorded, in all the three land types prior to transplantation. *Hirschmanniella* have been reported to be present, in all the irrigated rice fields all over the world. *H. oryzae* and *H. mucronata* are the dominant species, infecting rice crop in all the parts of India: irrigated, semi-deepwater and deepwater rice environments (Mathur and Prasad, 1971; Sivakumar and Khan, 1982; Prasad *et al*., 1987; Varaprasad *et al*., 1992). Varieties of weed species that grow, in and around paddy fields have also been reported to host *Hirshmanniella* spp. (Mohandas *et al*., 1979). Both these species were abundant in the morod land type in the present study. Maximum species abundance of *A. besseyi* was foundbefore transplanting. Qiu *et al*., (1991) suggested that, *A. besseyi* invades rice, mainly during sowing to the 3-leaf stage. Besides low temperature and more precipitation favours the growth of this species which is seen to be prevalent during transplanting season in Goa.

**SUMMARY**

From this study it is conlcuded that, 25 species were found to be present in the paddy fields of Goa. Of these 25 species, maximum species belonged to order Tylenchida, followed by Dorylaimida and minimum to Aphelenchida and Araeolaimida. Paddy fields ecosystem favour Tylenchids as these are mostly plant feeders.

Of the three land types, species abundance was maximum (22 Species) in the soil samples collected from **morod** land type and minimum (13 Species) in **khazan** land type. **Khazan** lands being saline, do not favour nematode growth and population. **Morod** land also has high abundance (299) of individual Species. Mostly the species were evenly distributed.

20% of the species were found to be common to all the three land types. In the soil samples collected during various stages of paddy cultivation, those collected prior to harvesting had maximum species abundance. Root growth is more during this stage of paddy cultivation, and since herbivores mostly depend on plant roots for their food, and not on soil microfauna, their number increases. The soil ecosystem of paddy fields provides favourable environment for the growth of herbivores.

# CONCLUSION

*Nematodes do not furnish hides, horns, tallow, or wool.*
*They are not fit for food, nor do they produce anything fit to eat;*
*neither do they sing or amuse us in any way; nor are they ornamental (...).*
*Lacking in all these respects, they fail even in furnishing*
*any moral or praiseworthy example;*
*they are not known to be industrious like the ant,*
*or provident like the bee (...), or anything else that is admirable.*
*What claim, then, one may ask,*
*can such beings lay to our attention?*

(Cobb, 1915)

# CONCLUSION

Nematodes aren't exactly on the radar of most people, but they play an important role in the environment. From the present studies it can be concluded that, the soils of Goa harbour a considerable diversity of nematode species and these play a vital role in the fertilization of the soil. This study also reports that, among the soil inhabiting, free living nematofauna, maximum species belonged to order Dorylaimida and minimum to Monhysterida. It is well known that, soil ecosystem of the tropical region favours Dorylaims. Of all the 12 talukas, species diversity was more in the soil samples collected in Bicholim taluka and minimum in Ponda taluka. Vegetable plots and roadside weeds / bushes had maximum species diversity. In the soil samples of the talukas as well as of the landscapes elements, species were evenly distributed as 73.4 % of the soil in Goa is lateritic, rich in organic matter and nitrogen. Of the three paddy land types, viz., **Khazan, Kher** and **Morod**, species diversity was more in the soil samples collected from morod land type and less in **khazan** land type. **Khazan** lands being saline do not favour nematode growth and population. **Morod** land also has high abundance of individual species. Plant feeders were found to be more abundant in paddy fields. Species abundance was more at pre harvest period than during the transplantation and post harvest period.

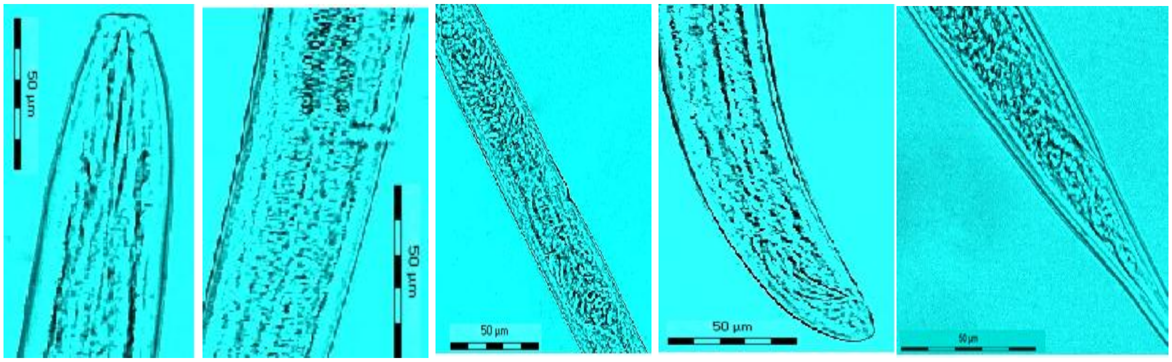
This thesis provides basic information and data required on the diversity, abundance and distribution of soil nematodes of Goa, in different soil and vegetation types, including paddy fields. It could form a strong foundation for further studies and intense research, in this field on various aspects. It could also provide a strong basis for further exploration on the nematodes of various landscapes and vegetation types including paddy field. It could help to study nematode diversity of the different soil and vegetation types, based on the type and frequency of the fertilizers used, advantage of use of natural fertilizers over chemical fertilizers, use of pesticides, nematodes as bio indicators of the health of soil ecosystem and effective means of controlling the pest nematodes. By and large, saline soils do not favour nematode growth but as the salinity of Khazan lands decreases during rainy season, one can use these lands during the monsoon season for paddy cultivation, as planned by the Government of Goa (Anonymous, 2015).

