Ministry of Environment, Forest and Climate Change

सत्यमेव जयते

ZOOLOGICAL SURVEY OF INDIA 1916

Current Status of FRESHWATER FAUNAL DIVERSITY IN INDIA

KAILASH CHANDRA | K. C. GOPI | D. V. RAO
K. VALARMATHI | J.R.B. ALFRED

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Current Status of
FRESHWATER FAUNAL DIVERSITY IN INDIA

डॉ कैलाश चन्द्र
निदेशक
Dr Kailash Chandra
Director

भारत सरकार
भारतीय प्राणि सर्वेक्षण
पर्यावरण, वन एवं जलवायु परिवर्तन मंत्रालय
Government of India
Zoological Survey of India
Ministry of Environment, Forest and Climate Change

Foreword

India is one among the seventeen mega biodiversity nations known from the worldendowed with remarkable biodiversity in its diverse ecosystems and habitats, and occupies the 9th position in terms of freshwater mega biodiversity. Freshwater biodiversity provides a broad spectrum of invaluable ecosystem services, besides a wide range of goods and services for human societies. The freshwater ecosystems of India include all types of inland wetlands: lakes, rivers, ponds, streams, groundwater, springs, cave waters, floodplains, as well as bogs, marshes and swamps, including 26 Ramsar Sites. India with 2.4% of global landmass has 4% of the world's freshwater resources.

This document entitled "*The Current Status of Freshwater Faunal Diversity in India*" is a compendium of 36 chapters, by 48 authors, dealing with the compiled and updated information on the faunal diversity of 19 phyla (18 invertebrate phyla and 01 vertebrate phylum with five classes) of freshwater ecosystems in India. The document focuses on species diversity, endemism and threat status of taxa of freshwater ecosystems, with identified gap areas of knowledge. The total number of species of freshwater animals named and recorded from India has been compared with the total number of species known from India and the world. As many as 9457 animal species, representing 9.7 % of the total number of Indian fauna (i.e., 97,708 species) have been recognized from the freshwater ecosystems in India, of which invertebrate groups comprise 7861 species (83.1%) and vertebrate groups, 1597 species (16.9%).

I hope this volume will be a timely scientific publication on the freshwater faunal diversity of India, very user-friendly to biodiversity researchers, teachers, students and general public at large.

26th May, 2017
Kolkata

(Kailash Chandra)

ZOOLOGICAL SURVEY OF INDIA 1916
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Preface

Zoological Survey of India (ZSI) is the pioneer institution undertaking taxonomic research in the country and has been carrying out, over the last hundred years, surveys of the diverse ecosystems, distributed in varied but unique biogeographic zones of the country for exploring, discovering/reporting and documenting the wealth of Indian faunal diversity. ZSI has brought out numerous publications—more than 1500 scientific books and many hundreds of scientific papers—on the faunal diversity of varied ecosystems and conservation areas of the country. It was felt that a scientific document dealing with an overall assessment on the faunal diversity of freshwater ecosystems in India was necessary to facilitate the biodiversity researchers and conservationists. We were convinced of the need of the book that covers most updated information on the diversity of all groups of animals of the freshwater systems in India, in such a manner that the biodiversity researchers, students and teachers, conservation managers and the general public may learn from this new volume ZSI is bringing out now. The exercise was not an easy task. It taxed the taxonomic skill of experts who had firsthand experience in handling the subject groups. We are extremely thankful to the contributors of chapters and as well many of our colleagues who helped us in various ways in preparing this document. The diversity of fauna pertaining to the freshwater ecosystems of India dealt in this document represents the present knowledge, covering the compiled, collated and updated data or information that is currently available and known from India. It was our endeavor to make this book as much exhaustive as possible to make it useful to all concerned. We hope that we have been able to meet these needs and that this book may prove of value to research students and to all who desire to know about the potential faunal diversity of Indian freshwater systems.

Kailash Chandra, K.C. Gopi, D.V. Rao,
K. Valarmathi and J.R.B. Alfred

Chapter 1

CURRENT STATUS ON FRESHWATER FAUNAL DIVERSITY OF INDIA – AN OVERVIEW

KAILASH CHANDRA, K.C. GOPI, D.V. RAO, K.A. SUBRAMANIAN AND K. VALARMATHI

INTRODUCTION

Freshwater systems form a subset of Earth's aquatic ecosystems. They include lakes and ponds, rivers, streams, springs, and wetlands, which can be broadly classified into lentic and lotic systems, i.e., still and flowing waters, respectively. The freshwater ecosystems constitute the major part of the "Inland waters", the aquatic systems or environment that can be fresh, saline or a mix of the two (brackish water), located within land boundaries. The estuaries are transitional brackish-water zones between rivers and the sea. Inland waters have more focus on fresh water mainly because of the global importance of fresh water environments, which dominate inland waters.

All freshwater ecosystems are regulated by the hydrological cycle, ultimately driven by the solar-energy evaporation, without which freshwater ecosystems would not exist on Earth. Freshwater ecosystems are important for many reasons: they help in regulating hydrological regimes, attenuating floods, recycling of nutrients, purification of water and recharging of aquifers. They support a wide range of biodiversity, sustaining and sheltering their living environment for the aquatic life, besides providing congenial riparian habitats for dependent terrestrial wildlife. Freshwater systems also provide vital ecosystem services for humans, e.g., drinking water, flood control, climate regulation, food production, etc. Aquatic ecosystems nowadays play a major role in the wellness industry like tourism and recreation as many natural open waters like backwaters and lakes, and their scenic beauties around in the coastal plains and highland or mountain environments are tagged as important tourism destinations.

Of all the water on Earth, approximately 3% is considered "fresh water" (i.e., salinity < 0.5 parts per thousand). Of the 3% of global water, that is fresh water, only an extremely small proportion is available as habitats for living organisms on the surface of the Earth. The available freshwater ecosystems cover only approximately 0.8% of the surface of the Earth. Thus, significantly, much of the Earth's aquatic biodiversity requires the freshwater habitats, both flowing (lotic) and static (lentic), found in these rare ecosystems. It is therefore not surprising that freshwater habitats contain some of the most endangered taxa in the biosphere.

The number of species inhabiting a given area is the species richness. Freshwater ecosystems support innumerable organisms as they require fresh water for survival, and the freshwater species are those which spend at least a portion of their lives in freshwater habitats. Many hundreds of freshwater species of different groups, invertebrates like annelids (polychaetes, earthworms, leeches, etc.), arthropods (insects and crustaceans), fishes, amphibians, molluscs (snails and mussels), and others have been described. The list of known diversity of freshwater species, unlike that of terrestrial life forms, is likely to be an underestimate. Despite the relative rarity of freshwater habitats (i.e., 0.8% of the Earth's total surface area), the freshwater ecosystems exhibit far more intrinsic physical and chemical characteristics, and support a disproportionately larger share of world's freshwater biodiversity in relation to the habitat areas occupied. The diversity and distribution of the well-studied taxonomic groups like fishes and amphibians provide an insight into the significance and the global patterns of freshwater biodiversity (Abell *et al*., 2008).

Another important measure of significance for freshwater biodiversity is the concept of species endemism—the indigenousness of a species by virtue of its natural origin or occurrence in a given location or region and nowhere else in the world. The global distribution of an endemic species is limited to a given area (i.e., they occur only within a particular ecoregion or watershed). Areas of high endemism often result from a combination of ecological forces including high biological productivity and geographic isolation, as is evidenced in the endemism in freshwater fishes and amphibians in India.

Indian Freshwater Ecosystems and Faunal diversity

India is the seventh largest country in the world covering an area of 32, 87,590 sq. km, the largest land mass of the Indian subcontinent, and lies to the north of the equator between 6° 45´ (the southernmost extremity, the Indira Point in Great Nicobar Islands of the Indian territory) and 37° 6´ north latitude and 68° 7´ and 97° 25´ east longitude. India is endowed with remarkable biodiversity in its diverse ecosystems and habitats that are distributed in varied, but unique biogeographic zones.

Its biodiversity richness is well-reflected in the fauna of not only the terrestrial ecosystems, but also the aquatic ecosystems (i.e., the marine and freshwaters). India is one among the seventeen mega biodiversity nations known from the world, and occupies the 9th position in terms of freshwater mega biodiversity (Mittermeier *et al*., 1997).

The freshwater ecosystems of India include all types of inland wetlands: lakes, rivers, ponds, streams, groundwater, springs, cave waters, floodplains, as well as bogs, marshes and swamps. India with 2.4% of global landmass has 4% of the world's freshwater resources (source: the Ministry of Water Resources, Govt. of India). The abundant water resources include 29,000 kms of rivers, 3.15 million hectares of reservoirs, 2.35 million hectares of ponds and tanks, 0.2 million hectares of floodplains and 33 wetlands (Ayyappan, 2007). The main freshwater systems are 14 major rivers and their tributaries, numerous minor/ small rivers, rivulets and streams, 44 medium reservoirs and lakes, and other small water bodies. The National Wetland Inventory and Assessment published recently by MoEFCC, Govt. of India estimates that 10.56 million hectares of inland wetlands exist in India, comprising of 6.62 million hectares of natural wetlands and 3.94 million hectares of manmade wetlands. The total area of Indian wetlands is only 0.03% of the geographical extent of the country.

Freshwater Ecoregions of India

Freshwater ecosystems and habitats of India are distributed in diverse biogeographic regions or environments, from cold arid Trans-Himalayan to wet Terai regions of Himalaya foot hills and Gangetic plains, extending down to the Southern peninsula of the mainland, and beyond to the two archipelagoes of the Andaman and Nicobar Islands in the Bay of Bengal and Lakshadweep Islands in the Arabian Sea. The varied freshwater systems in the mainland are directly or indirectly associated with the numerous river-drainage systems of India, such as the major rivers like Ganges and Brahmaputra, including their tributaries, of Himalaya's origin, Narmada, Tapti, and their tributaries from Vindya-Satpura Mountains, and Godavari, Krishna and Cauvery, and their tributaries as well as many other minor, west-flowing rivers of Western Ghats' origin.

Indian Wetlands

The wetlands are the most productive natural ecosystems in the world because of their physical proximity to both water and soil, thereby supporting large number plants and animals in their significant diversity of characteristic species. India has the representation of almost all types of wetlands as defined by the Ramsar convention. The wetland ecosystems in India constitute the natural water bodies, such as rivers, lakes, coastal lagoons, mangroves, peat land, coral reefs and man-made wetlands such as ponds, farm ponds, irrigated fields, sacred groves, salt pans, reservoirs, gravel pits, sewage farms and canals. At present, 115 wetlands (Table 1) have been identified under the National Wetland Conservation Programme (NWCP), and about 26 wetlands (Table 2) have been declared as Ramsar sites of international importance under Ramsar Convention (Ramsar, 2017). According to a study conducted by the Bombay Natural History Society (BNHS), around 160 Indian wetland sites that are home to thousands of water birds meet the criteria to qualify them to be included in the 'Ramsar' category. These include already designated 'Ramsar Sites'. In addition, many wetlands in India are protected as Sanctuaries and National Parks. The well known wetland protected areas are: Keoladeo National Park, Bharatpur Bird Sanctuary, Loktak Lake, Pong Dam, Renuka Lake, Point Calimere National Park and Chambal River Sanctuary.

Table 1. State-wise Ramsar Sites (Wetlands) in India

Sl. No.	Wetland name	State
1.	Kolleru Lake	Andhra Pradesh
2.	Deepor Beel	Assam
3.	Nalsarovar Bird Sanctuary	Gujarat
4.	Chandartal Wetland	Himachal Pradesh
5.	Pong Dam Lake	
6.	Renuka Wetland	
7.	Hokera Wetland	Jammu & Kashmir
8.	Surinsar-Mansar Lakes	
9.	Tsomoriri Lake	
10.	Wular Lake	
11.	Ashtamudi Wetland	Kerala
12.	Sasthamkotta Lake	
13.	Vembanad-Kol Wetland	
14.	Bhoj Wetland	Madhya Pradesh

Sl. No.	Wetland name	State
15.	Loktak Lake	Manipur
16.	Bhitarkanika Mangroves	Odisha
17.	Chilika Lake	
18.	Harike Lake	Punjab
19.	Kanjli Wetland	
20.	Ropar Wetland	
21.	Sambhar Lake	Rajasthan
22.	Keoladeo National Park	
23.	Point Calimere Wildlife and Bird Sanctuary	Tamil Nadu
24.	Rudrasagar Lake	Tripura
25.	Upper Ganga River (Brijghat to Narora Stretch)	Uttar Pradesh
26.	East Calcutta Wetlands	West Bengal

Table 2. State-wise list of wetlands identified under National Wetlands Conservation Programme

Andhra Pradesh
1. Kolleru

Assam
2. Deepar Beel
3. Urpad Beel
4. Sone Beel

Bihar
5. Kabar
6. Barilla
7. Kusheshwar Asthan

Gujarat
8. Nalsarovar
9. Great Rann of Kachh
10. Thol Bird Sanctuary
11. Khijadiya Bird Sanctuary
12. Little Rann of Kachh
13. Pariej
14. Wadhwana
15. Nanikakrad

Haryana
16. Sultanpur
17. Bhindawas

Himachal Pradesh
18. Renuka
19. Pong Dam
20. Chandratal
21. Rewalsar
22. Khajjiar

Jammu & Kashmir
23. Wullar
24. Tso Morari
25. Tisgul Tso & Chisul Marshes
26. Hokersar
27. Mansar-Surinsar
28. Ranjitsagar
29. Pangong Tsar
30. Gharana
31. Hygam
32. Mirgund
33. Shalbugh
34. Chushul & Hanley

Jharkhand
35. Udhwa
36. Tilaiya Dam

Karnataka
37. Magadhi
38. Gudavi Bird Sanctuary
39. Bonal
40. Hidkal & Ghataprabha
41. Heggeri
42. Ranganthittu
43. K.G. Koppa wetland

Kerala
44. Ashtamudi
45. Sasthamkotta
46. Kottuli
47. Kadulandi
48. Vembanad Kol

Madhya Pradesh
49. Barna
50. Yashwant Sagar
51. Wetland of Ken River
52. National Chambal Sanctuary
53.Ghatigaon
54. Ratapani
55. Denwa Tawa
56. Kanha Tiger Reserve
57. Pench Tiger Reserve
58. Sakhyasagar
59. Dihaila
60. Govindsagar
61. Sirpur

Maharashtra
62. Ujni
63. Jayakawadi
64. Nalganga

Manipur
65. Loktak Lake

Meghalaya
66. Umiam lake

Mizoram
67. Tamdil
68. Palak

Odisha
69. Chilka
70. Kuanria
71. Kanjia
72. Daha
73. Anusupa

Punjab
74. Harike
75. Ropar
76. Kanjli
77. Nangal

Rajasthan
78. Sambhar

Sikkim
79. Khecheopalri
80. Tamzey
81. Tembao Wetland Complex
82. Phendang Wetland Complex
83. Gurudokmar
84. Tsomgo

Tamil Nadu
85. Point Calimere
86. Kaliveli
87. Pallaikarni

Tripura
88. Rudrasagar
89. Gumti reservoir

Uttar Pradesh
90. Nawabganj
91. Sandi
92. Lakh Bahoshi
93. Samaspur
94. Alwara
95. Semarai
96. Nagaria
97. Keetham
98. Shekha
99. Saman Bird Sanctuary
100. Sarsai Nawar
101. Patna Bird Sanctuary
102. Chandotal
103. Taal Bhaghel
104. Taal Gambhirvan & Taal Salona
105. Aadi jal Jeev Jheel

Uttarakhand
106. Ban Ganga Jhilmil Tal
107. Asan

West Bengal
108. East Kolkata wetlands
109. Sunderbans
110. Ahiron Beel
111. Rasik Beel
112. Santragachi
113. Patlakhawa- Rasomati

Chandigarh (UT)
114. Sukhna

Puducherry (UT)
115. Ousteri

The National River Conservation Directorate, under the Ministry of Environment, Forest and Climate Change is engaged in implementing the River and Lake Action Plans under the National River Conservation Plan (NRCP) and National Lake Conservation Plan (NLCP).The Government of India and the World Bank have signed three agreements, May 2011, (of which 2 deal with biodiversity conservation) for cleaning Ganga River and to Strengthen Rural Livelihoods and Biodiversity Conservation in India. Government of India, in close collaboration with the State/UT Governments has been implementing the National Wetlands Conservation Programme (NWCP), since the year 1985-86, to prevent the degradation, ensuring the wise use for the benefit of local communities and overall conservation of biodiversity. Under the Programme, 115 wetlands (including the 26 wetlands of international importance under Ramsar Convention) in 24 states and 2 Union Territories have been identified under the National Wetland Policy by the Ministry which require urgent conservation and management interventions (National Report on Wetlands, 2009). As of now there is no specific legal framework for wetland conservation, management and their wise use. National Forest Commission, 2006 has demanded the launch of National Wetland Conservation Act, National Wetland Biodiversity, National Wetland Inventory and Wetland Ecosystem Monitoring Programmes and National Wetland information system for checking the health of the Wetlands, the transitional zones between wetlands. Baseline information on the biodiversity of water bodies in the form of an inventory of the fauna including birds, fishes, reptiles, mammals and invertebrates is essential to identify the wetlands that are to be designated as Ramsar sites for inclusion in the 'List of Wetlands of International Importance', and to prepare the MAPs as well as the IUCN Red List of Threatened Species. The National River Conservation Directorate, under the Ministry of Environment, Forest and Climate Change is engaged in implementing the River and Lake Action Plans under the National River Conservation Plan (NRCP) and National Lake Conservation Plan (NLCP) (MoEFCC, Annual report 2005).

Role of ZSI in Freshwater Ecosystem Conservation

Zoological Survey of India (ZSI) as a premier taxonomic research organization has been developing baseline information on the faunal diversity of water bodies in the form of an inventory of various fauna including birds, fishes, reptiles, mammals as well as invertebrates for monitoring and analysing the species population trends, as well as for the evaluation of Threatened taxa. Studies on the presence of exotic/ invasive alien species and their possible impacts have also been incorporated into the faunal documentation works. Accordingly, ZSI has developed need-based, fauna-related reference systems such as the species inventories or faunal inventories of selected wetlands on a priority basis to be incorporated into the information system or its Management Action Plans for wetland conservation. ZSI has contributed significantly to document the fauna of Indian wetlands. The scientists of ZSI have conducted extensive field surveys and described many new species of different faunal groups. Major contributions have been in molluscs, fishes, amphibians, lower invertebrates, crustaceans and various insect groups. Publications in the form of Fauna of India, Memoires, Occassional Papers, and numerous research articles have been published on wetland fauna of India. Exclusive publications have been brought out on the faunal diversity of wetlands of both natural and man-made lakes as Chilka, Renuka, Ujani, Kabar, Asan, Sambhar, Nath Sagar, Pichhola, Kopli, Vembanad, NalSarovar, Chaurs, Khijadia, Wyra, Deepor, Palar, Krishna Sagar, Cumbum, and Subarnarekha. Future surveys are proposed for lakes as Chandra Tal, Gobindsagar, Sasthamkota, Narayansarovar, Deeper Beel etc. as per Vision 2020 document of ZSI, approved by the Ministry.

ZSI has augmented its efforts in recent years to make better use of the existing expertise and knowledge, and also engaging young and talented taxonomic researchers to identify and catalogue, including part-by-part digitization, of the back-log zoological collections in its central and regional faunal repositories and museums. This ongoing task is being carried out through institutional initiatives as well as through AICOPTAX (All India Coordinated Programme on Taxonomy) programmes specially funded by the Ministry.

Freshwater Faunal Biodiversity in India

Global assessment on biodiversity of freshwater ecosystems demonstrates that the biodiversity potential of these systems is very much larger than that would be expected from the area occupied by inland waters (Balian *et al*. 2008). Balian and team estimated that out of the 1.32 million species described on Earth, 126,000 lived in fresh water, contributing to almost 10% of the global total.

Freshwater habitats in India support a significant proportion of the total diversity of organisms, representing most of the taxonomic groups. As much as about 9.7% of the total Indian fauna are associated with freshwater ecosystems of India. However this estimated faunal diversity may be an underestimate due to the inadequate exploration and identification of taxa (species) of many faunal groups, especially invertebrates. As a result, the authentic status of the near-absolute freshwater diversity of these groups is yet to be realized (factually true at the terrestrial ecosystem levels also as only a fraction of the extant diversity of these faunal groups has so far been revealed). The constraints are many with far-reaching implications. One serious constraint that retards the taxonomic activities of identifying, naming and documenting species is the dire dearth of skilled taxonomists. The replacement of new and upcoming generation of taxonomists in the country is not on parity—rather it is on a downward trend—with the veteran taxonomists leaving the field from their active research. The support from the funding institutions and agencies for undertaking biodiversity-related taxonomic research in the country is not that promising as it is to the front-line research areas in physics, chemistry and other modern streams of science. All this slackens the pace of scientific documentation of biodiversity and estimation of species. However, in the recent times, there is a surge of interest among new generation talents in the biodiversity-related studies, like taxonomy and systematics of fauna pertaining to various ecosystems, including freshwater ecosystems, in India.

A summary of the updated information on the freshwater faunal diversity of India is presented here. The diversity of vertebrate and invertebrate groups for which credible data are available is compared and discussed. Data are deficient for many groups of invertebrates owing to knowledge gaps, either lack of available data of work carried out in the country/or lack of taxonomic information from the country, which are pressing needs to be addressed. As regards freshwater biodiversity for sustainable management and conservation of freshwater resources, efforts are also required to gather the environmental and ecological information data based on monitoring observations in order to analyze the conservation issues so that freshwater biodiversity for sustainable utilization as well as management of the resources can be cross-linked with conservation of biodiversity.

Thirty-six chapters by 48 authors have been included in this document dealing with updated, compiled information the faunal diversity of the freshwater ecosystems of India. The chapters though have a general format of presentation, some authors have however differed from the normal pattern because of the specific features of the group of fauna they deal with. The present overview focuses on species diversity, endemism and threat status of taxa of freshwater ecosystems of India. The total number of species of freshwater animals, named and recorded from India has been compared with the total number of species known from the world, following Alfred *et al*. (1998); Balian *et al*. (2008); Chandra *et al*. (2016a & b).

The diversity of fauna pertaining to the freshwater ecosystems of India dealt in this document represents the present knowledge, covering the updated, compiled and collated data, but, doesn't claim to be full-proof, exhaustive information that is currently available and known from India. Almost all the authors, other than the authors of the chapters on mammals, birds and reptiles, are of the view that significant share of the species diversity yet remain to be discovered and described especially in the case of invertebrate groups. The record of 9456 species from freshwater ecosystems of India represents approximately 9.7% of the total number of animal species (i.e., 97,708 species) recognized from India. Given that the Indian wetlands have altogether only 0.03% area of the total geographic extent of the country, it becomes clear that the lotic and lentic freshwater systems of India harbour a disproportionally large fraction (9.7%) of India's total biodiversity.