## LIMITATIONS AND FUTURE DIRECTIONS

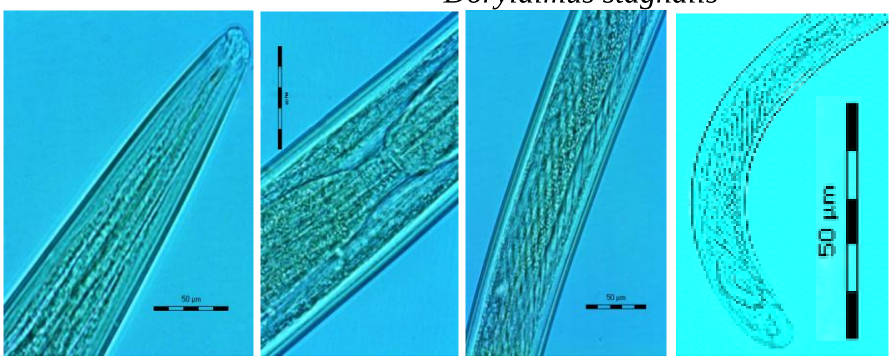
The results yielded important information on the diversity, distribution and abundance of soil inhabiting, free living nematodes of the state of Goa; but further studies, on the topic may wish to address some of the limitations faced in this research and interpretation. The initial limitation was that, this was a random survey and so every nook and corner of the state could not be surveyed. All the different soil types and different vegetation could not be assessed for lack of time and trained personnel in identification of nematodes. Identifcation was a major difficulty. The second limitation was lack of nematologists in the state of Goa, with the expertise and knowledge in the subject of nematology. The third limitation was a very minimal or hardly any literature available on nematode population of the state of Goa. The fourth limitation was, since this was a preliminary study, but first of its kind, with regard to the dimension and covering the entire state of Goa, much emphasis was not laid on detailed information.

Further research may include a systematic study on the diversity, distribution and density of the terrestrial types based specifically on different vegetation, soil types, terrains and topography. Apart from the above, as Goa happens to have proximity with Arabian Sea it would be more meaningful to study aquatic nematodes too, which has not been attampted so far. One can also extend his / her studies to nematodes from other freshwater bodies, mangroves, marshy areas, mudflats etc., The research can also be extended further, to understand community structure based on the feeding habits or different trophic groups. It can also add to the already known species and report some new species if any endemic to the state. Detailed study on specific orders, family, genera and species will be adding to the knowledge. Keeping pace with modern day biology, research at molecular and genetic level, laying emphasis on how nematodes could be beneficial to human beings, other than the already known beneficial aspects of nematodes, in the various developmental and biological processes of human beings, as well as to throw light on the diseases and physiological defects in human beings.

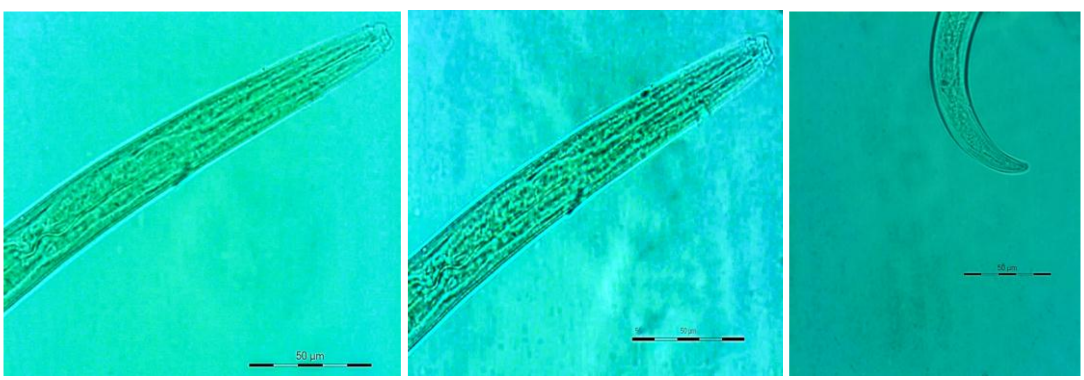
Some images of the species from the order **Dorylaimida**



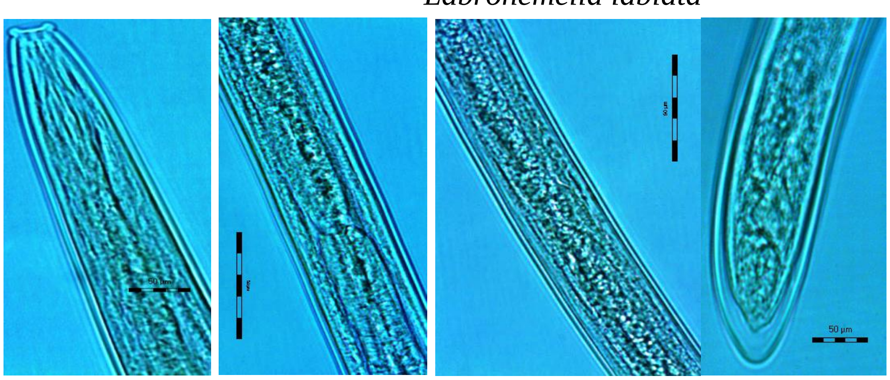

*Dorylaimus stagnalis*



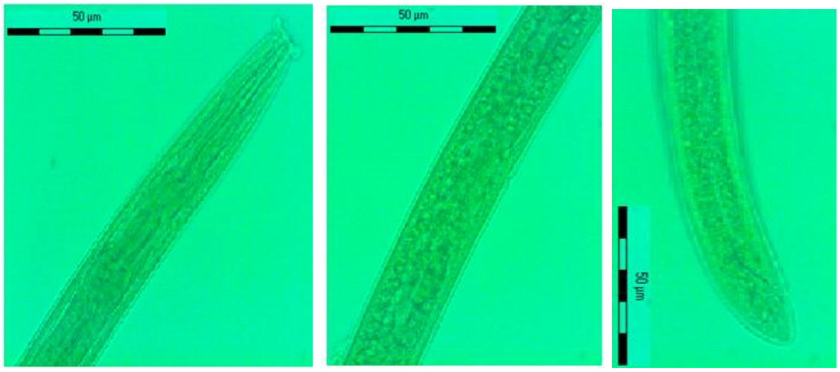

*Axonchium vulvulatum*



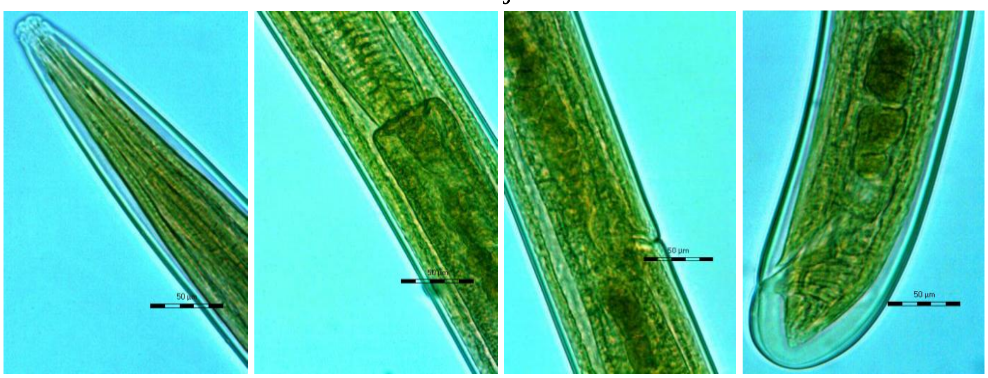

*Labronemella labiata*



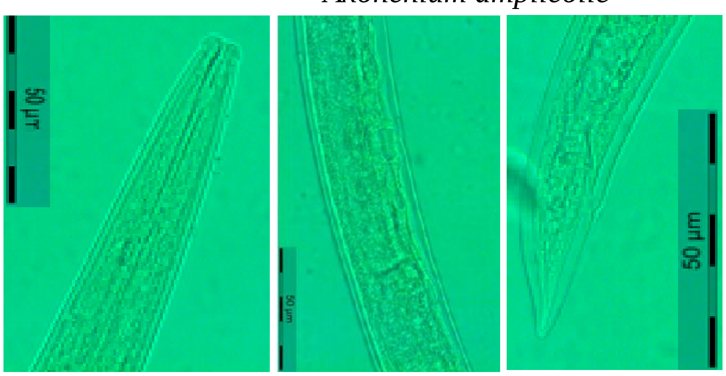

*Discolaimus texanus*



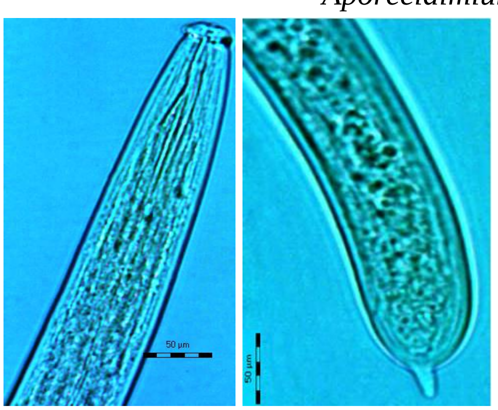
*Discolaimus major*



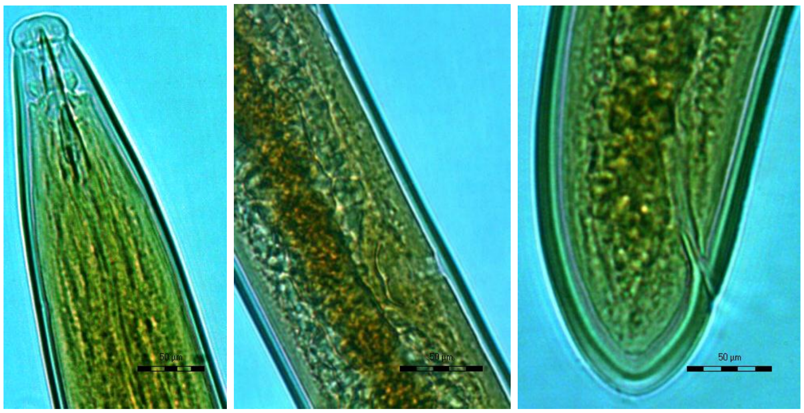
*Axonchium amplicolle*



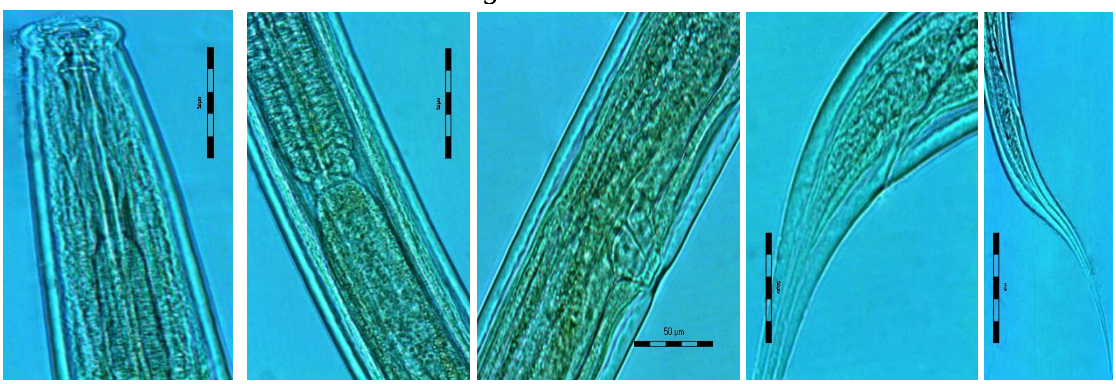