Out of the 9456 freshwater animal species known from India, among invertebrate groups, the phylum Arthropoda alone represents 5923 species or about 62.6% of the total. Insects (of 9 orders) have the majority with 4842 species (51.2%). The insect order Diptera (1588 species), is the most-species rich with 16.8%, and order Coleoptera (776 species) represents about 8.2% of all species, followed by the orders Odonata (482 species), and Hemiptera (325 species) with 5.1% and 3.4%, respectively. Another diverse Arthropod group class Crustacea (822 species) has the share of 8.7% of all freshwater species. The class Arachnida (259 species) with 2.7% share is dominated by the mites (253 species), and spiders with only a few in number (6 species). The phylum Nematoda (422 species) has the representation of 4.5% of total species. The phylum Rotifera (419 species) is represented by 4.4% of the total. The phyla such as Mollusca (217 species) and Annelida (167 species) are moderately diverse with 2.3%, 1.8% respectively of all the freshwater species. The Platyhelminthes with 163 species (Turbellaria 47 species + Cestoda 116 species) contribute 1.7% to the total. Among the remainder invertebrate groups, except for Acanthocephala with 140 species (1.5%), all other groups have less than 40 species (all <1% of the total): Porifera (31 species), Gastrotricha (24 species), Bryozoa (22 species), Tardigrada (10 species), Cnidaria (9 species), and Entoprocta (1 species), which are predominantly marine. The Kingtom Protista represented by phylum Protozoa (291 species) has a share of 3.0% of the total freshwater fauna.

The phylum Chordata comprising the vertebrates represent 1597 species (16.9%). Among these, Pisces (Fishes) are maximum (1027 species), followed by Amphibians (275 species) and Aves (birds) (243 species) with their shares 10.9%, 2.9% and 2.6%, respectively, of all freshwater fauna. The groups Reptiles, (46 species) and Mammals (6 species), are comparatively less in their number of species known from the freshwater systems of India.

Table 3. Freshwater faunal diversity in the world and India

Kingdom	Phylum	No. of Species in world		No. of species in India	
		Total	Freshwater	Total	Freshwater
Protista	**Phylum Protozoa**	**36400**	**2390**	**3510**	**291**
Animalia	**Phylum Mesozoa**	**136**	**--**	**10**	**--**
	Phylum Porifera	**10876**	**219**	**502**	**31**
	Phylum Cnidaria	**16383**	**40**	**1074**	**9**
	Phylum Ctenophora	**187**	**--**	**12**	**--**
	Phylum Platyhelminthes	**29488**	**1303**	**1666**	****116 + 47**
	Phylum Nemertea	**1362**	**22**	**6**	**--**
	Phylum Rotifera	**2049**	**2030**	**466**	**419**
	Phylum Gastrotricha	**794**	**320**	**100**	**24**
	Phylum Kinorhyncha	**196**	**--**	**10**	**--**
	Phylum Nematoda	**25043**	**1808**	**2914**	**422**
	Phylum Nematomorpha	**360**	**356**	**20**	**20**
	Phylum Acanthocephala	**1199**	*****	**229**	****140**
	Phylum Entoprocta	**172**	*****	**10**	**1**
	Phylum Annelida	**17426**	**1987**	**1004**	**167**
	Phylum Sipuncula	**147**	**--**	**35**	**--**
	Phylum Echiura	**198**	**--**	**43**	**--**
	Phylum Arthropoda	**1270711**	**94010**	**73657**	**5923**
	Subphylum Crustacea	73141	11990	3584	822
	Class Insecta	1070781	75874	63880	4842
	Class Arachnida	114275	6146	5907	259
	Class Pycnogonida	1346	--	17	--
	Class Chilopoda	3118	--	101	--
	Class Diplopoda	7842	--	162	--
	Class Symphyla	204	--	4	--
	Class Merostomata	4	--	2	--
	Phylum Onychophora	**187**	**--**	**1**	**--**
	Phylum Tardigrada	**1335**	**910**	**30**	**10**
	Phylum Mollusca	**118061**	**5000**	**5188**	**217**
	Phylum Phoronida	**16**	**--**	**3**	**--**
	Phylum Bryozoa	**11474**	**94**	**272**	**22**
	Phylum Brachiopoda	**7390**	**--**	**4**	**--**
	Phylum Echinodermata	**6600**	**--**	**779**	**--**
	Phylum Chaetogantha	**186**	**--**	**30**	**--**
	Phylum Hemichordata	**126**	**--**	**12**	**--**

Kingdom	Phylum	No. of Species in world		No. of species in India	
		Total	Freshwater	Total	Freshwater
	Phylum Protochordata	**3000**	**--**	**119**	**--**
	Phylum Chordata	**66471**	**17960**	**6002**	**1597**
	Class Pisces	33888	13000	3287	1027
	Class Amphibia	7534	4117	386	275
	Class Reptilia	10272	153	562	46
	Class Aves	9026	566	1340	243
	Class Mammalia	5751	124	427	6
		1627973	**128449**	**97708**	**9456**

*Not estimated; **Parasitic on freshwater fishes;

Source: Alfred *et al*. (1998); Balian *et al*. (2008); Zhang (2011); Chandra *et al*. (2016a & b)

In the biogeographic-zone perspective, the Western Ghats and Northeast India, and the Himalayas, the three of the four biodiversity hotspots known from India, are the most diversity-rich for most taxa, except for the groups of marine dominant minor phyla represented from freshwater ecosystems. These three hotspot areas also harboured the maximum number of endemic species with the highest endemism identified from the Western Ghats, followed by northeastern India.

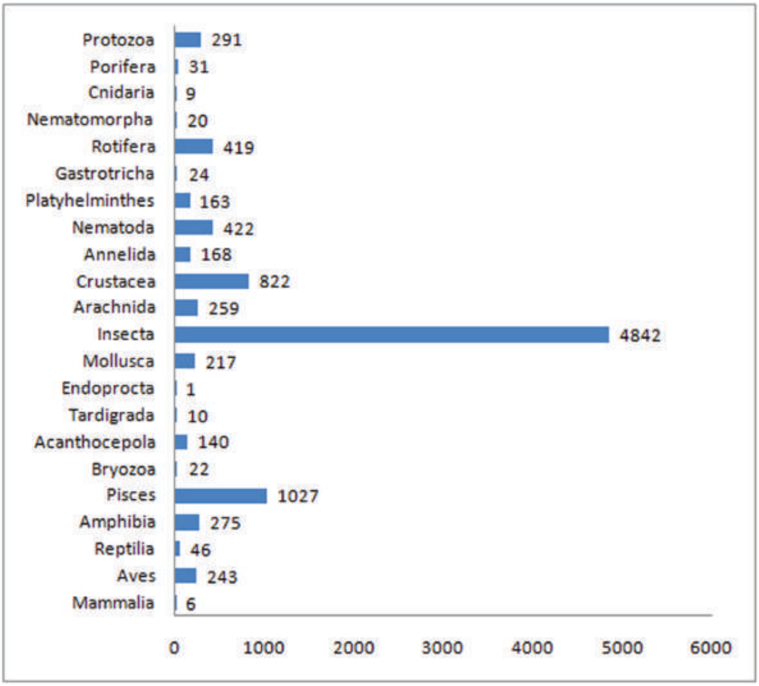

Fig. 1. Freshwater faunal Diversity in India

The present assessment of freshwater diversity from India is incomplete since the focus is on animal taxa, excluding micro-organisms such as bacteria, viruses, etc., though such groups are as significant to freshwater diversity and ecology, as the taxa from protozoa to mammals considered in this documentation work. The diversity of micro-organisms, their importance in freshwater ecology and their key role in ecosystem functioning are understudied, which is a perceptible gap area, among other things, in the biodiversity research and documentation works. It needs to be taken up in the future assessments of micro-organismal diversity in order to give the complete picture of freshwater biodiversity of India.

Kingdom Protista

Finlay and Esteban (1998) estimated about 2390 species of protozoans in freshwater habitats out of 36400 species known from the world. In India, 3510 species in 6 phyla have been reported, of which 52% are free-living and the rest parasitic species. According to the present estimate, about 1600 species of free living protozoans have been recorded from India including the estuarine species. A total of 106 species of ciliates belonging to 58 genera and 36 families are reported from the fresh water ecosystems of India. The rhizopods are represented by 185 species belonging to 175 genera and 17 families from India. Nearly 7% of free-living protozoans, as many as 90 species, are endemic to the country (Das, 1998).

Phylum Porifera

The poriferans, commonly known as sponges, are represented by over 219 freshwater species belong to 45 genera in six families globally. In India, 31 species of freshwater sponges belonging to 11 genera are represented by a single family Spongillidae (Soota, 1991), of which 11 species are endemic. Out of the 37 Oriental species, over 81% (31 species) are known to occur in India (Jakhalekar and Ghate, 2013).

Phylum Cnidaria

Cnidarians are a composite group of animals that include medusa, anemones, corals, polyps etc. They are remarkably successful in the marine realm and a few are thriving in inland waters. Their global diversity in freshwater habitats is less than 40 species. The Oriental region has 4 to 6 species in freshwater (Jankowski *et al*., 2008). In India, 9 species belonging to 6 genera and 4 families are reported to occur in freshwater.

Phylum Platyhelminthes

Among the platyhelminths, class Turbullaria includes free living forms found in all aquatic habitats both marine and freshwater, while other classes (3 or 4) are all parasitic. Globally about 6500 species of turbullarians are known, and 1303 species are reported from freshwaters, of which 36 species distributed in Oriental region (Schockaert *et al*., 2008). However, turbullarians could not be dealt with in this volume, and the related diversity information of 47 species follows Ghosh *et al*. (1998). Current status of cestoda fauna of India parasitic on freshwater fishes accounts for 5 orders, 11 families, 3 subfamilies, 25 genera and 116 species. A total of 46 species, 22 genera, 10 families and 5 orders of freshwater fishes are found to be infected by these 116 cestode parasites in India.

Phylum Rotifera

Rotifers play a vital role in many freshwater ecosystems and are ubiquitous, occurring in almost all type of freshwater habitats. Globally, 2030 species were recorded from freshwaters (Segers, 2007). Till date, 419 valid rotifer species belonging to 67 genera and 25 families are recorded from freshwater environs of India.

Phylum Nematomorpha

An interesting group of nematode-like animals, commonly called as horsehair worms, whose free-living adults are found in freshwaters (with only 5 marine forms), but the larval forms are parasitic, mainly on arthropods. As many as 356 freshwater species are known from the world (FADA 2017), with only 20 species belonging to 5 genera being reported from India (Schmidt-Rhaesa and Yadav 2004, 2013; Schmidt-Rhaesa and Lalramliana, 2011, 2016; Schmidt-Rhaesa *et al*., 2015).

Phylum Gastrotricha

Gastrotrichs are among the most abundant, but poorly known group of freshwater invertebrates. They are nearly omnipresent in the benthos and periphyton of freshwater habitats. Globally 324 species are known from freshwater habitats (Balsamo *et al*., 2013). In India, 24 species belonging to six genera are reported (Sharma, 1990).

Phylum Nematoda

Nematodes are typically thread-like, unsegmented pseudocoelomates. They are one of the most diverse groups of metazoa in aquatic sediments. Free living nematodes are found possibly in all types of limnetic habitats. Of the 27,000 nominal species, the freshwater forms are about 1808 species, about 7% of the total species known from world (Abebe *et al*., 2008). So for, 412 species of freshwater nematodes belonging to 119 genera and 57 families are reported from India.

Phylum Acanthocephala

Acanthocephala or thorny-headed worms form an important group of animal endoparasites. Their life history involves one or more hosts, generally invertebrates or lower vertebrates, mainly fishes and also affects piscivorous birds as intermediate host. Nabi *et al*. (2015) reported approximately 1150 species of these parasites, falling in four orders: Neoechinorhynchidea, Echinorhynchidea, Aporhynchidea and Gigantorhynchidea. Bhatacharya (1998) reported 140 species of these parasitic worms from fishes with indication of high degree of regional endemism.

Phylum Annelida

Polychaeta: Polychaetes, commonly called as 'brittle worms', a non-monophyletic group of animals among annilids, most abundantly living within sands and mud on the seashore and marine environment. Several marine forms have penetrated to and adapted to survive in pure freshwater systems. Globally, 168 species of ploychaeta (Glasby and Timm, 2008) are available in freshwater. Our knowledge on freshwater polychaete fauna of India reveals occurrence of 41 species belonging to 25 genera in 15 families.

Oligochaeta: The oligochaetes are elongate and segmented annelids with no appendages, and are either terrestrial soil-burrowing or aquatic in habit. About half of the annelids are placed in subclass Oligochaeta. Globally 1700 species of oligochaetes are reported from freshwater, and the present document recognises 72 species of oligochaetes placed under 20 genera and one family in the freshwater environments of India.

Hirudinea: Freshwater leeches (Hirudinea) are mainly predatory and parasitic annelids having terminal suckers that serve in attachment, locomotion and feeding. Most of the leeches are blood-suckers on vertebrates or invertebrates, while others are mainly predators and rarely scavengers. About 700 species of leeches are known from the world, of which 482 species are from freshwaters. Seventy leech species have been recorded so far from India, of which 55 species under 25 genera and 5 families are from freshwater bodies, while 36 of them are endemics.

Phylum Arthropoda

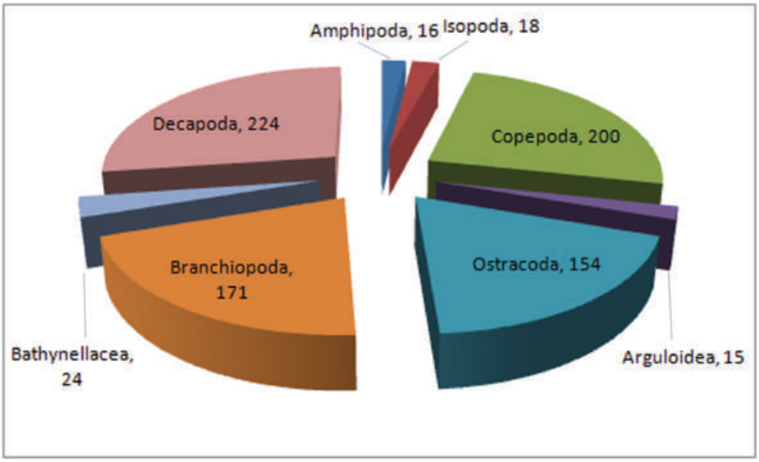

Fig. 2. The crustacean diversity in Indian freshwater

Subphylum Crustacea

Crustaceans constitute a large group of the Arthropoda comprising crabs, lobsters, crayfish, shrimp, krill, barnacles, copepods, ostracods, etc. inhabiting a wide range of habitats, and are free-living, parasitic or sedentary organisms. There are over 73141 known species of crustaceans divided into a number of major groups. Four classes namely Branchiopoda, Maxillipoda, Ostracoda and Malacostraca are available in Indian freshwater environments. As per global estimate, 11,990 species of crustaceans are known from freshwater (Balian *et al*., 2008) and about 822 species have been reported from Indian freshwater habitats.

Class Branchiopoda: The branchiopods include cladocerans or Water fleas, a group of small-sized, mostly microscopic branchiopods representing one of the most primitive groups of lower Crustacea. In all, 131 species of Cladocera are known from inland waters of India. Other than cladocerans, the remaining are known as large branchiopods or non-cladoceran branchiopods. Presently, 40 species of large branchiopods under 14 genera, 11 families and 4 orders are known to occur in India.

Class Maxillipoda: Subclass Copepoda: Of the nine orders known under the subclass Copepoda, the free-living freshwater copepods generally belong to three orders: Calanoida, Cyclopoida and Harpacticoida. All other orders contain predominantly brackish water, marine and/or parasitic forms. The free-living inland water Copepoda is so far known only by about 200 species in 60 genera from India. The order Calanoida has 40 families. Truly freshwater Indian species are typically planktonic, and belong to the family Diaptomidae. This family contains about 470 species in 61 genera in the world, and with 45 species in 13 genera in India. The order Cyclopoida comprises 12 families, but only four of them, viz. Oithonidae, Cyclopinidae, Cyclopettide and Cyclopidae, are found in inland waters of India. Out of 1,100 species in about 60 genera known worldwide, 86 species in 20 genera are known from India. The order Harpacticoida mostly represents benthic organisms, inhabiting the sediment as interstitial, burrowing or epibenthic forms. Nearly 50 families, with about 1,200 species occurr in freshwater as well as brackish waters in the world, while 66 species in 29 genera are presently known from Indian inland waters. The order Arguloidea comprises a group of primary freshwater parasitic crustaceans, commonly known as 'fish-lice'. The only family of this order, Argulidae, comprises four genera, out of which only the genus *Argulus* is represented by 17 species in India, of which 14 species are freshwater inhabitants.

Class Ostracoda: Ostracods, commonly known as seed shrimps, are microscopic organisms existing in all aquatic (marine, brackish and freshwater) ecosystems, including subterranean waters. Globally, 2103 species under three superfamilies, 15 families and 209 genera are known from freshwater systems (Martens *et al*., 2008), of which about 154 species belonging to 05 families, 40 genera have been documented from India.

Class Malacostraca: The class Malacostraca includes amphipods, isopods, Bathynellacea and decapods etc. Amphipods are small crustaceans, highly diverse in aquatic habitats and intertidal zones. Out of 161 species of amphipods known so far from India, only 16 species are from freshwater. Most of the isopods are marine inhabitants and have wide distribution. Out of the 11000 species of isopods known globally, only 301 species are reported from India, which include marine, backwater, terrestrial and parasitic forms, with only 18 species occurring in freshwater systems. The order Bathynellacea, comprising small eumalacostracan crustaceans, typically occurring in the

interstitial spaces of sandy shore sediments of lakes, sandy and gravelly banks of rivers, streams etc, is represented by 24 species under 7 genera and 2 families from India. The order Decapoda includes important crustaceans like shrimps and crabs comprising 655 species of caridean shrimps and 1,476 species of brachyuran crabs available in freshwater systems of the world. The caridean shrimps consisting of 118 species under 14 genera and two families, and the brachyuran crabs having 106 species under 40 genera and 5 families are known from freshwaters of India, which include 100 species of primary freshwater crabs and 6 species of secondary freshwater crabs.

Class Arachinida: The class Aracnida includes spiders and mites inhabiting mostly terrestrial habitats, some in freshwater environments (Foelix, 2011). There are 26 species under 12 genera belonging to nine families of spiders so far reported from the World (Nyffeler and Pusey, 2014) while 6 species under 6 genera and 3 families are known so far from India. Among the mites, the Hydrachnidia (water mites) represents the most important group of the Arachnida in fresh water. Over 6,000 species placed under 57 families, 81 subfamilies and more than 400 genera have been described worldwide (di Sabatino, 2008), of which 253 species, 70 genera and 25 families are reported from India, including 183 species endemic to the country.

Class Insecta: Insects constitute the most successful among all groups of animals. They are also the most diverse group of organisms in freshwater. It is estimated that as many as 4842 species inhabit inland wetlands of India.

Order Hemiptera: Freshwater hemipterans, commonly known as 'aquatic bugs', are secondarily adapted to aquatic ecosystems, with their nymphal and adult stages being fully aquatic. The aquatic bugs are represented by 325 species, 84 genera and 18 families under three infraorders of suborder Heteroptera, known from India.

Order Coleoptera: This order includes hard bodied beetles which are holometabolous in nature with complex metamorphosis. The beetles are most species-rich animal group existing on the earth. The water-beetle fauna of India consists of 776 species belonging to 137 genera, and 17 families in 3 suborders.

Order Odonata: The order odonata, one of the ancient groups of insects, includes insects with their adults having terrestrial and the larvae aquatic mode of living. Globally, 6233 species in 685 genera of odonates are known, of which 482 species with about 50 subspecies in 150 genera and 18 families exist in India.

Order Trichoptera: Trichoptera, commonly called Caddisflies, are among the most diverse holometabolous aquatic insects and are primary invaders of freshwaters. Trichopterans are extensively utilized in bio-monitoring service along with other micro-invertebrates as their larvae are an important beneficial component of the trophic dynamics and energy flow in their inhabiting lotic and lentic waters. Over the world, 14,548 species belonging to 616 genera in 49 families have been recognized (Morse 2017). In all, 28 families encompassing 102 genera and 1,227 species are on record from India.

Order Plecoptera: Plecoptera is a small monophyletic order of hemimetabolous insects, commonly called stoneflies with around 3625 described species globally included under 303 genera and 16 families, of which 128 valid species under 24 genera and 8 families are reported from India, including 91 species endemic to India.

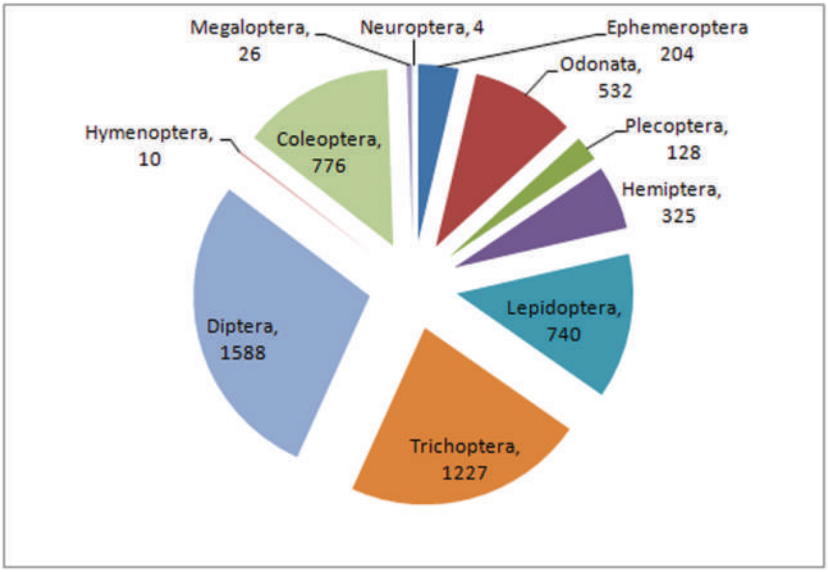

Fig. 3. The composition of aquatic-insect groups in Indian freshwater ecosystems

Order Ephemeroptera: Ephemeropterans, commonly known as Mayflies, are most primitive and ancient group of insects. Globally, about 3000 species in 400 genera and 42 families are known, of which 390 species, 84 genera and 20 families occur in Oriental region (Barber-James *et al*., 2008). The Indian subregion has the representation of 204 species, of which 146 species belonging to 58 genera and 13 families are reported from India.

Order Lepidoptera: Lepidoptera forms a fascinating group of insects of economic importance with high diversity of species consisting of butterflies and moths. The aquatic Lepidoptera is represented by 740 species under three subfamilies, Acentropinae, Pyraustinae (Crambidae) at global level, and in India, 80 species are available under 3 subfamilies and 2 families.

Order Diptera: Dipterans include the group of two-winged insects, known as true flies, inhabiting terrestrial, semi-aquatic and aquatic habitats. Adult dipterans are usually terrestrial in habit while their larvae and pupae are aquatic and dependent on water. In all, 40 families of Diptera are known to be aquatic worldwide, of which 36 families, 151 genera and 1,588 species known from India are aquatic or semi-aquatic in nature.

Order Hymenoptera: Hymenopterans are generally terrestrial insects and are mostly beneficial insects of economic importance as agents of biological control. Most of them have a parasitic mode of life (parasites or parasitoids) on other group of insects. Globally, 150 species 51 genera from 11 families of Hymenoptera are recognized as aquatic, of which 10 species in 7 genera under 3 families from or near water bodies are known from India.

The insect orders Megaloptera and Neuroptera (not dealt with among chapters of insect groups of this document) are closely related members of the superorder Neuropterida (Cover and Resh, 2008). A total of 328 species of Megaloptera and 73 species of Neuroptera are known globally. In India 26 species of Megaloptera belonging to 7 genera under a single family are known from the freshwater ecosystem. The Indian freshwater neuropterans are represented by 4 species placed under 2 genera and a single family.

Phylum Mollusca

Freshwater molluscs play an important role, as the prominent links in the trophic structure of freshwater ecosystem. The freshwater molluscs have an estimated global diversity of 5000 species, of which 217 species comprising 150 species of gastropods and 67 species of bivalves are reported from freshwater ecosystems of India. About 15 species of gastropods and 18 species of bivalves have discontinuous distribution. As many as 77 freshwater molluscs are endemic to the Western Ghats biodiversity hotspot.

Phylum Bryozoa

The Bryozoa, also known as polyzoa, ectoprocta or moss animals, are colonial organisms primarily inhabiting marine environment. Bryozoa is divided into two distinctive classes, Phylactolaemata and Gymnolaemata, of which the former is strictly restricted to fresh waters. Besides 5,000 marine species, 94 species under 24 genera, 10 families are known from the freshwaters from the world. The Indian fauna comprise 22 species under 13 genera and 6 families.

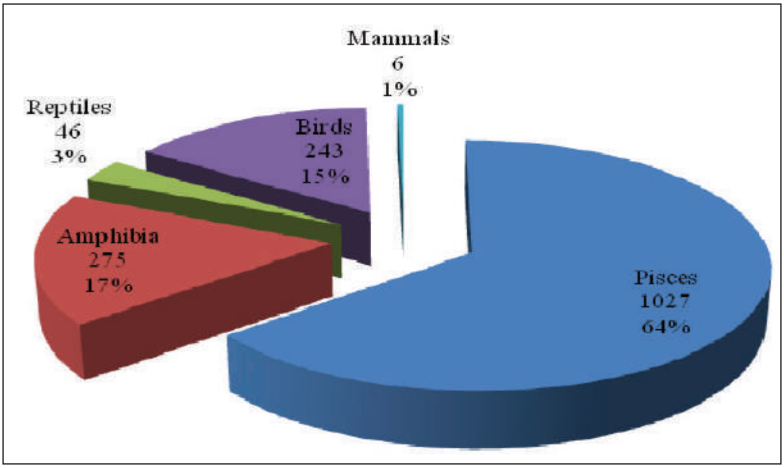

Fig. 4. Freshwater vertebrates in India

Phylum Chordata

Class Pisces: Indian freshwater fish diversity is very rich with as many as 1027 species, comprising of primary, secondary and alien freshwater fishes. Among them primary freshwater fishes include 858 species belonging to 167 genera under 40 families and 12 orders. Further, 137 species of secondary freshwater fishes that frequently enter and thrive in freshwater reaches of rivers are also known from India. Alien fishes that have become naturalized in Indian freshwater bodies account for 32 species, of which 16 are considered to be potentially invasive. More than 60.3% of the primary freshwater fishes of India are endemic to the country, with maximum endemism of species found in Western Ghats.

Class Amphibia: Amphibians include three living orders, Anura (frogs and toads with 6706 species worldwide), Caudata (salamanders and newts with 693 species worldwide) and Gymnophiona (caecilans or limbless amphibians with 205 species worldwide), thus, accounting 7604 species known from the world. Of these, 386 species belonging to 59 genera and 15 families are known from India, sharing about 5% of the total species from the world. Of the 386 species of Indian amphibians, about 275 species, out of 386, dwell in freshwater bodies.

Class Reptilia: Reptiles are the first terrestrial, poikilothermic and omniote vertebrates occurring in all kind of environment except severe cold region. About 250 species of turtles of the total 320 recognized in the world are freshwater dwellers (Bour, 2008); though none of the lizards are strictly aquatic, at least 73 species regularly utilize freshwater habitats (Bauer and Jackman, 2008); and, 24 species of crocodilians live in tropic and warm temperate freshwater ecosystems of the world (Martin 2008). More than 570 species of reptiles have so for been reported from India (3 crocodiles, 33 testudines, 234 lizards and 296 snakes), which include 46 species of freshwater species, comprising one species each of Crocodylia and Gavialidea, 21 species of testudines, two species of monitor lizards, one species of skink, and 21 species of snakes, which are primarily or partially occurring in freshwater habitats.

Class Aves: Birds (Aves) have colonized all continents (from the Arctic to the Antarctic) and all habitats on earth (from the desert to the open sea). Approximately 10,000 species have been described, of which nearly 5% (560 species) need imperative freshwater habitat in order to satisfy at least one of their life-history traits (Dehorter and Guillemain, 2008). A total of 243 species of birds, including wetland dependants were recorded from the wetlands of India. However, 67 forest birds also frequent freshwater bodies.

Class Mammalia: Mammals include about 5500 species belonging 29 Orders, 154 families, of which, a total of 124 species of mammals belonging to 11 orders are freshwater forms occurring in all continents except Antarctica. Out of 124 species of global freshwater mammals, only 6 species namely, South-Asian river dolphin, Oriental small-clawed otter, European otter, Smooth-coated otter, Himalayan water-shrew and Elegant water-shrew, are found in India.

Knowledge gaps

There are several groups for which the information on the diversity richness and distribution of species are vague or inaccurate. Other than the vertebrate groups, which are reasonably better-documented in the biodiversity-related studies, all other groups, especially minor phyla and many groups even within the major taxa such as many minor insect orders, and families of the large orders of insects, like Coleoptera, Diptera, Hemiptera, Hymenoptera, etc. are still understudied for their diversity known from the freshwater ecosystems. Similarly, knowledge-gaps on species-habitat interaction (autecology), systematic surveys and monitoring of species diversity, status dynamics *vis-à-vis* habitat degradation through scientific species sampling and analyses methodologies, need to be addressed appropriately.

Diversity and distribution of vertebrates, like fishes, are though better documented than other groups, new species of freshwater fishes, or amphibians, are still being described regularly from the previously unexplored or underexplored areas, which itself is the evidence for the gap areas in the spatial coverage of exploration of important ecosystems for biodiversity related assessment and status studies. Almost all invertebrate groups of the freshwater ecosystems, including molluscs, crustaceans, insects and arachnids that are generally better covered in the biodiversity documentation studies, are still remaining unrevealed for their realistic species diversity known from the pristine and riparian habitat environs of major ecosystems like tropical rainforests, which are geographical gaps in the exploration programmes. Because of these reasons, our current assessments of estimating the faunal-diversity potential of freshwater ecosystems, or of terrestrial ecosystems for that matter, should be interpreted with care and caution. Some primitive invertebrate phyla such as Platyhelminthes, Nemertea, Nematomorpha, Gastrotricha, Tardigrada, etc. are also amongst the less or least known groups for which taxonomic knowledge and available data are to be substantially generated. In most of these groups, their freshwater diversity is relatively poor studied, compared to their marine or terrestrial counterparts.

Threats to the freshwater faunal diversity

Around the world, freshwater habitats are under increasing threats and pressures due to both local and global changes (Dudgeon *et al*., 2005; Pattnaik, 2007). Besides, freshwater bodies like rivers, lakes, tanks and ponds are overstrained by poisoning in various ways like industrial wastes, sewage, and agricultural runoff with chemical wastes and excess nutrients. Discharges of pollutants can degrade the quality of water, as well as affect the health of its aquatic ecosystem. Wetzel (1992) reported that freshwater bodies of the world are collectively experiencing accelerating rates of qualitative and quantitative degradation. Dudgeon *et al*. (2005) documented threats to global freshwater biodiversity under five categories like overexploitation, water pollution, flow modification, distraction and degradation of habitat and invasion of exotic species. These combined and interacting influences have resulted in the population decline and range reduction of freshwater biodiversity worldwide.

Freshwater ecosystems are known to be the most endangered ecosystems in the world. Declines in biodiversity are far greater in fresh waters than in the most affected terrestrial ecosystems (Sala *et al*., 2000). The threats to global freshwater biodiversity due to overexploitation, water pollution, flow modification, destruction or degradation of habitat, and invasion of exotic species result in population declines and range reduction of freshwater biodiversity worldwide (Dudgeon *et al*., 2005). In addition, climate change, increasing levels of water scarcity and development goals such as increasing access to clean drinking water and sanitation are all going to have major impacts upon freshwater systems in the future (IUCN, 2008). Conservation efforts for freshwater biodiversity are constrained by the fact that most of the species in diverse communities are rare (Sheldon, 1988) and thus their natural histories tend to be poorly known. Globally, awareness of the need to conserve freshwater biodiversity seems limited. Between 1997 and 2001, only 7% of papers in the leading journal in the field of Conservation Biology were concerned with freshwater species or habitats (Abell, 2002).

Essential ecosystem services, such as fishes for consumption, water for drinking and food production as well as transportation and cultural purposes, are mostly contributed by freshwater ecosystems (Balian *et al*., 2008). Biodiversity of freshwater is declining at a faster rate than that of terrestrial ecosystem, and therefore the freshwater systems are also the most challenged ecosystem in the world (Sala *et al*., 2000; Covich *et al*., 2004; Dudgeon *et al*., 2005). Protection of one or a few water bodies cannot serve the purpose of conservation of all freshwater biodiversity within a region.

Freshwater biodiversity provides a broad variety of valuable goods and services for human societies. Some are irreplaceable. Conservation strategies protecting all elements of freshwater biodiversity would guarantee that water use for humans is sustainable while, in contrast, the magnitude of the threat to and loss of biodiversity would be an indicator of the extent to which current practices are unsustainable. A mixture of strategies will be essential to preserve freshwater biodiversity in the long term. It must include reserves that protect key, biodiversity-rich water-bodies (especially those with important species radiations) and their catchments. In parallel, scientists must more effectively communicate the importance and value of freshwater biodiversity to stakeholders and policy makers, so as to make certain that all available information on freshwater biodiversity is applied effectively to ensure its conservation.

Way forward for freshwater taxonomy in India

Inventories of freshwater biodiversity are incomplete in many parts of the world, especially in the tropics, and rates of species loss may be higher than the currently estimated. An immediate, coordinated effort to assess global freshwater biodiversity, including major hotspots is an imperative necessaity . This exercise should take place in parallel with the ongoing development of strategies for the conservation and management of freshwater biodiversity.

An inference emerged out of this documentation work by ZSI is that taxonomic research and identification of species based on increased systematic sampling efforts are needed to address the existing geographical and taxonomical knowledge gaps in the current understanding of knowledge on the faunal biodiversity of freshwater ecosystems in India. In terms of diversity-richness and endemism of species, considerable chunk of ecosystem areas including freshwater systems in the country still remains little or under-explored, and the situation is especially critical for the least-known groups of invertebrates. More systematic exploration surveys are imperative, which will require additional, young-generation taxonomic experts and increased financial means.

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Chapter 2

PROTOZOA (RHIZOPODA)

BINDU. L[1] AND JASMINE, P[2]

ABSTRACT

Testate amoebae are polyphyletic group of protozoans. These are unicellular testate forms that occur widely in a variety of freshwater habitats and also in marginally brackish environments. These amoebae also inhabit in the soil, moist places and also in association with mosses. According to the present estimate 1600 species of freeliving protozoa have been recorded from India including the estuarine species. Of these 185 species are rhizopods and the rest other groups. The present paper is an inventory analysis of freeliving rhizopods from wetlands of India has including some case studies of the present authors.

Keywords: Protozoa, Testate Amoeba, Freshwater

INTRODUCTION

Despite the important role in the food chain of wetland ecosystems, studies on the freeliving protozoan fauna from various wetlands in India is very meager. Importance of protozoa as bioindicators for pollution and environmental biomonitoring has been recognized since long particularly in water purification plants and activated sludge processes (Kelkwitz and Marson, 1908). Literature reveals several scattered reports including the ciliates reported recently by the present author from wetlands of Kolkata megacity. But the occurrence and distribution of free-living protozoa in different wetlands of India have not so far been fully surveyed and evaluated. Testate amoebae are a polyphyletic group of protozoans. These are unicellular testate forms occur widely in a variety of freshwater habitats and also in marginally brackish environments (Patterson and Kumar, 2002). These amoebae also inhabit in the soil, moist places and in association with mosses.

According to the present estimate 1600 species of freeliving protozoa have been recorded from India including the estuarine species. Of these 185 species are rhizopods. The present paper deals with an inventory analysis of freeliving rhizopods from wetlands of India has been made including some case studies of the present authors.

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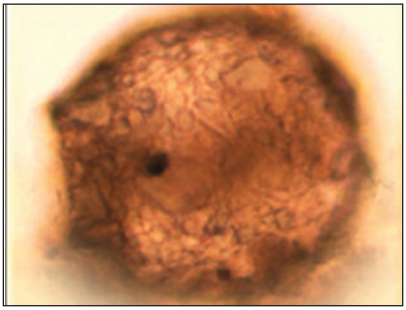
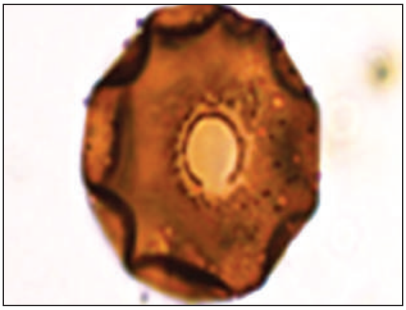
Some Rhizopods of India

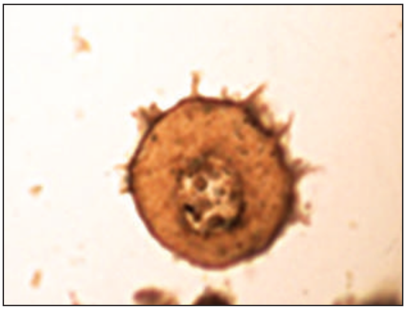
Cryptodifflugia oviformis



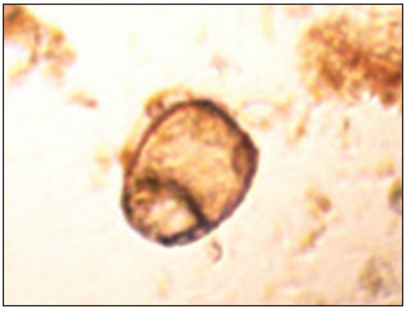
Difflugia binucleata



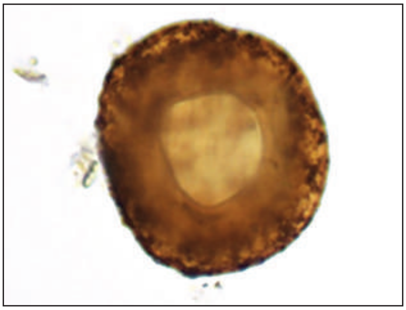
Arcella conica



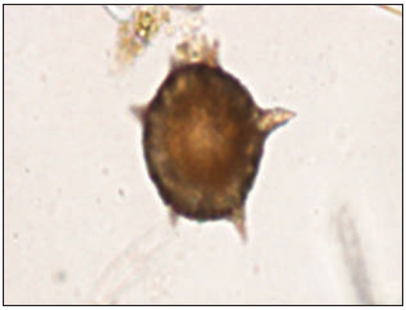
Centropyxis aculeate



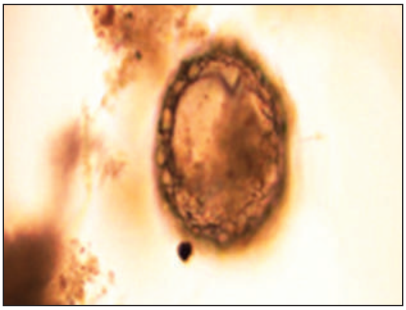
Centropyxis aerophila



Cyclopyxis arcelloides



Difflugia corona



Difflugia geosphaeria

Review of literature

Several investigators have recorded the freeliving protozoa from ponds and lakes in India since 1840s when Cantor (1842) recorded the occurrence of six species of freshwater protozoa from Kolkata while Mahajan and Nair (1965), Mahajan *et al*. (1981), Das *et al*. (1993), Das *et al.* (1995), Mukherjee and Das (2000), Bindu (2010), Ranju *et al*.(2013), Lekshmi *et al*. (2014) reported an appreciable number of rhizopods from freshwater and brackishwater wetland ecosystems across India. Nair *et al*.(1967, 1971) also reported 12 species of rhizopods and 20 species of heliozoans respectively from Calcutta and its environs. Das *et al*. (1993-2000) on freeliving protozoa of West Bengal and Mahajan (1965, 1981) on freeliving protozoa of Rajasthan. Mahajan (1971) had reported some freeliving protozoa from Bharatpur bird sanctuary. Recently Choudhury and his co-workers (1989) have contributed on soil inhabiting rhizopods of West Bengal. Mukherjee (1990) reported a new record of *Pseudochlamys patella,* a rhizopod from India. Mahajan and Nair (1965), Mahajan *et al*. (1981), Das *et al*. (1993), Das *et al*. (1995), Mukherjee and Das (2000), Bindu (2010-2016) reported an appreciable number of species from various fresh water and brackish water wetland ecosystems of India. Das and his collaborators published several species of free-living and symbiotic protozoa from various states in different fauna volumes. Taxonomic studies on Indian freshwater rhizopoda were initiated by Naidu (1966) followed by Mahajan (1971), Nair *et al*. (1971) and Mishra *et al*. (1977). In addition certain contributions under the state fauna series (Das *et al*., 1993, 1995, 2000) dealt with limited freshwater collections. Further Sharma and Sharma (2008) Bindu (2010) and Bindu and Das (2010) documented some more species of rhizopods from freshwater environs. Sharma and Sharma (2011) reported 21 species of testate amoebae from Deepor Beel (a Ramsar site from Assam) and Shaikh *et al*. (2012) reported some free-living protozoa from Salim Ali lake, Aurangabad. Kamble (2012) and Farooqui *et al*. (2012) also reported some freshwater species from India.

Several field and experimental studies have been carried out in this regard and results obtained there from support that protozoa may be conveniently used for environmental biomonitoring , particularly for ecological monitoring of water quality (Liebmann, 1962; Bick, 1973; Curds, 1973; Ricci, 1995).

Inspite of the above mentioned importance of these free-living protozoa, the occurrence and distribution of these organisms in different wetlands of India have not so far been seriously analyzed and evaluated and in the present communication an inventory analysis of freeliving rhizopods from wetlands of India has been made including some case studies of the present authors. According to the present estimate 1600 species of freeliving protozoa have been recorded from India including the estuarine and moss dwelling forms. Of which 185 species are rhizopods and the rest ciliates and other groups

Methodology

Freshwater samples along with some algae, water weeds, bottom ooze and flocculent matter arising out of washing of water weeds and aquatic plants were collected and kept in wide mouthed sampling jars made up of glass. These jars were then brought to the laboratory and kept for few days keeping their lids open to enable considerable increase in protozoa population. The samples were then thoroughly washed, examined under the light microscope from time to time, for protozoa.

For preparing permanent slides of freshwater testacid rhizopods empty tests were isolated from the bottom ooze of the samples. Testacids were also collected by squeezing different parts of the aquatic vegetation including their roots and submerged portion of leaves and also by culturing moss samples which were processed with non-flooded petri dish method as described by Foissner (1992). The testacids were placed in micro slides, air dried after two or three washings in absolute alcohol and then mounted in DPX. The species were identified following the classification of Adl *et al*., 2005.

Diversity

The present communication includes an inventory of freeliving rhizopods from wetlands of India has been made including the work of the present authors in Kolkata wetlands, freshwater part of Vembanad lake (Ranju *et al*., 2013) and Vellayani lake (Lekshmi *et al*., 2014); Sasthamkotta lake, at three from Kerala (unpublished work) and different freshwater bodies from Maharashra and Uttar Pradesh. The first report of freeliving protozoa from India dates back to 1842 when Cantor referred about the occurrence of six species of freshwater protozoa from West Bengal. Subsequently Wallich (1864) recorded four species of *Difflugia* from Gangetic Sundarbans of Lower Bengal. Ghosh (1918-1921) published a series of papers reporting 29 species of freeliving ciliates and one species of testacid rhizopod from Kolkata and its nearby localities.

A detailed study of the freeliving protozoa of wetlands of West Bengal was made by Das *et al.* (1993). A total of 248 species of freeliving protozoans under 124 genera belonging to 2 phyla, 2 subphyla, 7classes, 29 orders and 76 families were recorded from West Bengal. From the distribution list it is evident that number of freeliving protozoan species collected from Kolkata is considerably large compared to any other district of West Bengal. This may be due to the intensive surveys in Kolkata when compared to the other districts. As per the present record the greatest number of rhizopods are recorded from Himachal Pradesh compared to other states of India. 20 species of rhizopods recorded from Sasthamkotta lake, Kerala (unpublished work). The distribution pattern of rhizopods in different states of India is as shown below.

Table 1. Distribution of rhizopods in different states of India

Name of state	Number of species recorded
Andhra Pradesh	33
Arunachal Pradesh	33
Assam	21
Himachal Pradesh	72
Kerala	25+20*
Manipur	26

Name of state	Number of species recorded
Meghalaya	12
Maharashtra	25
Mizoram	26
Orissa	3
Nagaland	22
Rajasthan	6
Sikkim	49
Tamil Nadu	18
West Bengal	60
Tripura	25
Uttarakhand	24
Uttar Pradesh	41

*20 species recorded from Sasthmkotta lake (unpublished work)

Table-2. Diversity across family and species in the Indian subregion

Family	Species
Arcellidae	20
Centropyxidae	22
Cryptodifflugiidae	2
Hyalospheniidae	16
Microcoryciidae	2
Netzeliidae	2
Phryganellidae	2
Plagiopyxidae	4
Trigonopyxidae	8
Difflugiidae	49
Lesquereusiidae	3
Heleoperidae	7
Euglyphidae	28
Assulinidae	2
Trinematidae	12
Cyphoderidae	3
Paulinellidae	3
Total	**185**

Distribution: Protozoa are cosmopolitan in distribution; are found in each and every habitat of all terrestrial and aquatic ecosystems from sun splashed mountain peaks to the dark ocean bed and from tropical forests of the equator to the polar snows. They lead life as free-living, commensals, parasitic and symbiotic.

As such they are capable of exploiting diverse niches and reported from unusual environments such as thermal spring effluent, mountain snow banks, carapace of micro crustacea and even in eye of insects. In India the highest no. of species is recorded from Himachal Pradesh followed by West Bengal The distribution of rhizopods in different states of India is shown in Table 1.

Endemicity: Endemicity of free living protozoa in India is nearly 7% while that of parasitic protozoa is around 40%. Around 90 species of free living protozoa and 550 species of parasitic protozoa are endemic in India. From the data available none of the protozoan species has been demarcated as threatened or endangered.

Threats and conservation strategy

None of the species of protozoa in India can be demarcated as keystone species in marine, freshwater or terrestrial ecosystem. Protozoans are not thoroughly surveyed in India. Therefore, it would not be proper to indicate any protozoan species as rare since it is well known that protozoans are capable of rapid multiplication by both sexual and asexual reproduction. Threats to these organisms, more particularly freeliving protozoa appear to be remote unless there is indiscriminate destruction and distortion of habitats.