*Aporcelaimium labiatum*



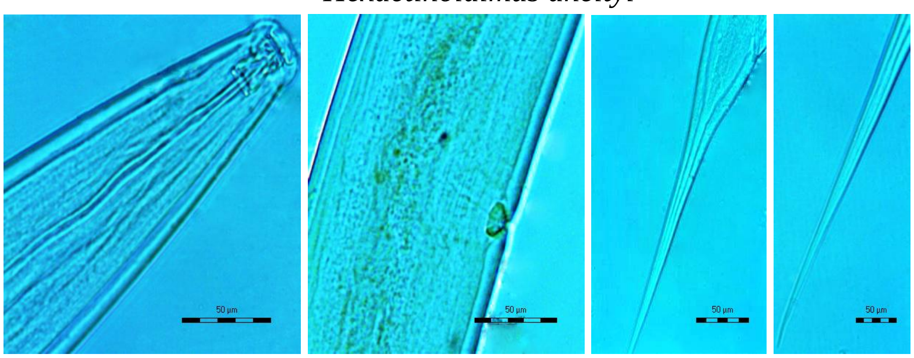
*Coomansinema dimodphicauda*



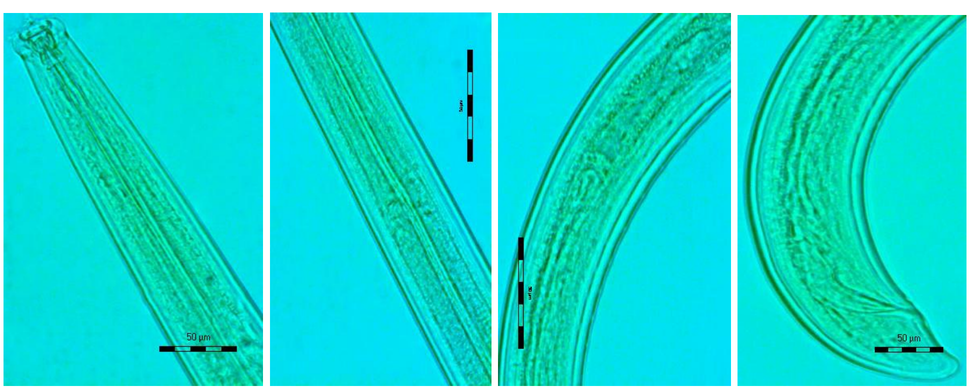
*Akrotonus vigor*



*Hexactinolaimus aneityi*

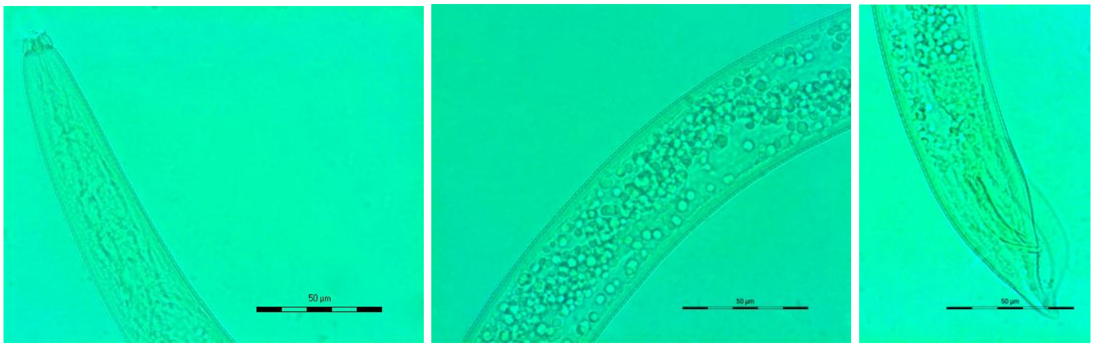


*Neoactinolaimus attenuates*

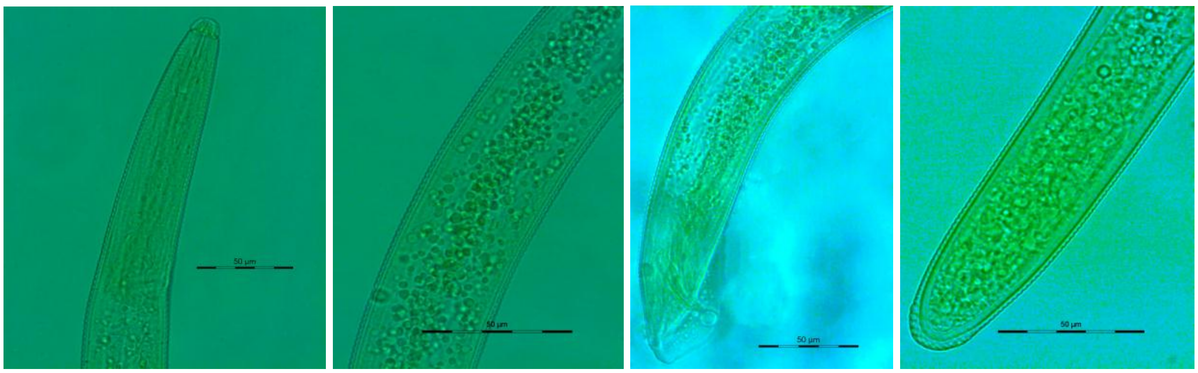


*Neoactinolaimus agilis*

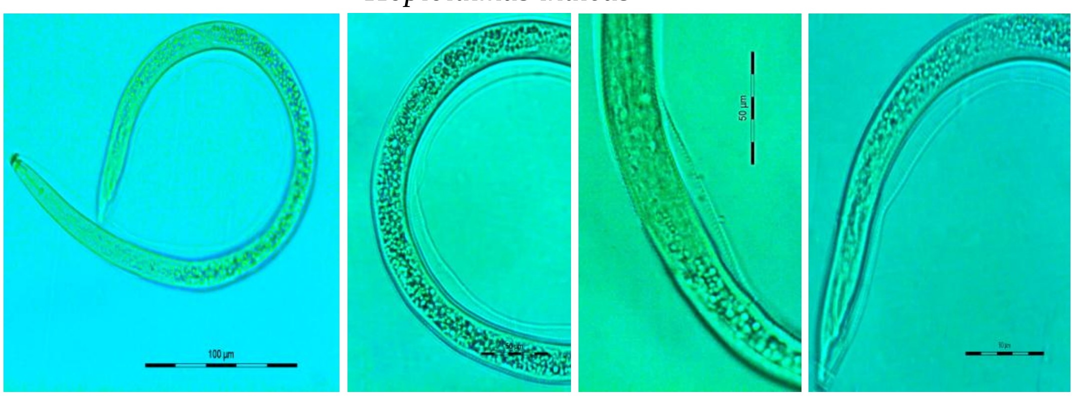
Some images of the species from the order **Tylenchida**