Future studies

Protozoa are cosmopolitan in distribution. It has been discussed earlier that free living protozoa are available in all habitats of aquatic and terrestrial habitats and this group is least explored in this country except in West Bengal, Rajasthan, Orissa and some north-eastern states. In view of above, some rapid surveys covering all underexplored states of India need to be conducted for the collection of all the major groups of protozoa from different freshwater environs. Subsequently detailed taxonomic study and inventorisation of these organisms are to be made to get a first hand estimate of the protozoan diversity of the country. Further, expertise on protozoa is to be developed in the country for the identification of the group.

Significance

Soil inhabiting protozoa (mainly rhizopods and ciliates) help in humification and mineralization of leaf litter on the forest floor in association with other microorganisms. They also contribute much in soil ecosystems mainly as primary consumers of microarthropods and soil nematodes which have significant role to determine soil fertility. Protozoa may be conveniently used for environmental biomonitoring particularly in evaluating water quality. Several experimental studies reveal that protozoans actively contribute to the regulation of entire complex of purification plants by regulating bacterial population and controlling BOD level, by controlling pathogenic and faecal bacteria and by releasing mucous substance to facilitate flake formation and successive sedimentation. Some species can be used as indicator species.

Conclusion

Although workers have recorded the above mentioned freeliving protozoa from different Indian wetlands, purposeful and thorough surveys were not so far done inspite of the importance of these organisms as bioindicators for pollution and environmental biomonitoring of water bodies. It is, therefore, quite probable that number of species occurring in Indian wetlands are much more than what is dealt in this paper.

Expertise in India

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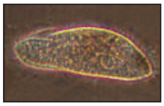
Chapter 3



PROTOZOA: CILIOPHORA (CILIATES)

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ABSTRACT

Ciliates are one of the important members in the eukaryotic microbial community. In order to better understand the distribution pattern of freshwater ciliates in India, a comprehensive literature review was done and compiled the current status of ciliates diversity in India. Altogether 106 species of ciliates belonging to 58 genera and 36 families are described from the fresh water ecosystems of India so far. Majority of the species reported from India belongs to family Oxytrichidae. It is concluded that extensive research should be made to assess the seamless diversity of this less studied microbes.

Key words: Protozoa, Ciliates, Freshwater

INTRODUCTION

Protozoans (ciliates and flagellates) are the main components of the "microbial loop", which is a distinct and important element of the trophic food web in aquatic ecosystems (Azam *et al.,* 1983). Free living ciliates are an important intermediate link between primary producers and higher trophic levels in every estuarine and marine ecosystem (Zingell *et al.*, 2007). They prey on autotrophic and heterotrophic pico and nano plankton and are preyed upon by larger zooplankton and contribute to the remineralization and cycling of nutrients (Blomqvist *et al.*, 2001; Ventela *et al.,* 2002).

The role of ciliates as an important component of the microbial loop in freshwaters is widely recognized (Wiackowsi *et al.*, 2001). Ciliates are a significant trophic link in energy transfer from heterotrophic (bacteria) and autotrophic picoplankton to the higher consumers (Zingell *et al.*, 2007) and play a significant role in energy transfer and nutrient remineralization in aquatic environments (Cleven & Weisse, 2001). Ciliates are an essential food source for rotifers, cladocerans and copepods (Jack and Gilbert, 1997) and some fish larvae, for example the guppy (*Poecilia reticulata*) larvae, can use ciliates as food in their early life stages (Lair *et al.*, 1994). The importance of the microbial loop is greater in oligotrophic than eutrophic lakes, although, Weisse *et al.*, (1998) demonstrated that almost 50% of carbon passed through the microbial loop in ameso-eutrophic lake.

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Many protozoan species can be considered as a highly valuable bioindicators in water quality analysis due to rapid growth, high turnover rates and short generation times which allow protozoan communities to respond quickly to changing environmental conditions (Berger *et al.*, 1997). Ciliates are important for the water industry because they can accelerate the process of water clarification by consuming bacteria, and their identification and quantification permit to rapidly assess the water quality (Curds & Cockburn, 1970; Al-Shahwani & Horan, 1991; Curds, 1992; Silva & Silva-Neto, 2001).

Ciliates are also used as bio indicators in rivers, lakes and waste waters. Foissner & Berger (1996) listed 300 ciliate species which can be used as bio indicators. Occurrence of the ciliate, *Metopus* sp. in any water body indicates the presence of hydrogen sulphide (Bick, 1972). Presence of this species and its associated ciliates belonging to the genera *Caenomorpha, Epalxella*, *Pelodinium* and *Sprodinium* in putrefying sludge are the indicators of the self purification process which has been stopped due to lack of oxygen and presence of high concentration of H_2S. Many species of ciliated protozoa are used as indicators for ecological monitoring of water quality and they can also be used in ecological studies of aquatic habitats in which mosquitos and other vectors and intermediate hosts of disease organisms are breeding (Bick, 1972).

The number of papers on freshwater ciliates has increased recently (Pace, 1982; Macek *et al.*, 1996; Weisse & Müller, 1998; Kalinowska, 2000, 2004; Mieczan, 2007). In both freshwater and marine ecosystems significant vertical gradients of protozoan diversity exist, these apparently being influenced by the distribution of their prey, and physical and chemical variables (Ventelä *et al.*, 1998, Thouvenot *et al.*, 1999, Jacquet *et al.*, 2005). Several investigators suggest that ciliate abundance and biomass reach maximum values in the epi- and metalimnion, with the lowest in the hypolimnion. In the epilimnion the oligotrich *Strombidium viride* frequently occurs, whereas in the meta- and hypolimnion the oligotrichs are gradually replaced by scuticociliates (Beaver & Crisman, 1990; Zingel, 2005). Zingel & Ott (2000) observed a positive significant correlation between ciliate numbers and chlorophyll *a* and bacterial densities in strongly stratified temperate lakes.

The importance of ciliate communities to the overall productivity of freshwater ecosystems has been well documented (Sorockin, 1972; Schonborn, 1977, 1982; Baldock *et al.*, 1983; Madoni, 1987a). Increasing attention is now being focused on planktonic and benthic microfauna of lakes (Madoni, 1989, 1990;Laybourn-Parry *et al.*, 1990a, b), reservoirs (Barbieri & Godinho Orlandi, 1989; Simek *et al.*, 1999), and rivers (Baldock & Sleigh, 1988; Blatterer & Foissner, 1990; Grolière *et al.*, 1990); however, studies on distribution and ecology of ciliates living in ponds covered by floating macrophytes are still few (Legner, 1964; Madoni & Viaroli, 1985).

Historical Resume

Ehrenberg (1838) and Dujardin (1841) initiated the work on ciliates. After them an exceptional contribution was made by Kent (1882) in his book named “Manual of Infusoria”.

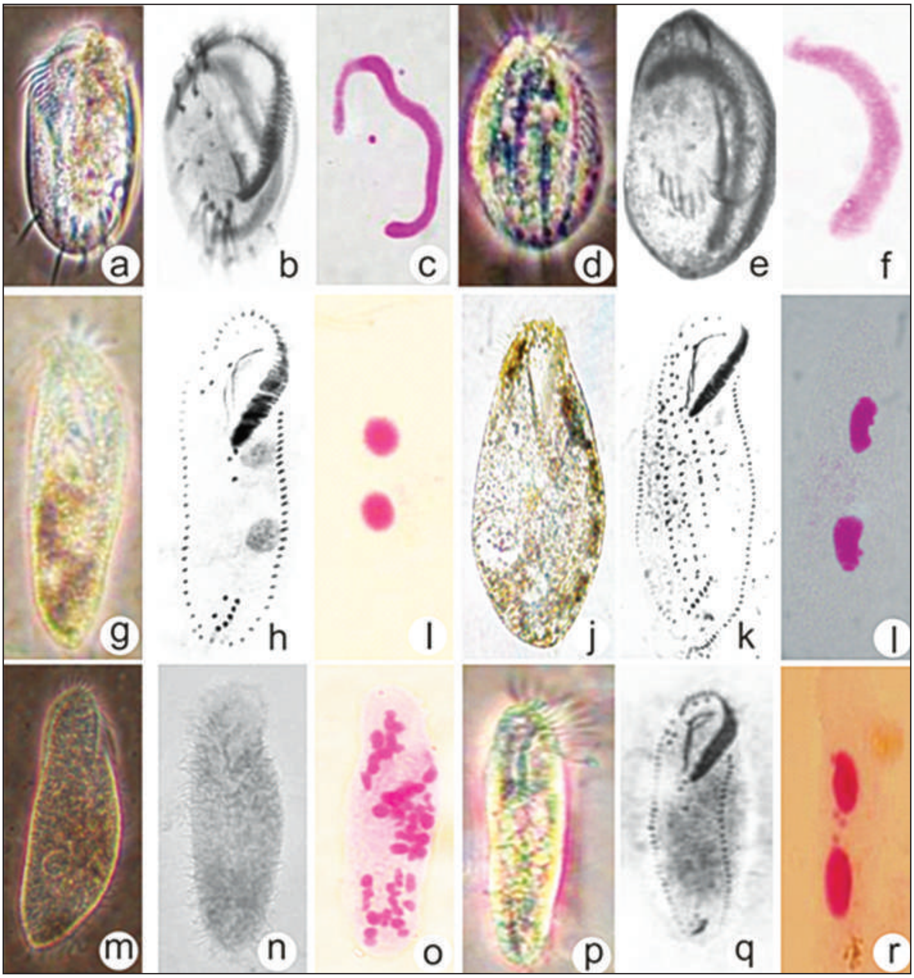
Hundreds of species have since been discovered and described by experts from different parts of the world. Foissner (1977-2013) has made significant studies on the taxonomy and ecobiology of ciliates from different parts of the world. The pelagic ciliate communities from 58 north German lakes were described and compared at species level by Pfitser *et al.*, (2002), about 140 ciliate species were identified and quantified in all investigated lakes.

Freshwater protozoa in Thailand were investigated in different provinces of northern, eastern, northeastern and southern parts of Thailand from 1982 till 1999. The total of 166 genera and 259 species found were identified as 36 genera and 72 species of Phytomastigophora, 9 genera and 11 species of Zoomastigophora, 23 genera and 38 species of Sarcodina, 2 genera and 2 species of Labyrinthomorpha and 95 genera and 134 species of Ciliophora (Charubun & Charubun, 2000). Ciliate diversity was investigated in situ in freshwater ecosystems of Antarctic (Victoria Land, 751S), and the High Arctic (Svalbard, 791N). In total, 334 speciesfrom 117 genera were identified in both Polar Regions (Petz *et al.*, 1995). The most detailed studies of Turkish inland waters were performed by Şenler *et al.*, (1998), Şenler and Yıldız, (1998, 1999, 2004) who worked especially on rivers, small ponds and sewage treatment plants and by Çapar, (1997, 2005, 2007a, b) on free living pond and wetland ciliates.

India, with 2.4% of the world's area, has over 8% of the world's total biodiversity, making it one of the 12 mega diversity countries in the world. Despite this richness, the data concerning ciliate diversity from India is rather scarce. First report of protozoa from India is made from freshwater by Grant (1842) which is an unpublished work Cantor (1842). Since then, considerable work on protozoa from this environs has been done by Ghosh, (1818-1929), Nair and his co-workers (1960-1974) and Das, (1971) from West Bengal, Bhatia and Mallick, (1930) from Kashmir and Mahajan, (1969, 1971, 1977) from Rajasthan. Earlier works on freshwater inhabiting ciliates are available in the Ciliophora volume in the Fauna of British India series, written by Bhatia, (1936).

The record of Ciliophora known from India, Myanmar and Sri Lanka included 274 species belonging to101genera (Bhatia, 1936).Ghosh, (1918-1929) published a series of papers reporting 29 species of free-living ciliates and one species of testacid rhizopod from Kolkata and its nearby localities. Mahajan and Nair (1965) published the occurrence of 19 species of free-living ciliates from Kolkata and its vicinity. Mukherjee and Das (2000) recorded 5 species of ciliates from Renuka wetland which is a Ramsar site in Himachal Pradesh. Shaikh *et al.*, (2012) recorded 7 species of protozoan ciliates from Salim AliLake, Aurangabad, India. 61 species of ciliates under 37 genera belonging to 31 families and 12 orders were reported by Bindu L, (2010).

In West Bengal, in all 152 species of ciliates, belonging to 2 classes, 16 orders, 52 families and 75 genera have been recorded by several investigators since 1840s (Das *et al.*, 1993; Piyali and Das, 1997). Ghosh (1918-29) in a series of papers recorded 29 species of ciliates from Kolkata, while Mahajan and Nair (1965), Das (1971), Das *et al.*, (1993) and Piyali and Das (1997) reported a considerable number of species from different freshwater ecosystems of Kolkata. Although Kolkata metropolis abounds with innumerable freshwater wetlands and even though several water bodies were surveyed from different parts of this mega city, the diversity and distribution of ciliates suggests that purposeful wetland specific surveys have not been conducted year round. Simmons (1889, 1891) recorded ciliates belonging to 12 genera from Calcutta, without giving any specific identification of the forms. Nair (1960) reported one new record of a ciliate from Sibpur (Howrah District). Mahajan & Nair (1971) reported 19 species of freshwater ciliates from Kolkata and its surrounding areas. Bindu L (2010) reported 23 species of free-living freshwater ciliates from Kolkata wetlands including Rabindra Sarovar, a National Lake, and an important freshwater wetland in Kolkata.



Photomicrographs of Spirotrich ciliates, a-c *Euplotes aediculatus*, d-f *Aspidisca* sp., g-i *Aponotohymena* sp., j-l *Paraurostyla coronate*, m-o *Pseudourostyla cristata*, p-r *Oxytricha granulifera*, showing live cell (a, d, g, h, m & p), after protargol impregnation (b, e, h, k, n & q) and after Feulgen staining (c, f, i, l, o & r).

The University of Delhi have been involved in the morphological and molecular taxonomy of ciliates from freshwater bodies namely, Okhla Bird Sanctuary, Sanjay Lake, Pond at Rajghat in Delhi region. Sripoorna *et al.,* 2015 studied the diversity of freshwater Spirotrich ciliate fauna from Okhla Bird Sanctuary, Delhi. They reported total of 12 species belonging to 10 different genera. From the Delhi region few Spirotrich freshwater ciliate species have been characterized and reported till date, namely, *Stylonychia ammermanni* (Gupta, R., *et al.,* 2001), *Pleurotricha curdsi* (Gupta, R., *et al.,* 2003), *Rubrioxytricha indica* (Naqvi, I., *et al.*, 2006), *Architricha indica* nov. gen., *Histriculus histrio* (Gupta *et al.*, 2006), *Coniculostomum bimarginata* (Kamra, K., 1994), *Notohymena limus,* (Naqvi, I., 2016), *Oxytricha granulifera, Aponotohymena* sp., *Paraurostyla coronata, Gastrostyla* sp., *Tetmemena* sp., *Laurentiella* sp., *Euplotes aediculatus, Aspidisca, Pseudourostyla cristata* and *Urostyla* sp. (Somasundaram *et al.*, 2015).

At molecular level, total 8 nucleotide sequences of the freshwater ciliates have been sequenced and submitted in Genbank database. 18S rRNA gene of *Tetmemena* sp. (Acc. No. KP336401), *Aponotohymena* sp. (Acc no. KP336402), *Gastrostyla* sp. (Acc. No. KT780432), *Pseudourostyla cristata* (Acc. No. KT731104), *Oxytricha granulifera* (Acc. No. KU715983), *Paraurostyla coronata* (Acc. No. KU715982), ITS (internal transcribed spacer) (Acc. No. KT731103) and histone (H_4) gene (Acc. No. KU761846) of *Tetmemena* sp. have been sequenced.

A new species of free living ciliated protozoa, *Oxytricha susheelum* was recorded from fresh water in Aurangabad by Deshmukh *et al.*, 2012. Ahamed & Sharma (2009) reported a total of seventeen species of ciliates from different pond localities of Lucknow city. A study on some free living protozoan from Salim Ali lake Aurangabad was done by Shaikh *et al.*, (2012), in which 7 species of ciliates have been recorded.

Methodology

Collection of ciliates is a two step process; collection from field site and transporting them to laboratory, examination and fixation. 2 litres of freshwater sample is filtered through 20 micron plankton net and the sample is collected in a plastic bottle. Sample should be collected from the bottom/surface/banks/submerged slops of water body. Samples should be fixed immediately to avoid loss of cell. The sample can be fixed in Lugol's iodine. After Lugol's fixation samples can be stored in cool dark place. Ciliate abundance can be obtained by settling the fixed samples in settling chamber and examining them under an inverted microscope (Hasle, 1978). Lugols is a relatively harmless and versatile fixation method, which is recommended for routine sampling of ciliates. Iodine not only enhances the sinking of cells but also stain them dark brown in colour. Lugol's fixed material can be processed in several ways: SEM (Montagnes & Taylor, 1994), DAPI, Protargol staining (Montagnes & Lynn 1993). Staining is an important process in ciliate study. Inverted microscopes are commonly used to quantify and identify ciliates and other microplankton in plankton samples. There are two types of staining; temporary and permanent staining. In temporary staining we can use Acetocarmine and 1% Methyl green in acetic acid as stain. Permanent staining method include three steps; adherence, fixation and staining. This will be done according to the standardised protocol (Foissner, 2007). Florescent dyes (DAPI) can also be used as a diagnostic feature in ciliate study. SEM photograph of ciliates will be taken for further identification of species.

Diversity

It is estimated that 85% of the ciliate diversity is still to be described. A total of 8,000 ciliate morphospecies are described of which about 200 are fossil tintinnids and 2,600 are commensals and about 5,200 are true free-living species Corliss, (2000a). About 400 new species have been described till date by Song and Wang 1999; Foissner *et al.,* 2002; Foissner 2006. So in total there are about 5,600 described free-living ciliate species. Combining classical and modern methods, a few researchers have discovered hundreds of new ciliate morphospecies during the past 15 years, suggesting that most ciliate diversity is still unknown (Foissner 1993a, b; Petz *et al.*, 1995; Song and Wang, 1999; Foissner and Xu, 2006). The ciliates species which are distributed in the fresh water ecosystems of India is represented in the Table.1. A total of 106 species of ciliates belonging to 58 genera and 36 families are described from the fresh water ecosystems of India.

Table 1. List of ciliate species described from the fresh water ecosystems of India

Phylum CILIOPHORA				
Class	**Family**	**Genus**	**Species**	**Name of the species**
Armophorea	Metopidae	1	4	*Metopus es* Muller 1776 *Metopus minor* var. *Minor* Kahl 1927 *Metopus nasutus* Cunha 1915 *Metopus spiralis* Smith 1897
Colpodea	Colepidae	1	4	*Colpoda cucullus* Müller, 1786 *Colpoda aspera* Kahl *Colpoda maupasi* Enriques, 1908 *Colpoda steinii* Maupas 1883
	Cryptolophosididae	1	1	*Opisthostomatella bengalensis* Ghosh 1928
Heterotrichea	Blepahrismidae	1	1	*Blepharisma intermedium* Bhandary 1962
	Caenomorphidae	1	1	*Caenomorpha medusula* Perty 1852
	Stentoridae	1	1	*Stentor roeseli* Ehrenberg 1835
Karyolectiae	Loxodidae	1	3	*Loxodes magnus* Stokes 1887 *Loxodess triatus*(Engelmann 1862) *Loxodes vorax* Stokes 1885
Litostomatea	Tracheliidae	3	5	*Dileptus monilatus* (Stokes, 1886) Kahl, 1931 *Dileptus gigas* (Claparède & Lachmann, 1859) *Pseudomonili caryonanser*(Müller, 1773) Vďačný& Foissner, 2012 *Trachelius gutta* Cohn 1866 *Trachelius ovum* (Ehrenberg, 1831) Ehrenberg, 1838

Phylum CILIOPHORA				
Class	**Family**	**Genus**	**Species**	**Name of the species**
	Amphiletidae	4	10	*Litonotus fasciola* (Ehrenberg) *Litonotus infusionus* Ghosh, 1920 *Litonotus procera* Penard 1922 *Litonotus obtusa* *Acineria incurvata* Dujardin 1841 *Hemiophrys procera* Penard 1922 *Hemiophrys bivacuolata* Kahl 1931 *Loxophyllum nimeccense* (Stein, 1859) *Loxophyllum levigatum* Sauerbrey, 1928 *Loxophyllum undulatum* Sauerbrey, 1928
	Mesodiniidae	1	1	*Mesodinium pulex* (Claparède & Lachmann, 1859) Stein, 1867
	Actinobolinidae	1	1	*Actinobolina radians*(Stein, 1867) Strand, 1928
	Enchylidae	3	6	*Lacrymaria olor*Müller, 1776 *Lacrymaria lagenula* Claparede &Lachmann, 1858 *Lacrymaria vermicularis* (Müller, 1786) Bory, 1824 *Trachelophyllum vastitum* Stokes 1884 *Phialina minima* (Kahl, 1927) Foissner, Agatha & Berger, 2002 *Phialina pupula* Müller, 1773
	Spathidiidae	2	4	*Bryophyllum spathidiodes* Gelei, 1933 *Spathidium moniliforme* Bhatia, 1920 *Spathidium muscicola* Kahl 1930 Spathidiumspathula
Nassophorea	Nasulidae	3	3	*Nassula ornata* Ehrenberg 1833 *Orthodonella banerjeei* Ghosh, 1921 *Pseudomicrothoraxagilis* Mermod 1914
	Orthodoneliidae	1	1	*Chilodontopsis bengalensis* (Ghosh, 1921)
	Leptopharyngidae	2	3	*Leptopharynx chlorophagus* Das, 1971 *Leptopharynx torpens* (Kahl, 1931) *Pseudomicrothorax dubius* (Maupas, 1883) Penard, 1922
	Microthoracidae	2	4	*Drepanomonas dentate* Fressenius 1858 *Drepanomonas hooghlyensis* Nair &Das 1974 *Drepanomonas revolute* Penard, 1922 *Opisthostomum bengalensis* Ghosh 1928