*Hoplolaimus galeatus*

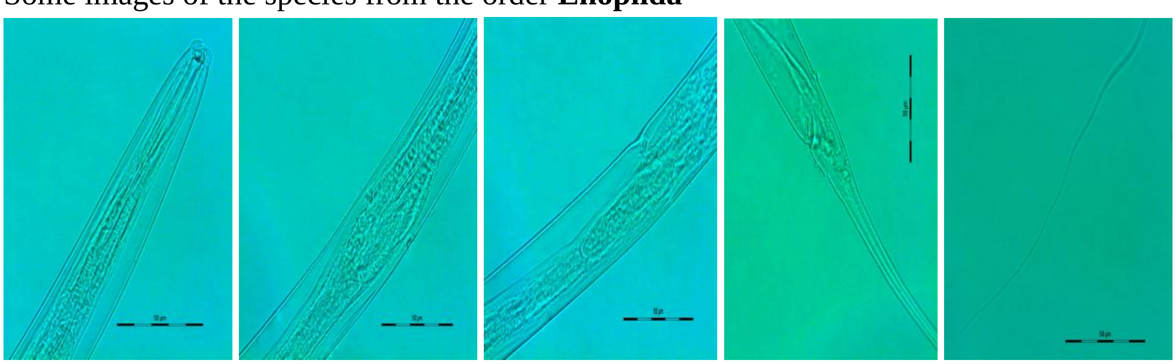


*Hoplolaimus indicus*

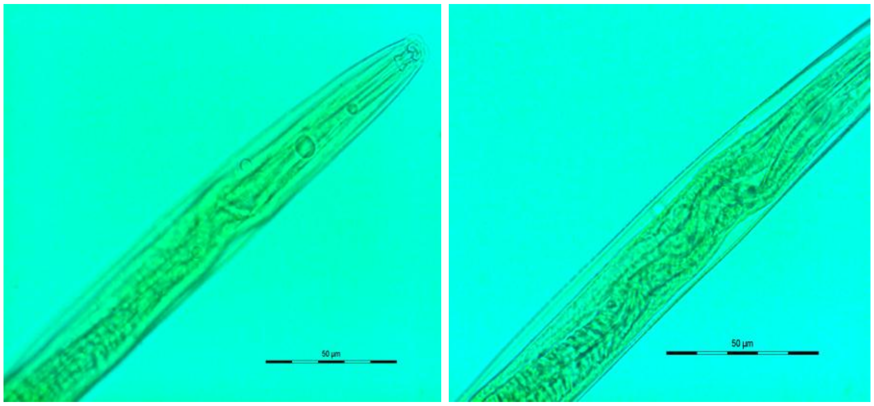


*Rotylenchoides brevis*

Some images of the species from the order **Enoplida**

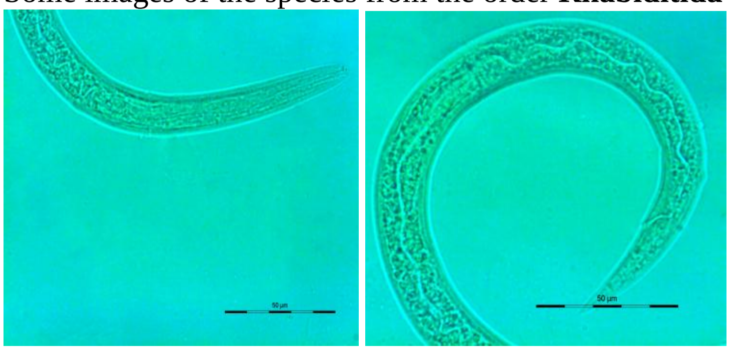


*Ironus longicaudatus*

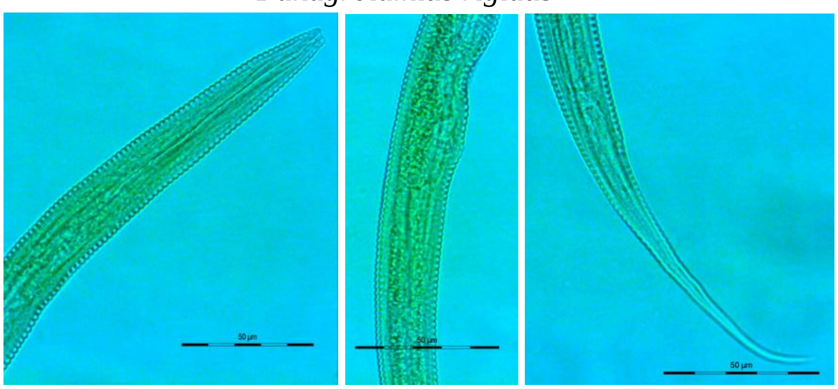


*Ironus ignavus*

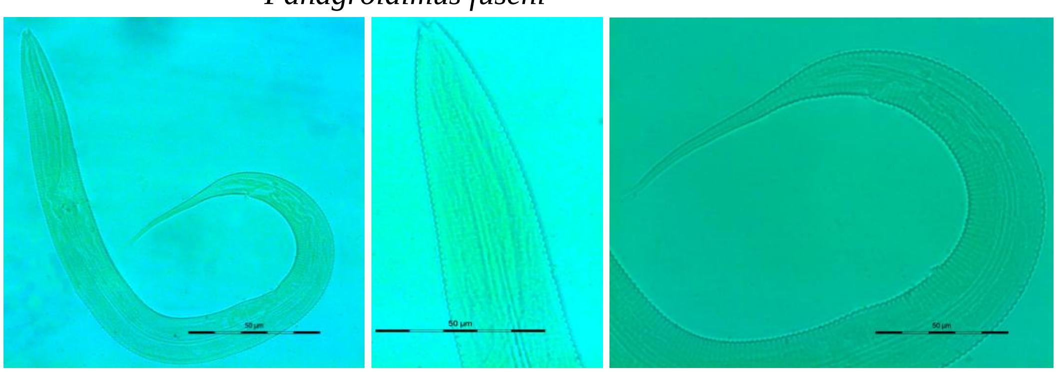
Some images of the species from the order **Rhabiditida**