Phylum CILIOPHORA				
Class	**Family**	**Genus**	**Species**	**Name of the species**
Oligohymenophora	Epistylidae	1	1	*Epistlylis niagaraKellicott* 1883
	Glaucomidae	1	1	*Glaucoma pyriformis* Ehrenberg 1838
	Neobursaridiidae	1	1	*Neobursaridium gigas* Balech 1941
	Paramecidae	1	2	*Paramecium bursaria* (Ehrenberg, 1831) Ehrenberg, 1836 *Paramecium caudatum* Ehrenberg, 1833
	Vaginicoloidae	3	3	*Platycola decumbens* (Ehrenberg, 1830) Kent, 1882 *Pyxicola affinis* Kent, 1881 *Vaginicola crystallina* Ehrenberg, 1830
	Pleuronematidae	1	1	*Pleuronema crassum*Dujardin, 1841
Phyllopharyngea	Chilodonellidae	1	3	*Chilodonella cucullus* (Muller, 1883) *Chilodonella uncinata* (Ehrenberg, 1838) *Chilodonella spiralidentis* (Bhatia & Mallik, 1930)
	Acinetidae	1	1	*Tokophrya lemnarum* Stein 1932
Plagiopylea	Plagiopylidae	1	1	*Plagiopyla nasuta* Stein, 1860
Prostomatea	Colepidae	1	5	*Coleps octospinus* Nolan, 1925 *Colep selongatus* (Ehrenberg, 1830) Diesing, 1866 *Coleps inermis* Perty 1852 *Coleps devdaniensis* Mahajan, 1971 *Coleps hirtus* (Muller 1786)
	Prorodontidae	1	4	*Prorodon edentates* Claparede &Lachmann 1858 *Prorodon discolor* (Ehrenberg, 1835) *Prorodon teres* Ehrenberg, 1838 *Prorodon stewarti* Ghosh, 1928
	Holophryidae	1	3	*Holophrya bengalensis* Ghosh, 1919 *Holophrya annandalei* Ghosh, 1919 *Holophrya simplex* Schewiakoff, 1889
	Urotrichidae	1	1	*Urotricha globosa* Schewiakoff, 1889
	Leptopharyngidae	1	1	*Pseudoprorodon lieberkuhni* Butschli, 1889
Spirotrichea	Euplotidae	1	2	*Euplotes patella* (0. F. Muller) Ehrenberg *Euplotes aediculatus* Pierson, 1943
	Aspidiscidae	1	1	*Aspidisca* sp. Ehrenberg, 1830

Phylum CILIOPHORA				
Class	**Family**	**Genus**	**Species**	**Name of the species**
	Halteriidae	1	1	*Halteriagrandinella* (Muller, 1773)
	Oxytrichidae	8	14	*Oxytricha susheelum* Deshmukh *et al.*, 2012 *Stylonchia mytilus* Müller, 1773 *Oxytricha granulifera* Foissner and Adam, 1983 *Aponotohymena* sp. Foissner, 2016 *Paraurostyla coronata* Arora *et al.*, 1999 *Gastrostyla* sp. Engelmann, 1862 *Tetmemena* sp. Eigner, 1999 *Laurentiella* sp. Dragesco and Njiné, 1971 *Stylonychia ammermanni*, Gupta *et al.*, 2001 *Pleurotricha curdsi* Shi *et al.*, 2002 *Rubrioxytricha indica* Naqvi *et al.*, 2006 *Architricha indica* Gupta *et al.*, 2006 *Histriculus histrio* Müller, 1773 *Coniculostomum bimarginata* Kamra *et al.*, 1994 *Notohymena limus* Naqvi *et al.*, 2016
	Pseudourostylidae	1	1	*Pseudourostyla cristata* Jerka-Dziadosz, 1964
	Urostylidae	1	1	*Urostyla* sp. Ehrenberg, 1830
	Total	58	106	

Classification

The phylum Ciliophora is composed of two sub phylum: Postciliodesmatophora and Intramacronucleata, with, 11 classes and 19 subclasses. Postciliodesmatophora consist of two classes; Karyorelictea and Heterotrichea. Intramacronucleata consists of 9 classes and 19 subclasses. The classes coming under Sub phylum Intramacronucleata are Spirotrichea, Armophorea, Litostomatea, Phyllopharyngea, Nassophorea, Colpodea, Prostomatea, Plagiopylea and Oligohymenophorea. Class Spirotrichea consists of 7 subclasses; Protocruziidia, Phacodiniidia, Hypotrichia, Oligotrichea, Choreotrichia, Stichotrichia, Licnophoria. Class Litostomatea consists of 2 sub classes; Haptoria and Trichostomatia. Class Phyllopharyngea has 4 sub classes; Crytophoria, Rhynchodia, Chonotrichia, Suctoria. Class Oligohymenophorea consists of 6 sub classes; Peniculia, Scuticociliata, Hymenostomatia, Apostomatia, Peritrichia and Astomatia.

The sub phylum Postciliodesmatophora represents 61 genera (+8 genus *incertae sedis*) belonging to 2 class, 4 order and 13 families. The sub phylum Intramacronucleata represents 1119 genera belonging to 9 class, 19 sub classes, 52 order and 264 families.

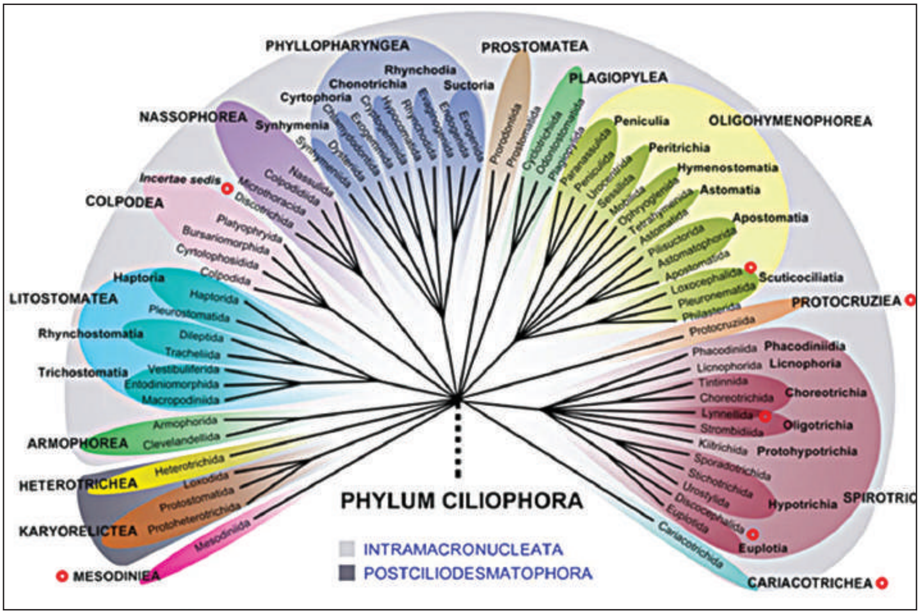


Fig : Systematic scheme for the phylum Ciliophora

Source: http://www.nature.com/articles/srep24874/figures/3

Distribution

The ciliophorans coming under the phylum Ciliophora are universally distributed in water bodies like freshwater ponds, streams and rivers and some species occur in wet soils and mosses. These free-living ciliates play an important role in the aquatic ecosystem and form an important component of the environment monitoring surveillance and these aquatic animalcules occupy an important position in the aquatic food chain. The role of ciliates as an important component of the microbial loop in freshwaters is widely recognized (Wiackowsi *et al.*, 2001).

Endemism

Ciliates are distributed globally in various habitats where they act as an important trophic link in variety of food webs (Adl, 2003). Ciliates exhibit lesser endemism and are considered ubiquitous and cosmopolitan in distribution. Some species show limited geographic distribution and low dispersal abilities. For example, the large tropical peniculine *Neobursaridium gigas*, a flagship tropical freshwater species, was described over 60 years ago in Africa and yet it has only been recorded from the Southern hemisphere (Foissner, 1999c).

Habitat

Many ciliates are associated with the surfaces of solid subjects, such as rocks, some species of algae, or some submerged substrates. Characteristic species, they are permanently attached forms are mainly peritrichs (eg. *Vorticella*,the colonial *Zoothamnium*, and the loricate *Cothurnia*). Folliculinid ciliates are brightly coloured ciliates, which build an ampulla shaped loricae. The suctorians are carnivorous and feed on the motile ciliates of the habitat. In microaerophilic environments such as the layers of decaying leaf litter and detritus layers, harbours the species *Loxodes*, and also large heterotrich ciliates belonging to the genera *Spirostomum* and *Blepharisma*. A true anaerobic fauna of ciliates also occurs in freshwater sediments, mainly represented by the genera *Metopus, Caenomorpha, Plagiopyla* and also the representatives of odontostomatids.

Dysterid ciliates feeding on cyanobacteria and filamentous bacteria same as that found in hypotrich ciliates such as *Euplotes, Aspidisca, Holosticha*, etc. Amphileptids ciliates are dominant carnivores and some of them are specialised to prey on the zooids of peritrich ciliates.The naked oligotrichs include Halteria and species of *Strombidium* among which *S. viride* contains Zoochlorellae. Hecky and Kling, (1981) found that in Lake Tanganyika the biomass of *S. Viride* equalled the phytoplankton biomass and they may play a substantial role as a primary producer. Among the fresh water pelagic ciliates, species of *Frontonia* and *Euplotes* are common, but which are not typically pelagic forms. Ciliates also show high diversity on feeding large food particles. Species of *Nassula* specialise on feeding filamentous Cyanobaceteria, whereas species of *Frontonia* and various prostomatids specialise on feeding larger food particles such as dinoflagellates and diatoms. The bacteriovorous ciliates are mainly the scuticociliates (*Cyclidium, Uronema*) and also some stalked but unattached peritrichs. The ciliate predators consists of prostomatids, such as *Didinium, Coleps, Acaryophyra,* and *Actinobolina and pleurostomatids,* such as *Paradileptus and Trachelius.*

Gap in Research

The vast majority of microbial eukaryotic organisms are undescribed and unknown in India. In the current scenario, the diversity of these small organisms are much less well understood than that of larger organisms. There is a fundamental need to document the taxonomic composition of fresh water ciliate diversity through systematic biodiversity surveys of representative fresh water habitats, since these microbial eukaryotic communities very much influence the health of the freshwater ecosystem. This will give a comprehensive data to generate diversity estimates of different fresh water habitat types and biogeographic maps for relatively common species of freshwater. This information is critical to manage and conserve the functional properties of freshwater ecosystems for the long term, particularly in areas that are vulnerable to human activities.

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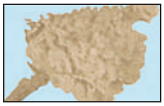
Chapter 4



PORIFERA (SPONGE)

M.M. SAXENA

ABSTRACT

Porifers, commonly called sponges, are sessile forms, found attached to some submerged substratum in water. Freshwater sponges belong to family Spongillidae of Class Demospongia and constitute an important component of an aquatic ecosystem. During different phases of their lifespan they exhibit a variety of living modes, viz., periphytonic, planktonic, neustonic, and benthic. Shape and microspination pattern of their siliceous spicules serve the most valuable taxonomic clues.

Out of a total 4562 sponge species, including both marine and freshwater ones, from the world, 486 species are recorded to harbor Indian waters. The freshwater species in the world are around 100 of which 31 belonging to 11 genera are recorded from India. Genera Corvospongilla and Radiospongilla are represented by greatest five species each, whereas genera Umbrotula, Dosilia and Metania are each represented by a single species.

Out of these total 31 species, 11 are recorded to be endemic to India. Distribution of different species reveals the sponge Eunapius carteri to be the most widely distributed form in India and elsewhere. On the contrary, Eunapius calcuttanus, E. geminus, Stratospongilla gravely, Corvospongilla bhavnagarensis, Pectinospongilla aurea, P. stellifera and P. subspinosa revealed very restricted distribution. Ecological notes are made on some sponge species including their inter-specific relations. Paper also points out the thrust areas of research relating to these lesser known invertebrate denizens of freshwater ecosystems.

Key words: Freshwater sponges, Porifera, Distribution, Ecology, Endemic species, India.

INTRODUCTION

Life in water is often more vivid than on land. Minute planktonic algae to large angiosperms as well as minute protozoans to mammoth mammals harbour bodies of freshwater. However, a larger variety of invertebrate forms, though not well known and appreciated, play a highly significant role in the ecology of aquatic ecosystems. They act as heterotrophs, themselves constitute food for many, help cycling of matter and flow of energy, and of course some play vectors or intermediate hosts of parasites. They inhabit almost all conceivable regions in water living as plankton, neuston, nekton, periphyton, and benthos (Saxena, 2008).

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Vast numbers of limnological investigations have been carried out in the country, but unfortunately most of these are deficient in proper taxonomic content of the biota. Very few studies project rightly identified flora and/or fauna; many do not extend beyond generic level while some quote erroneous species with no authentic record.

SPONGE FAUNA

Brief background

Out of a total 4562 sponge species, including both marine and freshwater ones, from the world, 486 species are recorded to harbor Indian waters (Thomas, 1998). However, a checklist published subsequently by Pattanayak (1999) showed 451 marine sponges from Indian waters. The freshwater species in the world are around 100 of which 31 belonging to 11 genera are recorded from India (Soota, 1991).

Since the pioneering work of Annandale (1907-1915) on the freshwater sponges of India, the subject remained almost ignored for about six decades. Following a revision of worldwide collection of freshwater sponges by Penny & Racek (1968) a check list was prepared by Khera & Chaturvedi (1976). Soota & Pattanayak (1982) dealt with the freshwater sponges from the unnamed collection of Zoological Survey of India reporting nine species belonging to six genera and extending the range of distribution of some species. Later, ecological studies of the forms in Rajasthan and Gujarat were initiated by Soota et al. (1983) and Soota & Saxena (1983), Soota (1991) reviewed the freshwater sponges of India in his occasional paper published by Zoological Survey of India. Sponge fauna of the Thar desert extending over Rajasthan and Gujarat States was reviewed by Saxena (1996) based on surveys conducted on over 100 bodies of water by him and his associates. He reported seven species belonging to five genera along with some ecological observations. In a small note Saxena (2001) observed cohabitation by several species within the body of sponge *Eunapius carteri*. This species of sponge was also recorded as a new record from Karauli district of Rajasthan by Devarshi (2006) following identification by the author. The species has also been documented from a lake in Maharashtra by Kakavipure & Yeragi (2008). Lately, in his lengthy paper on freshwater faunal diversity of the Indian desert, Saxena (2015) included seven sponge species from the region. Saxena (in press) has given a detailed account on the Sponge fauna of Rajasthan, including aspects covering history, identification, distribution and ecology.

Identification

Sponges, being sessile forms, are generally subject to great seasonal, geographical and habitat variability. This variability is found not among different species but also within the members of the same species. Hence, the characters like their external form, size, body consistency, and colour are diagnostically often unreliable. In freshwater sponges, the spicules always made of silica, are the determining character. These are of three types, the skeletal (megascleres), the flesh (microscleres), and the gemmule (gemmoscleres) spicules. Shape and microspination pattern of these spicules serve the most valuable taxonomic clues.

Chemically these spicules are made of 92 % silicon dioxide, 7% water, and traces of magnesium, potassium, and sodium (Butschli, 1901).

Freshwater Sponges of India

The basic taxonomic position of freshwater sponges is as below:

Phylum PORIFERA

Class DEMOSPONGIA

Sub-class CERACTINOMORPHA

Order HAPLOSCLERIDA

Family SPONGILLIDAE

Porifers, commonly called as sponges, are sessile forms, found attached to some submerged substratum in water. Freshwater sponges belong to family Spongillidae of Class Demospongia constitute an important component of an aquatic ecosystem. During different phases of their lifespan they exhibit a variety of living modes, viz., periphytonic, planktonic, neustonic, and benthic. They are well known for absorbing and utilizing material available in water (Soota & Saxena, 1983), while Harrison (1974) also considered them to be helpful in evaluating the quality of water they inhabit acting as delicate indicators of both population alterations and pollution induced cytopathology. Freshwater sponges characteristically produce asexual reproductive bodies called gemmules during dry summer period, which are quite often encountered in zooplankton samples during summer and winter seasons (Saxena, 2015).

Thirty one species belonging to eleven genera of freshwater sponges are noted from India, (Soota, 1991). Genera *Corvospongilla* and *Radiospongilla* are represented by greatest five species each, whereas genera *Umbrotula*, *Dosilia* and *Metania* are each represented by a single species (Table 1). Taxonomic details of Indian sponges are elaborated by Soota (1991) and those from Rajasthan are updated by Saxena (in press).

Out of these total 31 species, 11 are recorded to be endemic to India (Table 1). As is revealed from the distribution of different species, sponge *Eunapius carteri* is noted to be the most widely distributed form in India and elsewhere. On the contrary, *Eunapius calcuttanus*, *E. geminus*, *Stratospongilla gravely*, *Corvospongilla bhavnagarensis*, *Pectinospongilla aurea*, *P. stellifera* and *P. subspinosa* revealed very restricted distribution. This cannot be ruled out that insufficient explorations of sponge fauna could be a reason for its infrequent records; and work in this direction may extend the range of distribution of many. This doubt is also expressed by Saxena (1996) in his study on sponge fauna of the Thar desert. He pointed out that the greatest diversity of sponge fauna is revealed from Jodhpur district that could be a result of relatively more intense explorations in this region since the Desert Regional Centre of Zoological Survey of India is located here.

Ecological note

Soota & Saxena (1983) in their study on sponge fauna of some waters of Rajasthan supplemented the salient limnological features of the sponge localities. Saxena (1996) recorded the range of some physical and chemical factors of the waters harbouring different sponge species in the region. He noted these factors to range as: transparency 0.25-2.9 m, dissolved oxygen 3.003-11.011 mg/l, pH 6.4-10.3, carbonates 0-60.0 mg/l, bicarbonates 9.0-133.0 mg/l, free carbon dioxide 0-4.0 mg/l. *Eunapius carteri* (Fig. 1) was found to occur in the widest range of these factors, specially the carbonates and bicarbonates. Perhaps this makes this sponge the most widely distributed one. Besides that, this sponge is collected from a variety of substrates, such as submerged bushes, aquatic vegetation, dam walls, rocks and iron pipes. On the exposed rocks around Jawai dam (Pali, Rajasthan) its scars (having dry gemmules) measured even two meters in diameter. In Amer fort tank, Jaipur, these were in plenty attached to the iron pipes while in Pratapsagar, Jodhpur enormous bulks of this form were confined to the hydrophyte *Hydrilla* sp.

Sponge *Ephydatia meyeni* is reported to occur strictly on the undersurface of the submerged stones in the littoral region, avoiding direct sunlight. Its congener, *E. fluviatilis* has also been repoted to inhabit shaded habitats (Harrison, 1974) and constant illumination is reported to inhibit gemmule formation in it (Rasmont, 1970). However, Harrison (1974) also pointed out that "as might be expected, there is no hard and fast rule defining the relative tolerance of various sponge species to light. The effects of light intensity are greatly modified by two other environmental factors, water colour and transparency". Soota & Saxena (1983) pointed out that other species showed no specific trend of their occurrence and were usually found attached to the submerged bushes, hydrophytes and stones.

Table 1. Distribution of freshwater sponges in India (after Soota & Saxena, 1983; Soota, 1991; Saxena, 1996)
Species marked * are endemic to India

	Species	Distribution
1	Spongilla alba Carter, 1849	This species which has been reported both from fresh and low salinity waters, is of wide occurrence having been recorded from SE Asia, Africa, Australia, South America, and the U.S.A (Florida & Louissiana), and also from India-North Salt Lake, 24-Pargans; Port Canning and Calcutta and Igatpuri (Maharashtra), and back waters in Kerala. However, its clear distribution is still debatable in view of the fact that according to Racek & Harrison (1975, p, 163) the species shows observable speciation trends from South America northward; while it has been shown by Poirrier (1976, p. 211) that though its distribution is conditioned by percentage in water salinity of the habitat, probably more commonly restricted to tropical and subtropical climates, its occurrence in temperate latitudes cannot be ruled out.
2	Spongilla lacustris (Linnaeus, 1758)	According to Penney & Racek (1968), distribution restricted to Northern Hemisphere especially in cold temperature; but reported from India-Simla (Himachal Pradesh), Udhampur (Jammu), Ranchi (Bihar), Igatpuri (Maharashtra), and Mysore (Karnataka).

Species		Distribution
3	Eunapius calcuttanus* (Annandale, 1911)	Barring an unconfirmed report from Burma, apparently restricted to India where reported from Calcutta, and 24- Parganas (West Bengal)
4	*Eunapius carteri* (Bowerbank, 1863)	Confined from SE, S and W Asia to eastern Europe; probably also in Africa. In India, widely represented in the plains and even extending to moderate heights.
5	*Eunapius crassissimus* (Annandale, 1907)	Reportedly represented in S and tropical SE Asia and possibly also in Australia. In India-reported from Calcutta (West Bengal), Sur Lake (Orissa), and Assam. However, the distribution of the species in Australia requires to be more fully corroborated as in all probability it may be, considering the equally well protected gemmules of the species as those of *E. sinensis* (Annandale, 1910), sympatric with it.
6	*Eunapius geminus** (Annandale, 1911)	Only in India-Bangalore (Karnataka).
7	*Stratospongilla bombayensis* (Carter, 1882)	Recorded from central Africa. In India-Naukuchia Tal, alt. 4000 ft. (U.P.), Rajkot (Gujarat), Bhim river, Khed, Pune dist., and Bombay (Maharastra), Bangalore (Karnataka), Bikaner (Rajasthan).
8	*Stratospongilla gravely** (Annandale, 1912)	Only in India-Koyna river, Teloshi, Satara dist. (Maharashtra).
9	*Stratospongilla indica* (Annandale, 1908)	Reported from Thailand through India to Africa. In India-Chakradharpur, Chhota Nagpur (Bihar); and Nasik & Igatpuri (Maharashtra).
10	*Stratospongilla sumatraana* (Weber, 1890)	Reported from Indonesia through India to Africa. In India-river Yenna, Medha (Maharashtra).
11	*Corvospongilla bhavnagarensis** Soota, Pattanayak and Saxena, 1983.	Embankment about 4 meters away from Gorishankar Lake, Bhavnagar (Gujarat).
12	*Corvospongilla burmanica* (Kirkpatrick, 1908)	Extending from Burma (type locality) to India-Bhima river, Khed, Pune dist., & Pimpli, Ratanagiri dist. (Maharashtra); Idar ("occurring as incrustations on pebbles of recent conglomerate left by subsidence of the water").

Species		Distribution
13	*Corvospongilla caunteri** Annandaee, 1911	Only in India-Hazatganj, Lucknow (U.P.), Santhal Parganas (Bihar), Lake Kailana, Jodhpur(Rajasthan), Gori Shankar Lake & Kodiyar Lake, Bhavnagar(Gujarat), and Medha, Satara dist. (Maharashtra).
14	*Corvospongilla lapidosa** (Annandale, 1908)	Only in India-Pulta (West Bengal), Azidam, Rajkot (Gujarat), Igatpuri and river Godavari, Nasik, and Pune (Maharashtra), and Manjra reservoir, Sangareddy (Andhra Pradesh.)
15	*Corvospongilla ultima** (Annandale, 1910)	Only in India-Lake Kailana, Jodhpur (Rajasthan), Medha (Maharashtra), Kerala, and Cape Comorin & Tanjore(Tamil Nadu).
16	*Radiospongilla cerebellata* (Bowerbank, 1863)	Shown as distributed in tropical and subtropical S and SE Asia, as well as from China to USSR, even perhaps extending to south- eastern Europe. In India-Mangal-dai near Bhutan frontier (Assam), Sur Lake and Rambha(Orissa), River Jharia, Siripur, Saran dist. (Bihar), Calcutta and neighbourhood, Behrampore (West Bengal), Malwa Tal, alt. 3600 ft., Kumaon (U.P.), Igatpuri, Aurangabad, & Khandalla (Maharashtra), Bangalore (Karnataka), Ernakulum & Trichur (Kerala), Madras and neighbourhood (Tamil Nadu), and Pagnor talug, Nellore dist. (Andhra Pradesh).
17	*Radiospongillla cinerea** (Carter, 1849)	Only in India-Bombay; Nasik; Bhima river, Khed; Kayna, Satara fort; and Karla, Pune dist. (Maharashtra); Chakradharpur, Chhota Nagpur (Bihar); and Naukuchia Tal (alt. 4000ft.), Kumaon (U.P.).
18	*Radiospongilla crateriformis* (Potts, 1882)	Discontinuously distributed in the U.S.A. and Mexico, China, Japan, and SE Asia; and also in India-Malabar (Kerala), Khandalla (Maharashtra), and Ross Island & Diglipur (Andamans).
19	*Radiospongilla hemephydatia* (Annandale, 1909)	Recorded from eastern Australia, and possible occurrence in New Guinea. In India-Sur Lake (Orissa) where reportedly growing with *Radiospongilla cerebellata* (= *Spongilla lacustris* subsp. *reticulate*), *Eunapius carteri* (= *Spongilla carteri*) and Eunapius *crassissimus* (= *Spongilla crassissima*). Its report from Matha river near Kharakwasla. Pune (Maharashtra) by Tonapi (1964) requires confirmation as possibly confused with *Stratospongilla*.
20	*Radiospongilla indica* (Annandale, 1907)	Ranging from India to Indonesia and southeastwards to as far as probably New Guinea. In India-Calcutta (West Bengal), and Igatpuri (Maharashtra).
21	*Pectispongilla aurea** Annandale, 1909	Only in India-Tenmalai, (Kerala).

	Species	Distribution
22	*Pectispongilla stellifera** Annandale, 1915	Only in India-Trichur (Kerala).
23	*Pectispongilla subspinosa** Annandale, 1911	Only in India-Trichur & Ernakulum (Kerala).
24	*Ephydatia fluviatilis ramsayi* (Haswell, 1882)	All faunal realms. In India-only in western Himalayas namely, Kumaon, Naukuchia Tal, Bhim Tal, SatTal, and Nainital.
25	*Ephydatia meyeni* (Carter, 1849)	China. In India-Calcutta and neighbourhood (West Bengal), Bhim Tal, Kumaon, alt. 4500ft. (U.P.), Jodhpur, Udaipur and Kota (Rajasthan), Bombay and Pune (Maharashtra), Kerala and Cape Comorin (Tamil Nadu). Specimens examined by the author from new localities; Lake Rainuka (H.P); Dudhwa National Park, and Roorkee (U.P.); and Rohtak, Panipat, Ottu lake, and Sirsa, Hissar (Haryana).
26	*Umborotula bogorensis* (Weber, 1890)	In Indian region recently reported from Andaman Islands. According to Racek (1969, p.300) SE Asia to eastern Australia. He remarked that "The typically minute size of this species represents a major obstacle in the assessment of its true distributional range and additional collections may yet demonstrate the fallacy of the present assumption, that U. bogorensis displays a widely scattered dispersal."
27	*Dosilia plumose* (Carter, 1849)	Reported from the Philippines, probably also in other parts of SE Asia, [vide Gee (1932, p. 533), and Penney and Racek (1968)]. In India-Pulta water tank (West Bengal), Hazaribagh (Bihar), Jodhpur, Udaipur, and Jaipur (Rajasthan), Bombay (Maharahtra), and Rambha (Orissa).
28	*Trocbospongilla paulula* (Bowerbank, 1863)	Ranging from southern and SE Asia north to China and south to eastern Australia; and Amazon River (type locality). In India-Calcutta and neighbourhood (West Bengal). In Burma (now Myanmar)-Kawkarlik, Amherst dist., Tenasserim.
29	*Trochospongilla pennsylvanica* (Potts, 1882)	Cosmopolitan. In India-Kerala.
30	*Trochospongilla philottiana* Annandale, 1907	From India-Calcutta & neighbourhood (West Bengal) and through southern China and SE Asia to the Philippines, and possibly also occurring in Africa.
31	*Metania vesparioides* (Annandale, 1908)	Reportedly restricted to Burma (now Myanmar); then published as fauna of India

*Endemic to India

Waters with greater fluctuations in water level are found to hold poor taxa diversity. Annandale (1911) observed that the sponges are found in the water bodies in which there is a certain mixture of light and shade, containing suitable support, and free of disturbance, for instance, result from emptying out the pond. This statement is vindicated by Soota *et al.* (1983) who observed that in two twin bodies of water at Jodhpur, having same range of physical-chemical parameters, the least disturbed stagnant lake was represented by well flourishing five species of sponges while the other one facing great fluctuation in water level, resulting from constant in and outflow, was represented by a very sparse population of a single species.

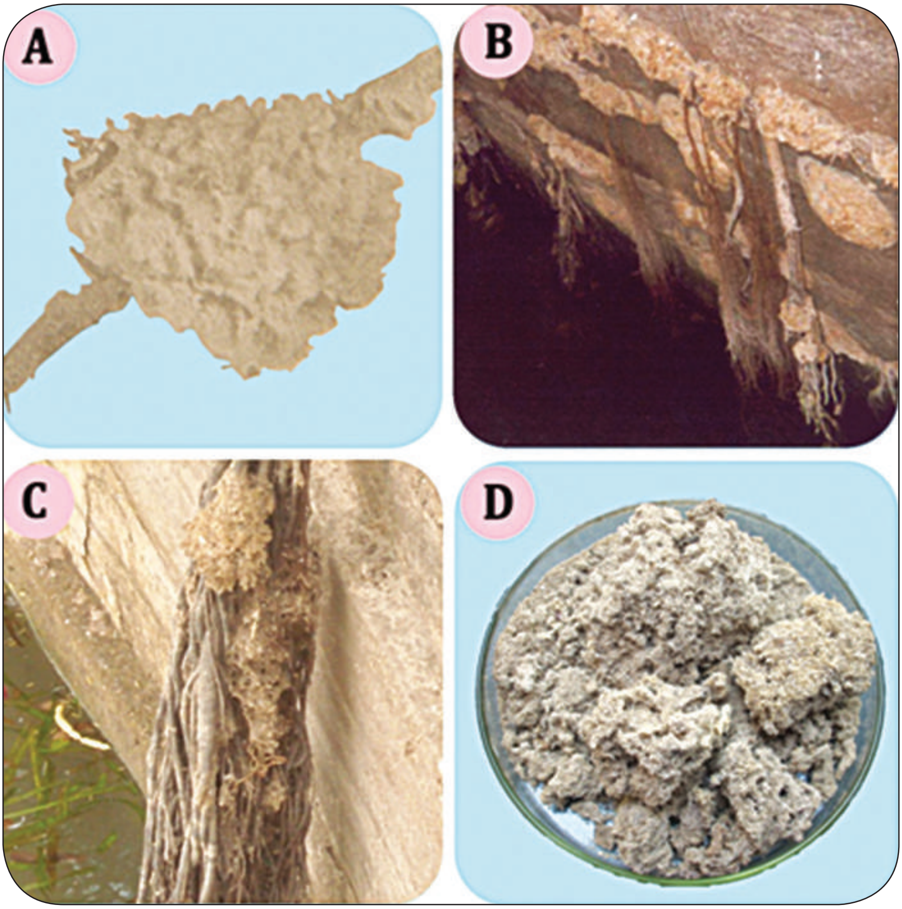

Fig. 1. Sponge *Eunapiuscarteri*: A. on a submerged twig, B. on dam wall, C. on *Ficusroots* down water, D. full of gemmules

Sponges are known to display good inter-specific relations. These are known to provide safe sanctuary to a variety of animals ranging from minute protozoans to lower chordates. Sisyrid insects of order Neuroptera are regarded as 'spongilla flies' as their larvae suck nutritive fluid from sponge tissue (Tonapi, 1980). The fishes *Gobius alcockii* and *Percilia gillisi* are reported to lay eggs inside the osculum of sponges *Eunapius carteri* and *E. mackayi* respectively (Soota, 1991). During a survey for sponge fauna in the Indian desert, in a lake near Bikaner the author (Saxena, 2001) noted sponge *Eunapius carteri* to harbour a number of young water scorpions *Laccotrephes maculates* (Fabr.) (Insecta: Hemiptera: Nepidae) measuring 10 to 12.5 mm. A pair of adult water scorpions was also found in coitus. He pointed out that the fact features the spongocoel as a breeding site of the insect. However, he doubts that this relationship may be an intentional or accidental lodgment. The other colonizers of the sponge included backswimmer *Notonecta glauca* (Linn.) (Insecta: Hemiptera); seed shrimp *Stenocypris malcosoni* (Brady) (Crustacea: Ostracoda) and snails *Lymnaea accumineta* (Lamarck) and *Bellamya bengalensis* (Lamarck) (Mollusca: Gastropoda). Kakavipure & Yeragi (2008) made a stray mention of symbiotic algae imparting brown green to yellow colour to sponge *Eunapius carteri* in a lake in Maharashtra.

Thrust areas

In spite of the fact that several limnological studies are made over last about four decades in the area, very little attention is paid to taxonomy and ecology of lower invertebrates, and sponges are no exception. There is increasing need to explore the sponge fauna from diverse bodies of water which may surely yield some new records and extend the range of distribution of many. Further, the role of sponges as bioindicators of water quality and water purifiers are yet another areas of research need to be explored. These forms of lower level of biological organization can also serve as good material for cytological and regenerative studies. Above all, a correct identification of the species is very important for which there is dire need of trained taxonomists in the country, particularly for such lower obscured groups of animals.

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Chapter 5

CNIDARIA

SANTANU MITRA*, K. VALARMATHI AND SUBHRENDU S. MISHRA

ABSTRACT

Among the varied categories of Cnidarians, Hydrozoans are the only group known to colonize freshwater habitats. Only nine species belonging to six genera in four families and two orders of the class Hydrozoa are reported from freshwater bodies of India till date. Although, they are considered as a valuable source of potential bio-medical compounds, little has been studied and there is a need for further contribution from taxonomists and scientific communities as well.

Key words: Cnidarian fauna, Hydrozoa, bio-medical compound, freshwater habitat.

INTRODUCTION

Cnidarian fauna are most diverse in their forms, among the lower group of animals. They are well known under their common names like Sea anemones, Corals, Jellyfishes, Hydras, Sea-whips, Sea-fans, Sea-pens etc. All of them are aquatic and linked together by their carnivorous feeding habits, simple anatomical structures and possession of nematocysts. Most of the Cnidarians successfully colonize marine environment, only few Hydrozoans, which form phylogenetically a distinct group, found in freshwater.

Globally there are about 10,100 species of Cnidarian fauna (Zhang, 2011), belongs to 5 classes Hydrozoa, Scyphozoa, Cubozoa, Anthozoa and Polypodizoa. Diversity of Cnidarian fauna is quite good in India as per global context (8.5%), and comprises 842 species (Venkatraman & Wafer, 2005). These animals are predominantly marine and estuarine inhabitants, though a very few species are adapted to live in lentic or lotic freshwater ecosystems. Only about 40 species of Hydrozoan cnidarians were reported from freshwater bodies of the world (Jankoski *et al*., 2008), of which only 9 species were recorded from India.

The present paper provides an updated list of the Cnidarian (Hydrozoa) fauna occurring in freshwater habitats of India with their status and distribution. In spite of immense ecological role, contributing a valuable source of potential Bio-medical compounds, very little work has been done towards study of this group of animals in India. More attention and exploration for these animals are needed along with taxonomical studies to understand species diversity and distribution of this diversified group.

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Historical Resume

Study of Indian freshwater Cnidaria began with the work of the first Director of the Zoological Survey of India, Dr. Nelson Annandale during his tenure at the Indian Museum (Annandale, 1905). He reported the first cnidarian species from India as *Hydra orientalis,* but later treated as *H. vulgaris* Pallas (Annandale 1911a). A second species of the same genus, *Hydra oligactis* Pallas, was reported by Annandale (1911a). Annandale (1911b) indicated occurrence of freshwater madusae in deep pools of Koyna and Yenna river in Western Ghats, that was later described as *Limnocnida indica* by Annandale (1912). Kramp (1958) described *Moerisia gangetica* from Shambazar Khal, near Calcutta [=Kolkata] during low tide, which seems to be possibly tolerant of freshwater and *Moerisia lyonsi* Boulenger was reported from a high altitude lake of Meghalaya (Haldar & Mandal, 1999). *Eirene menoni* Kramp was reported from Baally khal, at Howrah district of West Bengal a tributaries of River Ganges (Haldar and Choudhury 1995). Three more new species of freshwater Hydrozoan are described from India, *Mansariella lacustris* from Mansar Lake, Jammu (Malhotra *et al*., 1976); *Keralica idukkensis* from Kerala (Khatri, 1984) and *Limnocnida biharensis* from a freshwater aquarium at Bihar (Ahmed et al. 1987). Caleb (1956) described a new species of *Hydra* in his Ph.D thesis but there is no published data, hence this species has no taxonomic validity and so, not included here.

Diversity

As mentioned above, only nine species belonging to six genera, four families, two orders of the class Hydrozoa are recorded from freshwaters of India. A systematic list of the recorded species is given herewith.

Systematic list of Freshwater cnidarians of India

Phylum CNIDARIA Verill, 1865

Class HYDROZOA Owen, 1843

Sub class HYDROIDOLINA Collins, 2000

Order ANTHOATHECATA Cornelius, 1992 [=Anthomedusae Haeckel, 1879]

Suborder APLANULATA Collins et al., 2005

Family HYDRIDAE Dana, 1846

1. *Hydra oligactis* Pallas, 1766
2. *Hydra vulgaris* Pallas, 1766

Suborder CAPITATA Kuhn, 1913

Family MOERISIIDAE Poche, 1914

3. *Moerisia gangetica* Kramp, 1958
4. *M. lyonsi* Boulenger, 1908

Order LEPTOTHECATA Cornelius, 1992 [=Leptomedusae Haeckel, 1879]

Family EIRENIDAE Haeckel, 1879

5. *Eirene menoni* Kramp, 1953

Subclass TRACHYLINAE Haeckel, 1879

Order LIMNOMEDUSAE Kramp, 1938

Family OLINDIIDAE Haeckel, 1879

6. *Limnocnida indica* Annandale, 1912
7. *Limnocnida biharensis* Ahmed *et al.,* 1987
8. *Mansariella lacustris* Malhotra, Duda and Jyoti, 1976
9. *Keralica idukkensis* Khatri, 1984

Distribution

Hydra vulgaris Pallas has a very wide distributional range in India. Prasad & Mookerjee (1986) reported about 16 ecotypes of *Hydra vulgaris* from India. *Eirene menoni* Kramp, 1953 was reported from Baally khal, at Howrah district of West Bengal a tributary of River Ganges (Haldar and Choudhury 1995). *Moerisia gangetica* reported from the Ganges river and also from different parts of India, where as *M. lyonsi* only reported from a high altitude lake of Meghalaya (Haldar & Mandal, 1999); *Limnocnida indica* Annandale, 1912 is very widely distributed in freshwater ecosystems of India; *Limnocnida biharensis* was only reported from a freshwater aquarium at Bihar (Ahmed *et al*., 1987). *Mansariella lacustris* was described from Mansar lake at Jammu (Malhotra *et al*., 1976) and there is no other report of this species. *Keralika idukkensis* was described from a freshwater lake of Kerala (Khatri, 1984).

Endemicity

A total 5 species of freshwater medusae are endemic to India, i.e. *Moerisia gangetica* Kramp, 1958; *Limnocnida indica* Annandale, 1911; *Limnocnida biharensis* Ahmed *et al*., 1987; *Mansariella lacustris* Malhotra *et al*. 1976 and *Keralika idukkensis* Khatri, 1984. Last three species are known from the type locality only.

Discussion

Taxonomic characters of Freshwater hydrozoans are very complicated and the validity of many species is questionable (Jankowski, *et. al.,* 2008). Bouillon *et al.,* (2006) published an excellent work on Hydrozoans, which may help extremely in study of these cnidarians of our country. Some freshwater medusae was described from some specific locality of India, namely *Limnocnida biharensis*; *Mansariella lacustris* and *Keralika idukkensis.* Last two species has uncertain taxonomic status and needs re-examination of the type material (Boulion and Boero 2000) as both the genera, *Mansariella* and *Keralica,* are treated as *nomen dubium* by Jankoski (2001). The genera, *Moerisia* and *Eirene,* are usually found in coastal waters and their presence in freshwater ecosystems is questionable but included here for their possible tolerance to freshwater. But record of *Moerisia lyonsi* from a high altitude lake of Meghalaya (Haldar and Mandal, 1999) having no connection to sea or estuary needs to be reassessed. The recent reports of Hydrozoans from India reflect that their study probably based on accidental encounters. Information on Cnidarians (Hydrozoa) from several parts of the country is lacking. Study of old water bodies will definitely provide more information on diversity and distribution of this little known group.

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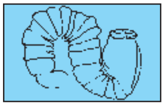
Chapter 6



PLATYHELMINTHES : CESTOIDEA (CESTODE PARASITES) FROM FRESHWATER FISHES

SURANJANA BANERJEE AND K. RAJAMOHANA

ABSTRACT

Current status of freshwater fish cestode fauna of India is represented by 5 orders, 11 families, 3 subfamilies, 25 genera and 116 species. A total of 46 species, 22 genera, 10 families and 5 orders of Indian freshwater fishes are found to harbour 116 cestode parasites. However, considerable gaps still exist in our knowledge of the diversity and species composition of fish cestodes in the Indian subcontinent. In addition, there are still vast areas, where surveys of fish parasites have not been carried out. In the present study the current status of cestode parasites of Indian freshwater fishes is discussed.

Key words: Cestoda, current status, diversity, freshwater fishes, India.

INTRODUCTION

Cestoda (Cestoidea) is a class of parasitic flatworms of the phylum Platyhelminthes. The best-known species are commonly called tapeworms. Cestodes have perfectly adapted to parasitic mode of life amongst all the helminths and inhabit the intestinal tract of almost all the vertebrates including humans in their adult stages. Larval and cystic forms are found in different body organs of almost all vertebrates and invertebrates such as mites, crustaceans, ants, etc. Cestodes are specialized endoparasites that are characterized by their dorsoventrally flat, segmented bodies. The ribbon-shaped tapeworms are the largest and among the oldest of the intestinal parasites that have plagued humans and other animals since time immemorial. They are cosmopolitan in distribution and exist in many forms. There are 14 orders of Eucestoda. Most of the cestode orders (except Cyclophyllidea) have members that can infect fish (both Chondrichthyes and Osteichthyes) as adults. Eight cestode orders Amphilinidea, Spathebothriidea, Caryophyllidea, Trypanorhyncha, Pseudophyllidea, Proteocephalidea, Haplobothriidea and Nippotaeniidea are found in freshwater fishes. Many cestodes are known to be the agents of serious fish diseases and also represent important public health problem.

Historical Resume

The British researchers Southwell (1913 a and b) and Woodland (1924) provided the first data on fish cestodes from India, followed by the Indian helminthologists Moghe (1925) and Verma (1926). Since then, freshwater fish cestode diversity

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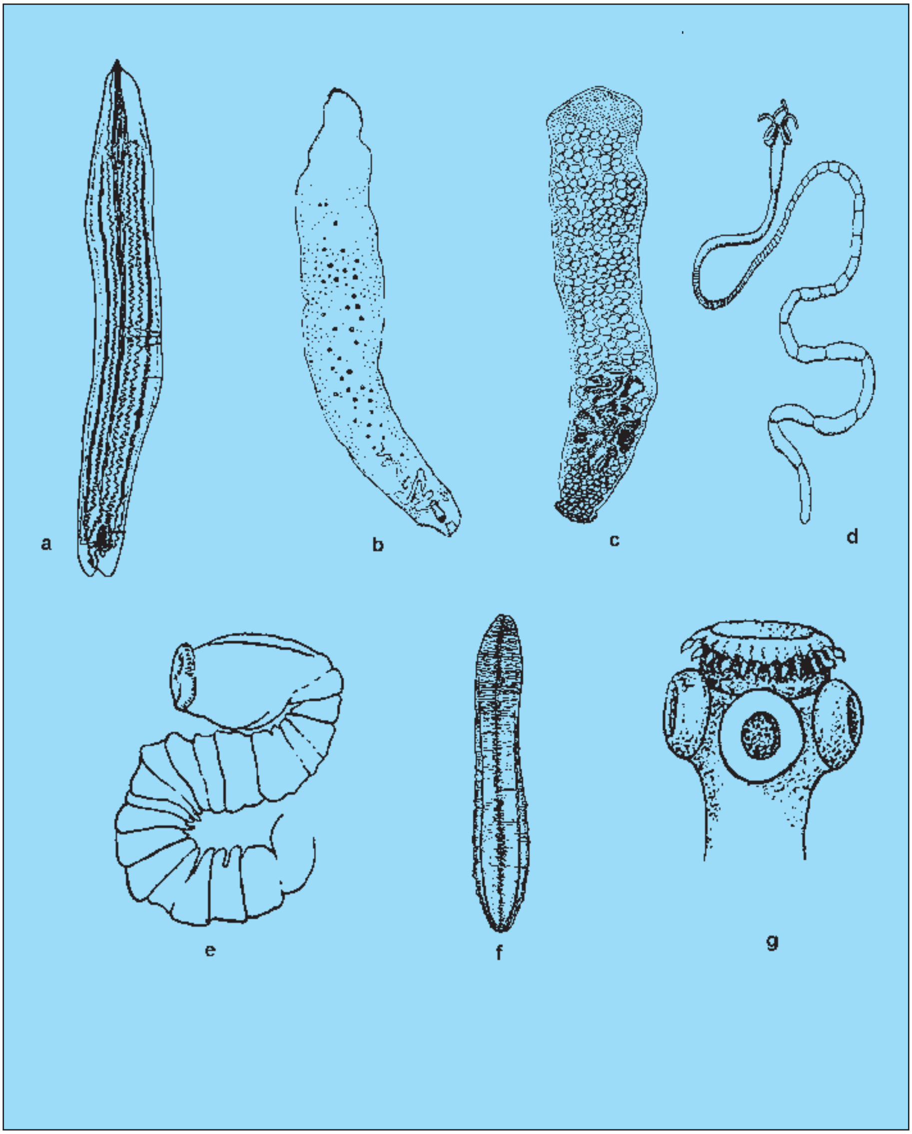
has been documented from different parts of the country by a number of Indian helminthologists. Most of these studies comprised descriptions of new taxa and as a result, high numbers of species (more than 250) of cestodes from freshwater fish, have been described from the Indian subcontinent (Mackiewicz, 1981; Agarwal, 1985; Chakravarty and Tandon, 1989; Hafeezullah, 1993; Jadhav *et al*., 2010; Ash *et al*., 2011 a & b). The Zoological Survey of India published an index catalogue of cestode parasites of freshwater fishes from India (Kundu, 1992). Ash (2012) made critical evaluations of earlier described species from freshwater fish hosts of India using morphological and molecular approaches that made it possible to clarify the species composition, host specificity and phylogenetic relationships of selected cestode orders found in freshwater fishes like Caryophyllidea and Proteocephalidea. However, checklist of freshwater fish cestodes of India is yet not published.