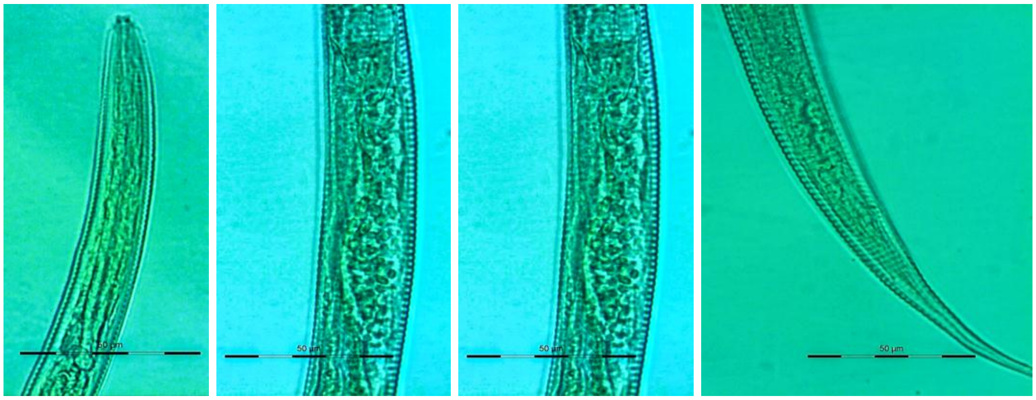
*Panagrolamius rigidus*



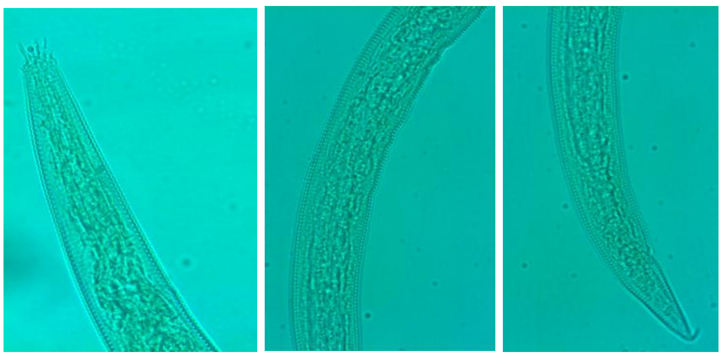
*Panagrolaimus fuschi*



*Panagrellus dorsobidentata*

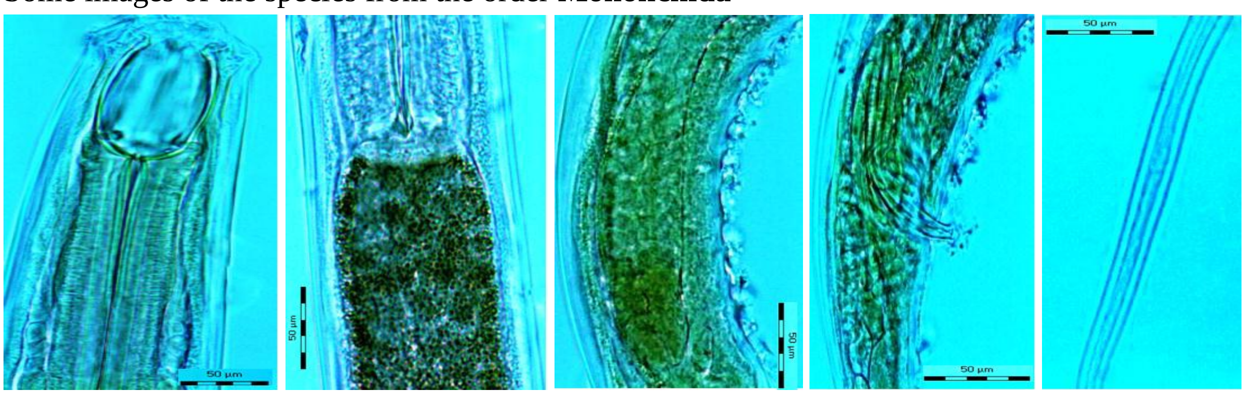


*Mesorhabiditis spiculigera*

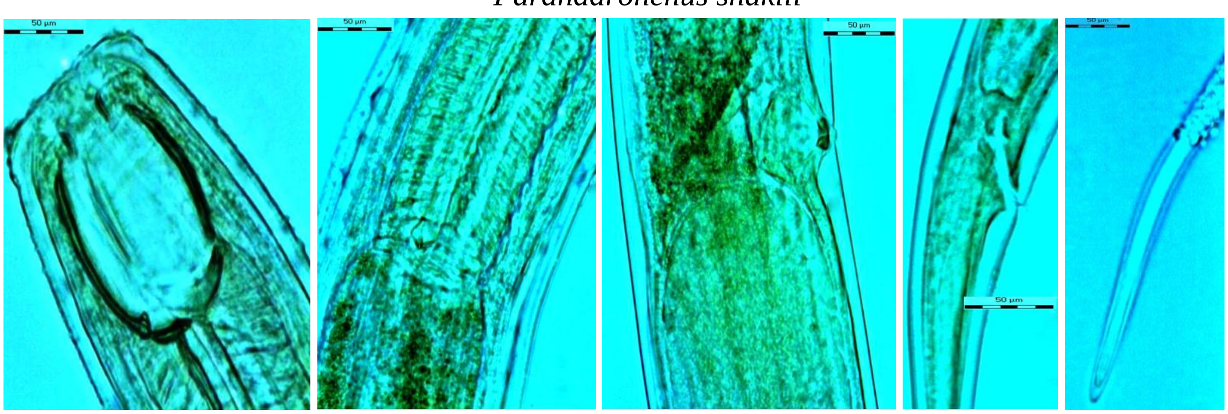


*Acrobeles ciliata*

Some images of the species from the order **Mononchida**




*Parahadronchus shakili*



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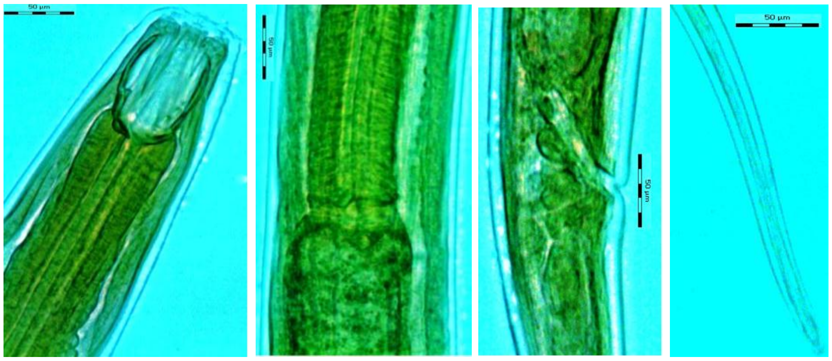