Kundu (1992) listed as many as 78 species of cestodes from freshwater fishes of India. However, *Ptychobothrium cypseluri* Rao, 1959 listed in the catalogue is collected from a marine fish host *Cypselurus poecilopterus*. Ash *et al*. (2011 a & b, 2012) have synonymised 17 species of order Caryophyllidea and 10 species of order Proteocephalidea listed in the catalogue by Kundu (1992). *Proteocephalus ritae* Verma, 1926 listed in the catalogue is a synonym of *Ritacestus ritaii* (Verma, 1926) de Chambrier *et al.*, 2011 reported from Uttar Pradesh. Out of the 78 species 27 species have thus been synonymised. Two species *Moravekia chotanagpurensis* Sahay and Sahay, 1976 and *Neolytocestus vitellodiscontinutus* Sahay and Sahay, 1976 are under *genera inquirenda*; one species *Adenoscolex kashmirensis* Mehra,1930 is treated as *species inquirenda* and four species *Guptaia garhwalensis* Malhotra,1985; *Mastacembellophyllalus nandensis* Shinde and Chincholikar 1977; *Mastacembellophyllalus pseudeutropiusii* Jadhav and Shinde 1982 and *Mastacembellophyllalus taakree* Jadhav and Shinde,1977 are treated as *genera incertae sedis* (Khalil *et al*., 1994). Thus, 43 species are valid species in the published catalogue (Kundu, 1992). In recent years as many as 28 species of *Senga* Dollfus, 1934 and 27 species of *Circumoncobothrium* Shinde, 1968 have been described from India by various authors after the publication of Index catalogue of freshwater fishes (Kundu, 1992).

A total of 108 nominal species of eight genera of Order Bothriocephalidea were described mainly from perciform and synbranchiform fishes from the Indian subcontinent, but Kuchta and Scholz (2007) considered valid only 17 species of three genera, namely *Bothriocephalus* Rudolphi, 1808; *Ptychobothrium* Loennberg, 1889 (though Kuchta and Scholz, 2007 casted doubts upon taxa reported as species of *Ptychobothrium* from Indian freshwater fish); and *Senga* Dollfus, 1934. The total number of valid species under Order Bothriocephalidea needs critical evaluation.

Fourteen genera and nearly 100 species of Order Caryophyllidea belonging to three families have been described from the Indomalayan region from catfishes (Siluriformes: Bagridae, Clariidae, Heteropneustidae, Schilbeidae and Siluridae), cyprinid and cobitid fishes.83 species have been synonymised and 17 are considered to be valid (Ash *et al*., 2011).

PLATE I



Line drawings of freshwater fish cestodes of India (a,d,e,f,g : after Southwell, 1930; b,c : after Hafeezullah, 1993)

a. *Gephyrolina paragonopora* (Woodland, 1923) Poche, 1926; b. *Lytocestus indicus* (Moghe, 1925) Woodland, 1926; c. *Breviscolex naldurgensis* Shinde *et al.,* 1987; d. *Tentacularia ilisha* (Southwell & Prashad, 1918) Dollfus, 1942; e. *Senga pycnomerus Dollfus,* 1934; f. *Ligula intestinalis* (Linnaeus, 1758) Bloch, 1782; g. *Gangesia bengalensis* (Southwell, 1913) Meggitt, 1927

In Order Proteocephalidea more than 50 species of four genera (*Gangesia* Woodland, 1924; *Proteocephalus* Weinland, 1858; *Silurotaenia* Nybelin, 1942; and *Vermaia* Nybelin, 1942) have been described from the siluriform and cypriniform fish in the Indian subcontinent. Ash *et al*., 2011 have synonymised nearly 30 species of *Gangesia* Woodland, 1924 described from India. They have considered 4 species to be valid, 6 species of *Gangesia* to be under Uncertain Taxa and 5 to be *Nomen nudum*.

Diversity

After the publication of the catalogue of cestode parasites of Freshwater fishes (Kundu, 1992) the number of species added in this study is listed in Table-1 (recorded till March, 2017).The species marked in asterix had been described before 1992 but had not been included in Freshwater fish cestode catalogue (Kundu,1992).

Table 1. List of freshwater fish cestodes added in the present study

Sl. No.	Genus	Species	Distribution in India
1.	*Djombangia*	*mannai* Banerjee, Manna and Sanyal, 2016	West Bengal
2.	*Lobulovarium*	*longiovatum* Oros, Ash, Brabec, Kar and Scholz, 2012	West Bengal, Assam
3.	*Lobulovarium*	**osteobramense* Gupta and Sinha, 1984) Oros, Ash, Brabec, Kar and Scholz, 2012	Uttar Pradesh
4.	*Lucknowia*	**microcephala* (Bovien, 1926) Ash, Scholz, Oros and Kar, 2011	Assam, Uttar Pradesh, West Bengal
5.	*Breviscolex*	**naldurgensis* Shinde,Mohekar, Jadhav and Haffezullah,1987	Maharashtra
6.	*Gangesia*	**agraensis* Verma, 1928	Uttar Pradesh, West Bengal, Assam, Karnataka, Haryana, Kashmir, Maharashtra
7.	*Gangesia*	**vachai* (Gupta and Parmar, 1988) Ash, Scholz, de Chambrier, Brabec, Oros, Kar, Chavan & Mariaux, 2012	Uttar Pradesh, West Bengal, Assam
8.	*Senga*	**yamunica* Gairola and Malhotra, 1986	Uttar Pradesh
9.	*Senga*	**nayari* Malhotra, 1988	Uttarakhand

Sl. No.	Genus	Species	Distribution in India
10.	Senga	**mastacembali* Gupta and Sinha,1980	Uttar Pradesh
11.	Senga	**teleostei* Banerjee *et al*., 1990	Uttar Pradesh
12.	Senga	**aurangabadensis* Jadhav and Shinde, 1980	Maharashtra
13.	*Senga*	**godavarii* Shinde and Jadhav, 1980	Maharashtra
14.	*Senga*	**paithanensis* Kadam *et al*., 1981	Maharashtra
15.	*Senga*	**maharashtrii* Jadhav *et al*., 1991	Maharashtra
16.	*Senga*	*mohekarae* Tat *et al*., 1997	Maharashtra
17.	*Senga*	*armatusae* Hiware, 1999	Maharashtra
18.	*Senga*	**pathankotensis* Duggal and Bedi, 1989	Punjab
19.	*Senga*	*kaigaonensis* Wankhede and Reddy, 2009	Maharashtra
20.	*Senga*	*panzraensis* Mangale and Kalse, 2009	Maharashtra
21.	*Senga*	*chauhani* Hasnain, 1992	Bihar
22.	*Senga*	*tappi* Patil and Jadhav, 2003	Maharashtra
23.	*Senga*	*jadhavae* Bhure *et al*., 2007	Maharashtra
24.	*Senga*	**gachuae* Jadhav *et al*., 1991	Maharashtra
25.	*Senga*	*govindii* Jadhav *et al*., 2012	Maharashtra
26.	*Senga*	*ayodhensis* Pande *et al*., 2006	Uttar Pradesh
27.	*Senga*	*baughi* Pande *et al*., 2006	Uttar Pradesh
28.	*Senga*	*madhavii* Bhure *et al*., 2010	Maharashtra
29.	*Senga*	*rupchandensis* Pardeshi and Hiware, 2011	Maharashtra
30.	*Senga*	*sataraensis* Bhure and Nanware, 2011	Maharashtra
31.	*Senga*	*rostellare* Dhole *et al.,* 2011	Maharashtra
32.	*Senga*	*chandrasekhari* Dhole *et al*., 2011	Maharashtra
33.	*Senga*	*nathsagarensis* Nilima, 2008	Maharashtra
34.	*Senga*	*chandikapurensis* Khadap *et al*., 2007	Maharashtra
35.	*Senga*	*tictoi* Srivastav *et al*., 2007	Uttar Pradesh

There are about 450 families of freshwater fishes globally. Approximately, 40 are represented in India. About 25 of these families contain commercially important species. Major warm water species are: *Bagarius bagarius, Catla catla, Channa marulius, C. punctatus, C. striatus, Cirrhinus mrigala, Clarias batrachus, Heteropneustes fossilis, Labeo bata, L.calbasu, L. rohita, Aorichthys seenghala, Notopterus chitala, N. notopterus, Pangasius pangasius, Rita rita, Wallago attu.* (http://nptel.ac.in/courses/120108002/module3/lecture3.pdf)

Around the world 102 species in 14 families and 7 orders of freshwater fishes are reported to harbor cestode parasites. In the present study 46 species, 22 genera, 10 families and 5 orders of Indian freshwater fishes are found to harbour 116 cestode parasites. Current status of freshwater fish cestode fauna of India is represented by 5 orders, 11 families, 3 subfamilies, 25 genera and 116 species.

Distribution

The majority of the species were described from Maharashtra (67 species), Uttar Pradesh (32 species), West Bengal (23 species) and Assam (10 species). A detailed Host-Parasite list with state wise distribution of species is given as **Annexure 1**.

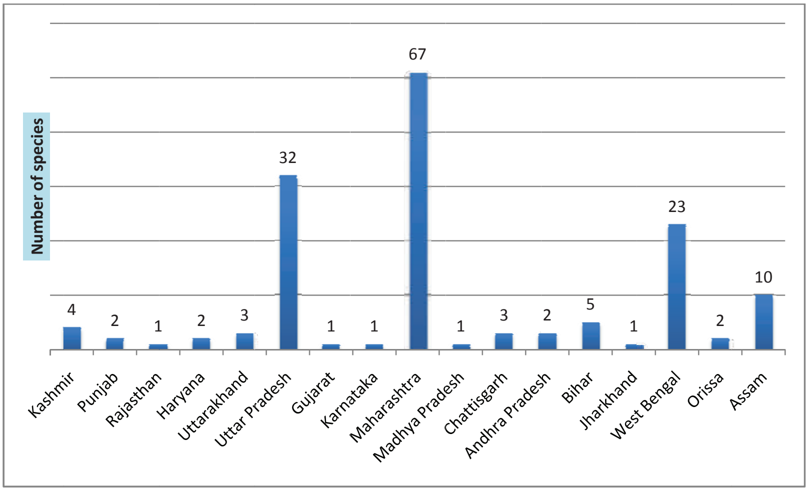


Fig. 1. State-wise distribution of species in India

Life cycle

The life cycle of cestodes is extremely varied with fish used as the primary or intermediate host.

The general scheme of life cycle of most aquatic cestodes, including fish cestodes, is as follows: cestode eggs in the uterus, which may contain embryos, named oncospheres (lycophora in Cestodaria), pass with host's faeces into the environment. Eggs (except those taxa have coracidium) are eaten by the intermediate hosts (crustaceans). Larvae hatch in the gut of the intermediate hosts (with some exceptions), and using their hooks and glands, penetrate through the intestinal wall and locate in the body cavities or other internal organs where they metamorphose into infective larval stages or metacestodes (Ash, 2012). Three types of metacestodes namely procercoid, plerocercoid, and merocercoids are commonly found in intermediate hosts. The final host is infected by eating an intermediate host that harbours metacestodes. Diphyllobothriidean tapeworms have three host life-cycles, in which teleost fishes play a role of the second intermediate hosts and represent a source of human infection (Scholz and Kuchta, 2016).

Significance

Fish helminthes with their complex life cycles may represent excellent models for the solution of a number of theoretical questions, including host-parasite relationships, host manipulation, biology ,ecology, zoogeography and phylogeny of these parasites and their hosts (Williams and Jones, 1994). Fisheries are important for the Indian economy as it provides employment opportunities, is a source of nutritional food and foreign exchange earnings. Catfishes are an important part of the fish fauna in wetlands and many of them are economically important as a food source of high nutritive value. Among them five families-Bagridae, Clariidae, Heteropneustidae, Schilbeidae and Siluridae, have been reported as definitive hosts of cestodes (Hafeezullah, 1993; Jadhav *et al*., 2010). It is estimated that about 10 million tons of fish are required annually to meet the present-day demand of fish proteins in India compared to an actual annual production of only 3.5 million tons (Shukla and Upadhyay, 1998). Parasitic disease is the single most important factor threatening the fishery industry worldwide, particularly in the tropics (Williams and Jones, 1994; Schmidt and Roberts, 2000).Mortality of fishes occurs due to heavy infestation of parasites. Therefore knowledge about fish parasites needs to be updated periodically.

Gaps in research

Much has been accomplished in the last few years in terms of survey work on the helminth parasite fauna of freshwater fishes in India. But the information gathered thus far allow us to seek for general patterns about the way this host-parasite association is established, addressing the evolutionary and biogeographical factors that determine such association. However, considerable gaps still exist in our knowledge of the diversity and species composition of fish cestodes in the Indian subcontinent. Many of the biogeographical regions are practically unexplored and intensive survey is needed to generate data on distribution of several species of cestodes. The Deccan peninsula, North East India, Trans Himalaya and Andaman and Nicobar Islands are under-explored. The Northern part, especially Kashmir region and whole Southern part (among the world's ten "Hottest biodiversity hotspots"), which hosts some endemic catfishes, are some of the unexplored regions of the country (Ash, 2012).

Future dimensions

The future plan should focus on intensive explorations in unexplored and under-explored areas. More attention need to be paid to less studied fish hosts. Modern molecular methods should be applied in systematic studies to bring the knowledge of the India's helminth fauna to the level corresponding to the current global knowledge. The main emphasis should be given to building a network of specialists all over India. Furthermore, reliable data on various hosts and their helminth parasites should be incorporated into freely available on-line database resources, for the benefit of those working on parasites and their impact on hosts and ecosystems, including farmed animals and aquaculture (Ash, 2012).

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Annexure-I: Host - Parasite list with state wise distribution of species

HOST			PARASITE				
Order	**Family**	**Genus and species**	**Order**	**Family/Sub-Family**	**Genus**	**Species**	**Distribution**
Siluriformes	Bagridae	*Sperata aor* *Sperata seenghala* *Bagarius bagarius*	Amphilinidea	Fam:Schizochoeridae Subfam: Schizochoerinae	*Gephyrolina*	*paragonopora* (Woodland, 1923) Poche,1926.	Uttar Pradesh, Punjab
Cypriniformes	Cobitidae	*Lepidocephalichthys guntea*	Caryophyllidea	Caryophyllaeidae	*Paracaryophyllaeus*	*lepidocephali* (Kundu, 1985) Hafeezullah, 1993	West Bengal
Siluriformes	Clariidae	*Clarias batrachus*	Caryophyllidea	Lytocestidae	*Bovienia*	*indica* (Niyogi, Gupta and Agarwal, 1982) Ash, Scholz, Oros and Kar, 2011	Assam, Madhya Pradesh, Maharashtra, Uttar Pradesh,West Bengal
Siluriformes	Clariidae	*Clarias batrachus*	Caryophyllidea	Lytocestidae	*Bovienia*	*raipurensis* Satpute and Agarwal, 1980) Mackiewicz, 1994	Chattisgarh, West Bengal
Siluriformes	Clariidae	*Clarias batrachus*	Caryophyllidea	Lytocestidae	*Bovienia*	*serialis* (Bovien,1926) Fuhrmann, 1931	Maharashtra
Siluriformes	Claridae	*Clarias batrachus*	Caryophyllidea	Lytocestidae	*Djombangia*	*penetrans* Bovien, 1926	Maharashtra, West Bengal, Assam, Bihar, Chattisgarh,
Siluriformes	Claridae	*Clarias batrachus*	Caryophyllidea	Lytocestidae	*Djombangia*	*mannai* Banerjee , Manna and Sanyal, 2016	West Bengal
Cypriniformes	Cyprinidae	*Puntius sophore*	Caryophyllidea	Lytocestidae	*Lobulovarium*	*longiovatum* Oros, Ash, Brabec, Kar and Scholz, 2012	West Bengal, Assam
Cypriniformes	Cyprinidae	*Osteobrama cotio*	Caryophyllidea	Lytocestidae	*Lobulovarium*	*osteobramense* Gupta and Sinha, 1984) Oros, Ash, Brabec, Kar and Scholz, 2012	Uttar Pradesh

HOST			PARASITE				
Order	**Family**	**Genus and species**	**Order**	**Family/Sub-Family**	**Genus**	**Species**	**Distribution**
Cypriniformes	Cyprinidae	*Puntius sophore*	Caryophyllidea	Lytocestidae	*Lytocestus*	*longicollis* Ramadevi, 1973	Andhra Pradesh
Cypriniformes	Heteropneustidae	*Heteropneustes fossilis*	Caryophyllidea	Lytocestidae	*Lytocestoides*	*fossilis* Kanth, Sinha and Srivastav, 1984	Bihar
Cypriniformes	Heteropneustidae	*Heteropneustes fossilis*	Caryophyllidea	Lytocestidae	*Lucknowia*	*fossilisi* Gupta, 1961	Assam, Maharashtra, Uttar Pradesh, West Bengal
Siluriformes	Clariidae	*Clarias batrachus*	Caryophyllidea	Lytocestidae	*Lucknowia*	*microcephala* (Bovien, 1926) Ash, Scholz, Oros and Kar, 2011	Assam, Uttar Pradesh, West Bengal
Siluriformes	Clariidae	*Clarias batrachus*	Caryophyllidea	Lytocestidae	*Lytocestus*	*indicus* (Moghe, 1925) Woodland, 1926	Assam, Bihar, Uttar Pradesh, West Bengal, Chattisgarh, Maharashtra
Siluriformes	Bagridae	*Rita rita*	Caryophyllidea	Lytocestidae	*Pseudocaryophyllaeus*	*ritai* Gupta and Singh, 1983	Uttar Pradesh, West Bengal
Siluriformes	Clariidae	*Clarias batrachus*	Caryophyllidea	Lytocestidae	*Pseudocaryophyllaeus*	*tenuicollis* (Bovien, 1926) Ash, Scholz, Oros and Kar, 2011	Andhra, Uttar Pradesh, West Bengal, Assam, Jharkhand, Maharashtra
Siluriformes	Clariidae	*Clarias batrachus*	Caryophyllidea	Lytocestidae	*Lytocestus*	*filiformis* (Woodland, 1923) Fuhrmann and Baer, 1925	North East India
Cypriniformes	Cyprinidae	*Schizothorax richardsonii*	Caryophyllidea	Capingentidae	*Adenoscolex*	*oreini* Fotedar, 1958	Kashmir

HOST			PARASITE				
Order	**Family**	**Genus and species**	**Order**	**Family/Sub-Family**	**Genus**	**Species**	**Distribution**
Cypriniformes	Cyprinidae	*Hypselobarbus kolus* *Labeo calbasu*	Caryophyllidea	Capingentidae	*Breviscolex*	*aurangabadensis* Shinde,1970	Maharashtra
Cypriniformes	Cyprinidae	*Cirrhinus cirrhosus*	Caryophyllidea	Capingentidae	*Breviscolex*	*naldurgensis* Shinde, Mohekar, Jadhav and Haffezullah,1987	Maharashtra
Siluriformes	Clariidae	*Clarias batrachus*	Caryophyllidea	Capingentidae	*Capingentoides*	*gorakhnathai* Agarwal and Singh, 1985	Uttar Pradesh
Siluriformes	Bagridae	*Rita rita*	Proteocephalidea	Proteocephalidae, Subfam: Proteocephalinae	*Ritacestus*	*ritaii* (Verma 1926) de Chambrier, Scholz, Ash and Kar, 2011	Uttar Pradesh
Cypriniformes	Cobitidae	*Triplophysa kashmirensis*	Proteocephalidea	Proteocephalidae, Subfam: Proteocephalinae	*Proteocephalus*	*torulosus* (Batch,1786) Nufer, 1905	Kashmir
Siluriformes	Sisoridae	*Bagarius bagarius*	Proteocephalidea	Proteocephalidae, Subfam: Proteocephalinae	*Proteocephalus*	*vitellaris* Verma, 1928	Uttar Pradesh
Synbranchiformes	Mastacembelidae	*Mastacembelus armatus*	Proteocephalidea	Proteocephalidae, Subfam: Proteocephalinae	*Proteocephalus*	*vitellaris* Verma, 1928	Uttar Pradesh
Siluriformes	Siluridae	*Wallago attu*	Proteocephalidea	Proteocephalidae, Subfam:Proteocephalinae	*Gangesia*	*agraensis* Verma, 1928	Uttar Pradesh, West Bengal, Assam, Karnataka, Haryana, Kashmir, Maharashtra
Siluriformes	Siluridae	*Wallago attu*	Proteocephalidea	Proteocephalidae, Subfam: Gangesiinae	*Gangesia*	*bengalensis* (Southwell, 1913) Meggitt, 1927	Uttar Pradesh, West Bengal, Assam, Gujarat, Haryana, Kashmir, Maharashtra

HOST			PARASITE				
Order	**Family**	**Genus and species**	**Order**	**Family/Sub-Family**	**Genus**	**Species**	**Distribution**
Siluriformes	Bagridae	*Sperata seenghala*	Proteocephalidea	Proteocephalidae, Subfam: Gangesiinae	*Gangesia*	*macrones* Woodland, 1924	Maharashtra, Uttar Pradesh
Siluriformes	Bagridae	*Catfish*	Proteocephalidea	Proteocephalidae, Subfam: Gangesiinae	*Gangesia*	*vachai* (Gupta & Parmar, 1988) Ash, Scholz, de Chambrier, Brabec, Oros, Kar, Chavan and Mariaux, 2012	Uttar Pradesh, West Bengal, Assam
Cypriniformes	Cobitidae	*Acanthocobotis botia*	Pseudophyllidea	Bothriocephalidae	*Ptychobothrium*	*khami* Shinde and Deshmukh, 1975	Maharashtra
Cypriniformes	Cyprinidae	*Salmophasia phulo*	Pseudophyllidea	Bothriocephalidae	*Ptychobothrium*	*phuloi* Shinde and Deshmukh, 1975	Maharashtra
Cypriniformes	Cyprinidae	*Salmophasia balookee*	Pseudophyllidea	Bothriocephalidae	*Ptychobothrium*	*chelai* Shinde and Deshmukh, 1976	Maharashtra
Cypriniformes	Cyprinidae	*Salmophasia balookee*	Pseudophyllidea	Bothriocephalidae	*Ptychobothrium*	*clupeoidesii* Chincholikar, Shinde, Deshmukh and Jadhav, 1976	Maharashtra
Cypriniformes	Cyprinidae	*Raiamas bola Schizothorax richardsonii*	Pseudophyllidea	Bothriocephalidae	*Ptychobothrium*	*nayarensis* Malhotra, 1983	Uttarakhand
Channiformes	Channidae	*Channa gachua*	Pseudophyllidea	Bothriocephalidae	*Senga*	*besnardi* Dollfus, 1934	Maharashtra
Channiformes	Channidae	*Channa striatus*	Pseudophyllidea	Bothriocephalidae	*Senga*	*ophiocephalina* (Tseng,1933) Dollfus, 1934	West Bengal
Cypriniformes	Cyprinidae	*Labeo rohita*	Pseudophyllidea	Bothriocephalidae	*Senga*	*ophiocephalina* (Tseng,1933) Dollfus, 1934	West Bengal
Synbranchiformes	Mastacembelidae	*Mastacembelus armatus*	Pseudophyllidea	Bothriocephalidae	*Senga*	*lucknowensis* Johri, 1956	Uttar Pradesh
Channiformes	Channidae	*Channa punctata*	Pseudophyllidea	Bothriocephalidae	*Senga*	*lucknowensis* Johri, 1956	Uttar Pradesh