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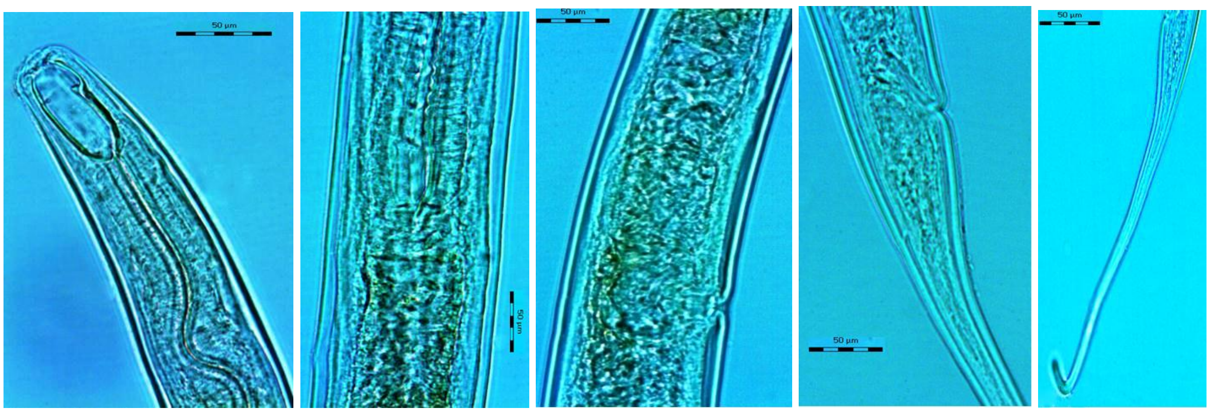

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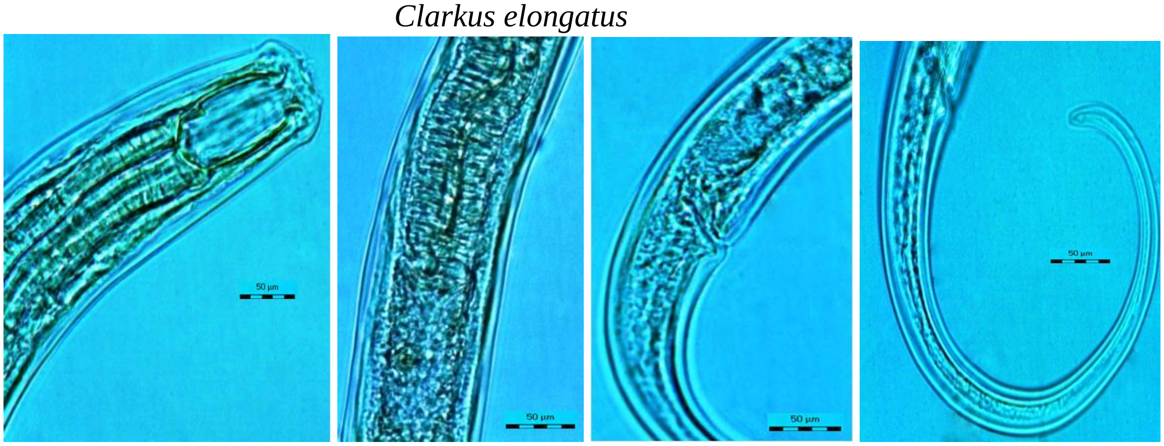

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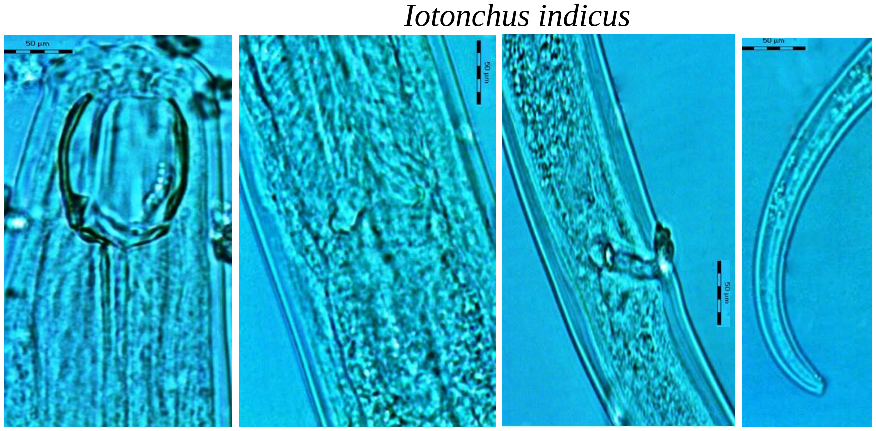
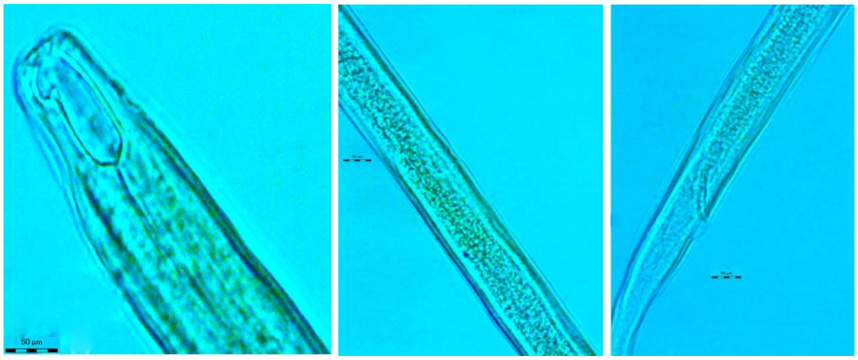
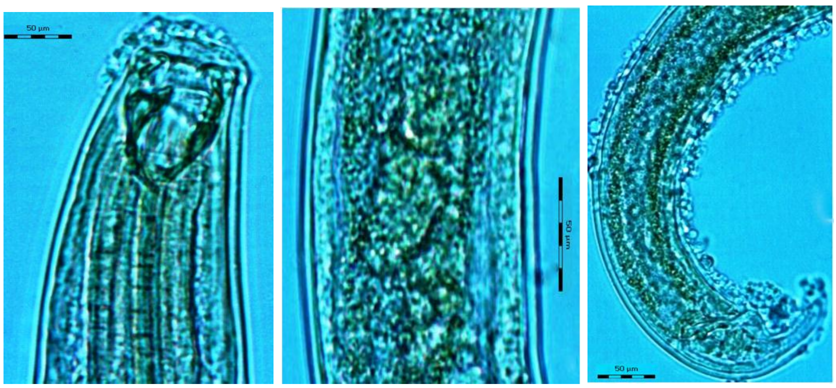


*Parahadronchus andamanicus*

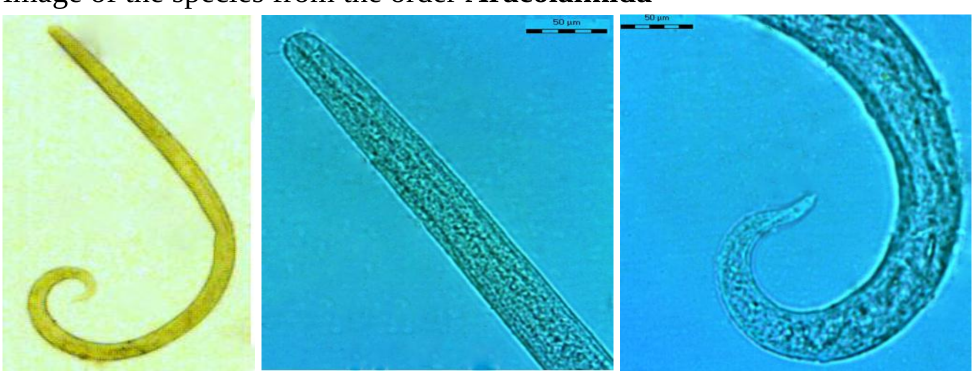



*Mononchus tunbridgensis*



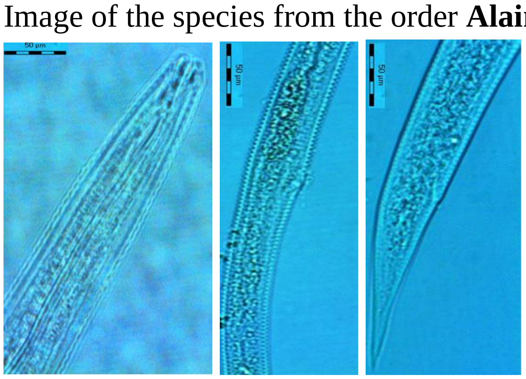

*Mylonchulus subsimilis*

Image of the species from the order **Araeolaimida**



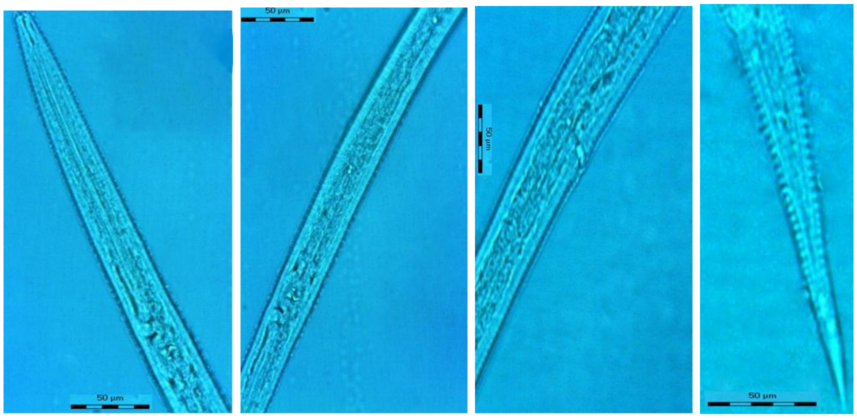

*Plectus cirratus*

Image of the species from the order **Alaimida**



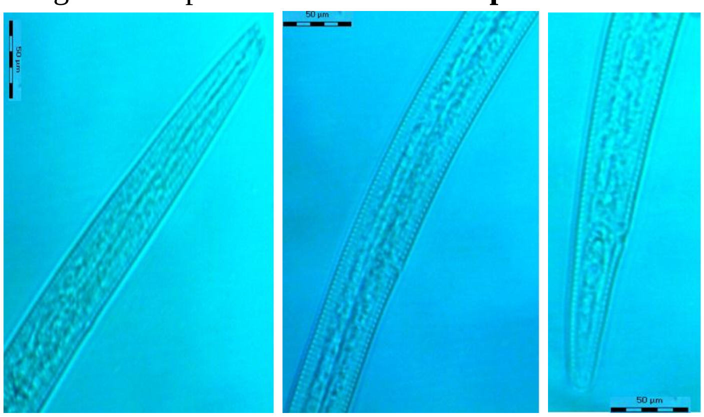

*Amphidelus novus*

Image of the species from the order **Monhysterida**



*Prismatolaimus andrassyi*

Image of the species from the order **Aphelenchida**



*Aphelenchus avenae*

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# PUBLICATIONS

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# PRESENTATIONS

## Publications:

**Maria Lizanne A.C. and I. K. Pai, (2013)** “Checklist of soil nematodes, based on vegetation, from the South Goa District, Goa”, *Biojournal*, Vol.8 No.: **2**, 23 -31.

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