HOST			PARASITE				
Order	**Family**	**Genus and species**	**Order**	**Family/Sub-Family**	**Genus**	**Species**	**Distribution**
Siluriformes	Bagridae	*Bagarius bagarius*	Pseudophyllidea	Bothriocephalidae	*Senga*	*lucknowensis* Johri, 1956	Uttar Pradesh
Channiformes	Channidae	*Channa marulius*	Pseudophyllidea	Bothriocephalidae	*Senga*	*pycnomerus* Dollfus, 1934	Uttar Pradesh
Channiformes	Channidae	*Channa marulius*	Pseudophyllidea	Bothriocephalidae	*Senga*	*khami* Shinde and Deshmukh, 1980	Maharashtra
Siluriformes	Bagridae	*Sperata vittatus*	Pseudophyllidea	Bothriocephalidae	*Senga*	*yamunica* Gairola and Malhotra, 1986	Uttar Pradesh
Synbranchiformes	Mastacembelidae	*Mastacembelus armatus*	Pseudophyllidea	Bothriocephalidae	*Senga*	*indica* Gupta and Parmar, 1985	Uttar Pradesh
Synbranchiformes	Mastacembelidae	*Mastacembelus armatus*	Pseudophyllidea	Bothriocephalidae	*Senga*	*nayari* Malhotra, 1988	Uttarakhand
Channiformes	Channidae	*Channa punctatus*	Pseudophyllidea	Bothriocephalidae	*Senga*	*punctati* Gupta and Sinha, 1980	Uttar Pradesh
Synbranchiformes	Mastacembelidae	*Mastacembelus armatus*	Pseudophyllidea	Bothriocephalidae	*Senga*	*mastacembali* Gupta and Sinha,1980	Uttar Pradesh
Channiformes	Channidae	*Channa punctatus*	Pseudophyllidea	Bothriocephalidae	*Senga*	*teleostei* Banerjee *et al.*, 1990	Uttar Pradesh
Synbranchiformes	Mastacembelidae	*Mastacembelus armatus*	Pseudophyllidea	Bothriocephalidae	*Senga*	*aurangabadensis* Jadhav and Shinde, 1980	Maharashtra
Synbranchiformes	Mastacembelidae	*Mastacembelus armatus*	Pseudophyllidea	Bothriocephalidae	*Senga*	*godavarii* Shinde and Jadhav, 1980	Maharashtra
Synbranchiformes	Mastacembelidae	*Mastacembelus armatus*	Pseudophyllidea	Bothriocephalidae	*Senga*	*paithanensis* Kadam *et al.*, 1981	Maharashtra
Synbranchiformes	Mastacembelidae	*Mastacembelus armatus*	Pseudophyllidea	Bothriocephalidae	*Senga*	*maharashtrii* Jadhav *et al.*, 1991	Maharashtra
Synbranchiformes	Mastacembelidae	*Mastacembelus armatus*	Pseudophyllidea	Bothriocephalidae	*Senga*	*mohekarae* Tat *et al.*, 1997	Maharashtra

HOST			PARASITE				
Order	Family	Genus and species	Order	Family/Sub-Family	Genus	Species	Distribution
Synbranchiformes	Mastacembelidae	*Mastacembelus armatus*	Pseudophyllidea	Bothriocephalidae	*Senga*	*armatusae* Hiware,1999	Maharashtra
Siluriformes	Bagridae	*Mystus vittatus*	Pseudophyllidea	Bothriocephalidae	*Senga*	*vittati* Gairola and Malhotra, 1987	Uttar Pradesh
Siluriformes	Bagridae	*Mystus vittatus*	Pseudophyllidea	Bothriocephalidae	*Senga*	*gangesii* Gairola and Malhotra, 1986	Uttar Pradesh
Channiformes	Channidae	*Channa punctatus*	Pseudophyllidea	Bothriocephalidae	*Senga*	*raoi* Majid and Shinde, 1984	Orissa
Channiformes	Channidae	*Channa punctatus*	Pseudophyllidea	Bothriocephalidae	*Senga*	*jagannathae* Majid and Shinde, 1984	Orissa
Cypriniformes	Cyprinidae	*Labeo rohita*	Pseudophyllidea	Bothriocephalidae	*Senga*	*pathankotensis* Duggal and Bedi 1989	Punjab
Synbranchiformes	Mastacembelidae	*Mastacembelus armatus*	Pseudophyllidea	Bothriocephalidae	*Senga*	*kaigaonensis* Wankhede *et al.*, 2010	Maharashtra
Channiformes	Channidae	*Channa punctatus*	Pseudophyllidea	Bothriocephalidae	*Senga*	*panzraensis* Mangale and Kalse, 2009	Maharashtra
Synbranchiformes	Mastacembelidae	*Mastacembelus armatus*	Pseudophyllidea	Bothriocephalidae	*Senga*	*chauhani* Hasnain, 1992	Bihar
Synbranchiformes	Mastacembelidae	*Mastacembelus armatus*	Pseudophyllidea	Bothriocephalidae	*Senga*	*tappi* Patil and Jadhav, 2003	Maharashtra
Channiformes	Channidae	*Channa gachua*	Pseudophyllidea	Bothriocephalidae	*Senga*	*jadhavae* Bhure *et al.*, 2007	Maharashtra
Synbranchiformes	Mastacembelidae	*Mastacembelus armatus*	Pseudophyllidea	Bothriocephalidae	*Senga*	*gachuae* Jadhav *et al.*, 1991	Maharashtra
Synbranchiformes	Synbranchidae	*Monopterus cuchia*	Pseudophyllidea	Bothriocephalidae	*Senga*	*govindii* Jadhav *et al.*, 2012	Maharashtra
Siluriformes	Bagridae	*Rita rita*	Pseudophyllidea	Bothriocephalidae	*Senga*	*ayodhensis* Pande *et al.*, 2006	Uttar Pradesh

HOST			PARASITE				
Order	Family	Genus and species	Order	Family/Sub-Family	Genus	Species	Distribution
Synbranchiformes	Mastacembelidae	*Mastacembelus armatus*	Pseudophyllidea	Bothriocephalidae	*Senga*	*baughi* Pande *et al*., 2006	Uttar Pradesh
Channiformes	Channidae	*Channa striatus*	Pseudophyllidea	Bothriocephalidae	*Senga*	*madhavii* Bhure *et al*., 2010	Maharashtra
Channiformes	Channidae	*Channa striatus*	Pseudophyllidea	Bothriocephalidae	*Senga*	*rupchandensis* Pardeshi and Hiware, 2011	Maharashtra
Synbranchiformes	Mastacembelidae	*Mastacembelus armatus*	Pseudophyllidea	Bothriocephalidae	*Senga*	*sataraensis* Bhure and Nanware, 2011	Maharashtra
Synbranchiformes	Mastacembelidae	*Mastacembelus armatus*	Pseudophyllidea	Bothriocephalidae	*Senga*	*rostellare* Dhole *et al*., 2011	Maharashtra
Synbranchiformes	Mastacembelidae	*Mastacembelus armatus*	Pseudophyllidea	Bothriocephalidae	*Senga*	*chandrasekhari* Dhole *et al*., 2012	Maharashtra
Synbranchiformes	Mastacembelidae	*Mastacembelus armatus*	Pseudophyllidea	Bothriocephalidae	*Senga*	*nathsagarensis* Dhole *et al*., 2012	Maharashtra
Synbranchiformes	Mastacembelidae	*Mastacembelus armatus*	Pseudophyllidea	Bothriocephalidae	*Senga*	*chandikapurensis* Khadap *et al*., 2007	Maharashtra
Cypriniformes	Cyprinidae	*Pethia ticto*	Pseudophyllidea	Bothriocephalidae	*Senga*	*tictoi* Srivastav *et al*., 2007	Uttar Pradesh
Synbranchiformes	Mastacembelidae	*Mastacembelus armatus*	Pseudophyllidea	Bothriocephalidae	*Polyonchobothrium*	*srivastavai* Pande *et al*., 2006	Maharashtra
Synbranchiformes	Mastacembelidae	*Mastacembelus armatus*	Pseudophyllidea	Bothriocephalidae	*Polyonchobothrium*	*thapari* Pande *et al*., 2006	Maharashtra
Siluriformes	Bagridae	*Mystus vittatus*	Pseudophyllidea	Bothriocephalidae	*Polyonchobothrium*	*allahabadense* Malhotra, 1987	Uttar Pradesh
Synbranchiformes	Mastacembelidae	*Mastacembelus armatus*	Pseudophyllidea	Bothriocephalidae	*Polyonchobothrium*	*armatus* Malhotra, 1984	Uttar Pradesh
Synbranchiformes	Mastacembelidae	*Mastacembelus armatus*	Pseudophyllidea	Bothriocephalidae	*Polyonchobothrium*	*faizabadensis* Singh and Capoor, 1986	Uttar Pradesh

HOST			PARASITE				
Order	**Family**	**Genus and species**	**Order**	**Family/Sub-Family**	**Genus**	**Species**	**Distribution**
Synbranchiformes	Mastacembelidae	*Mastacembelus armatus*	Pseudophyllidea	Bothriocephalidae	*Polyonchobothrium*	*visakhapatnamensis* (Devil & Rao, 1973) Blair, 1978	Andhra Pradesh
Channiformes	Channidae	*Channa punctatus*	Pseudophyllidea	Bothriocephalidae	*Polyonchobothrium*	*indicum* Nama, 1979	Rajasthan
Cypriniformes	Cyprinidae	*Schizothorax plagiostomus* *Raiamus bendelisis* *Raiamus bola* *Garra gotyla* *Bangana dero* *Labeo rohita*	Pseudophyllidea	Bothriocephalidae	*Bothriocephalus*	*teleostei* Malhotra, 1984	Uttar Pradesh
Cypriniformes	Cyprinidae	*Labeo calbasu* *Labeo rohita,* *Catla catla* *Danio* sp. *Puntius* sp. *Amblypharyngodon microlepis*	Pseudophyllidea	Diphyllobothriidae	*Ligula*	*intestinalis* (Linnaeus, 1758) Bloch, 1782	West Bengal
Cypriniformes	Cobitidae	*Schistura rupecola*	Pseudophyllidea	Diphyllobothriidae	*Ligula*	*intestinalis* (Linnaeus, 1758) Bloch, 1782	West Bengal
Siluriformes	Bagridae	*Arius gagora*	Trypanorhyncha	Gymnorynchidae	*Gymnorhynchus (larval form)*	*gigas* (Cuvier, 1817) Rudolphi, 1819	West Bengal
Clupeiformes	Clupeiidae	*Tenualosa ilisha*	Trypanorhyncha	Gymnorhynchidae	*Gymnorhynchus (larval form)*	*gigas* (Cuvier, 1817) Rudolphi, 1819	West Bengal
Clupeiformes	Clupeiidae	*Tenualosa ilisha*	Trypanorhyncha	Otobothriidae	*Poecilancistrum*	*ilisha* (Southwell & Prashad, 1918) Dollfus, 1942	West Bengal
Clupeiformes	Clupeiidae	*Tenualosa ilisha*	Trypanorhyncha	Pterobothriidae	*Pterobothrium*	*filicolle* (Linton, 1890) Yamaguti, 1952	Bihar, West Bengal
Clupeiformes	Clupeiidae	*Tenualosa ilisha*	Trypanorhyncha	Tentaculariidae	*Tentacularia*	*ilisha* (Southwell & Prashad, 1918) Dollfus, 1942	West Bengal

Chapter 7

ROTIFERA : EUROTATORIA (ROTIFERS)

B.K. SHARMA AND SUMITA SHARMA

ABSTRACT

The Indian literature on the phylum published since inception is reviewed, all taxa recorded till date are evaluated and 419 valid rotifer species belonging to 65 genera and 25 families are recognized from freshwaters environs of India. The nature and composition of Eurotatoria is analyzed with reference to richness from different parts of India, elements of global and regional biogeography value, distribution of interesting taxa and taxonomic anomalies. The rich rotifer diversity of the relatively extensively sampled northeast India (NEI); and the floodplains of Assam and Manipur states of NEI, and Deepor Beel and Loktak Lake-two Ramsar sites of India in particular focused attention on the '*Rotiferologist effect*'. Impediments hampering the biodiversity progress of the Indian Rotifera are highlighted, and the scope of systematic and biogeography is indicated with suggestions for improvement of the state-of-art.

Key words: Biodiversity, ecosystem diversity, anomalies, dubious report, interesting taxa, misidentification, status, scope.

INTRODUCTION

Rotifera or 'Rotatoria' or 'wheel animalcules' are pseudocoelomate metazoans usually microscopic in size and characterized by unique 'wheel organ' or 'corona' and diagnostic 'trophi'; the former impart an illusion of a pair of rotating wheels and hence 'rotating' locomotion. The members of this phylum form an integral component of aquatic food-webs, serve as useful bio-indicators of water quality (Sladecek, 1983), test organisms in toxicology experiments (Arnold et al. 2011), and fish-food in aquaculture (Lubzens, 1987; Ogata and Kurokura, 2011). The rotifers exhibit endless profusion of body forms adapted to the living habits and closely associated with their habitats. These micro-invertebrates are ideal tools for ecological considerations and population dynamics analysis because of their ability to colonize diverse aquatic and semi-aquatic biotopes and an inherent quality to build up substantial densities within short time intervals.

The rotifers have attracted attention of naturalists and hydro-biologists globally ever since invention of the microscope. The systematic studies on the Indian Rotifera were initiated by Anderson (1889) based on collections from Kolkata (Calcutta) and its environments from West Bengal. Early taxonomic

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progress till mid of 20th century was rather slow with important works of Murray (1906), Edmondson and Hutchinson (1934), Hauer (1936, 1937a, 1937b), Donner (1949), Brehm (1950, 1951) while the revisions of Ahlstrom (1940, 1943) on *Brachionus* and *Keratella*, respectively also referred to collections from India. 'Synopsis of taxonomic studies on Indian Rotifera' (Sharma and Michael, 1980) provided an overview of the progress till 1980's. A resurgence of taxonomic interest was registered in the following two decades till end of 20th century culminating in a series of works. The salient features of this progress were traced in overviews of the state-of-art of the Indian Rotifera by Sharma (1991, 1996, 1998a) and the works of Sharma (1983, 1987), Battish (1992) and Dhanapathi (2000).

The period from the beginning of 21st century till date registered marked spurt of apparently non-peer viewed or poorly reviewed publications mostly including 'ad-hoc' ecology reports and faunal listing in various online journals and ironically loaded with incomplete species inventories, fuzzy identifications and questionable records warranting validation (Sharma personal communication). Nevertheless certain notable works during this period included paper on Rotifera diversity of Northeast India (Sharma and Sharma, 2014a) and the reviews on the Indian Lecanidae (Sharma and Sharma, 2014b), Brachionidae (Sharma and Sharma, 2014c) and Lepadellidae (Sharma and Sharma, 2015a). Besides, the works of Sharma and Sharma (2008, 2013) provided valuable information for meta-analysis of the rotifer diversity. On the contrary, the local inventories from Wasim district of Maharashtra (Tayade and Dabhade, 2011), Andhra Pradesh (Karuthapandi *et al.*, 2013) and Jammu and Kashmir (Shah *et al.*, 2015) are uncritical compilations loaded with duplicate and dubious reports and thus merit caution.

The published literature and reports of all taxa of the phylum known till date from India are scrutinized, 419 valid species are recognized and a detailed break-up of the documented diversity is presented. A comprehensive checklist of the Indian Rotifera is, however, being published separately and shall be available thereafter for its reference. The nature and composition of the rotifer fauna of India is analyzed with reference to interesting elements, biogeography and taxonomic anomalies and nomenclatural discrepancies. The impediments hampering progress of Rotifera taxonomy in India are analyzed vis-à-vis various lacunae and the future biodiversity scope is indicated with suggestions for improvement of the state-of-art of the taxon.

METHODS

This meta-analysis assessment of Rotifera biodiversity is the result of critical overview of the Indian literature coupled with possible validation of the documented taxa based on the published reports and on the collections examined by the author from different parts of India. The available reports are compared against the standard works of Koste (1978), Koste and Shiel (1987, 1989, 1990), Shiel and Koste (1992), Segers (1995, 1996), De Smet (1996, 1997), Sharma (1983, 1987, 1998b), Sharma and Sharma (1999, 2000, 2014b, 2014c, 2015a), Sharma and Sharma (2008, 2013), and Nogrady and Segers (2002). Segers (2002, 2007) and Jersabek and Leitner (2013) are followed for classification, nomenclature and biogeography. All the rotifer taxa described or recorded from India are considered with particular attention to their status, validity and distribution.

RESULTS

The Indian Rotifera literature is loaded with several anomalous, ambiguous, fuzzy and unverifiable reports which render any critical assessment of diversity evaluation a difficult task till all the reported taxa are virtually verified. We recognize 419 species validly known till date from India; the family-wise breakup of the recorded rotifer is indicated in Table 1 while a critical annotated check list of Indian freshwater Rotifera is being published separately and thus not presented herein because of conflict of interests.

Table 1. Family-wise break up of composition of Indian Rotifera*, #
(Source: BKS, unpublished)

Families	Species	Genera
Subclass MONOGONONTA		
Order PLOIMA		
Family BRACHIONIDAE	46	7
Family EPIPHANIDAE	07	4
Family EUCHLANIDAE	13	5
Family MYTILINIDAE	10	2
Family TRICHOTRIIDAE	08	3
Family LEPADELLIDAE	44	3
Family LECANIDAE	89	1
Family PROALIDAE	03	1
Family NOTOMMATIDAE	32	6
Family SCARIDIIDAE	01	1
Family GASTROPODIDAE	06	2
Family TRICHOCERCIDAE	35	2
Family ASPLANCHNIDAE	08	2
Family SYNCHAETIDAE	11	3
Family DICRANOPHORIDAE	08	3
	321	**45**
Order FLOSCULARIACEAE		
Family FLOSCULARIDAE	19	6
Family CONOCHILIDAE	04	1
Family HEXARTHRIDAE	04	1
Family TESTUDINELLIDAE	13	2
Family TROCHOSPHAERIDAE	11	3
	51	**13**

Families	Species	Genera
Order COLLOTHECACEAE		
Family ATROCHIDAE	01	1
Family COLLOTHECIDAE	08	1
	09	**2**
Sub-class BDELLOIDEA		
Family ADINETIDAE	02	1
Family HABROTROCHIDAE	08	1
Family PHILODINIDAE	27	3
	37	5
TOTAL TAXA	**419**	**65**

* Not included: Philodinavidae and Lindiidae: unconfirmed reports.
# an annotated check list of Indian freshwater Rotifera is being published separately.

DISCUSSION

Composition, richness and diversity

A total of 419 species (S) belonging to 65 genera and 25 families are considered valid in this biodiversity assessment of the Indian Rotifera. The richness is in contrast to synopsis of taxonomic studies (Sharma and Michael, 1980) firstly enlisting 241 species. Sharma (1991, 1996, 1998a) reported 310, 316 and 330 species (excluding doubtful taxa), respectively while Battish (1992) reported 242 taxa based on a slightly modified list *vide* Sharma and Michael (1980). The compilation by Dhanapathi (2000) listed 300 species which on critical scrutiny (BKS, unpublished) represented 260+ species. The distinct biodiversity update presented in this account is facilitated by several new records by authors from different states of NEI during the last two decades. Total rotifer richness (S) now known from India comprised ~81% and ~24% of species of the taxon reported (vide Segers, 2008) from the Oriental region and world-wide, respectively and thus deserved biodiversity interest. Nevertheless, the Indian fauna is more biodiverse than 398 species known from the relatively well studied Thai rotifer fauna (Sa-Ardrit *et al.,* 2013) amongst south and Southeast Asia. It is, however, not feasible to compare the diversity of Eurotatoria of India with other countries of the Indian sub-continent because of yet incomplete species inventories.

Indian Rotifera is characterized by notable fraction (~16 % of S) of taxa of global biogeography interest of the following categories:

Endemic: *Asplanchnopus bhimavaramensis* Dhanapathi, *Collotheca hexalobata* Banik, *C. tetralobata* Banik, *Lecane jaintiaensis* Sharma, *L. schraederi* Wulfert, *L. pawlowski* Wulfert, *L. vasishti* Sharma, *Lepadella kostei* Wulfert, *L.nartiangensis* Sharma & Sharma, *Platyias quadricornis andhraensis* Dhanapathi, *Proales indirae* Wulfert, *Pseudoeuchlanis longipedes* Dhanapathi, and *Rotaria ovata* (Anderson);

Australasian: *Brachionus dichotomus reductus* Koste & Shiel, *B. kostei* Shiel, *Macrochaetus danneelae* Koste & Shiel, *Lecane batillifer* (Murray), *L. shieli* Segers & Sanoamuang, *Notommata spinata* Koste & Shiel, *Testudinella walkeri* Koste & Shiel, and *Philodina squamosa* Murray;

Oriental endemics: *Brachionus donneri* Brehm, *Colurella sanoamuangae* Chittapun, Pholpunthin & Segers, *Filinia camasecla* Myers, *Keratella edmondsoni* Ahlstrom, *Lecane acanthinula* (Hauer), *L. blachei* Berzins, *L. bulla diabolica* (Hauer), *L. isanensis* Sanoamuang & Savatenalinton, *L. latissima* Yamamoto, *L. niwati* Segers, Kothetip & Sanoamuang, *L. solfatara* (Hauer), *L. superaculeata* Sanoamuang & Segers, *Proales indirae* Wulfert, and *Ptygura stephanion* (Anderson);

Paleotropical: *Keratella javana* Hauer, *Dipleuchlanis ornata* Segers, *Euchlanis semicarinata* Segers, *Lepadella bicornis* Vasisht & Battish, *L. discoidea* Segers, *L. minoruoides* Koste & Robertson, *L. vandenbrandei* Gillard, *Lecane eswari* Dhanapathi, *L. lateralis* Sharma, *L. simonneae* Segers, *L. unguitata* (Fadeev), *Trichocerca abilioi* Segers & Sarma, *T. brazieliensis* (Murray), *T. hollaerti De Smet, T. kostei* Segers, *Polyarthra indica* Segers & Babu, *Testudinella brevicaudata* Yamamoto, and *T. greeni* Koste;

Palaearctic: *Squatinella bifurca* (Bolton), *Cephalodella trigona* (Rousselet), and *Encentrum longipes* Wulfert;

Holarctic: *Lecane depressa* (Bryce), *Lecane elasma* Harring & Myers, *L. elongata* Harring & Myers, *L. galeata* (Bryce), *L. levistyla* (Olofsson), *L. stokesii* (Pell), *L. styrax* (Harring & Myers), *Trichocerca taurocephala* (Hauer), and *T. uncinata* (Voigt); and

Indo-Chinese: *Lecane dorysimilis* Trinh Dang, Segers & Sanoamuang.

The report of the Australasian elements in the Indian Rotifera imparted a unique character and distinct biogeography importance and an interesting affinity with the faunas of Southeast Asia and Australia. This salient aspect endorsed the remarks of Sharma (2005), Sharma and Sharma, (2008), Sharma and Sharma (2012, 2014a) and Sharma *et al.* (2016) based on NEI Rotifera. The presence of a sizable component of the Oriental endemics and Palaeotropical species is notable; the former reiterated its affinity with Southeast Asian faunas. The relative paucity of endemic taxa is elusive as several species are awaiting descriptions pending examination of more materials (BKS, personal communication) while several others added recently as new records from India have been newly described elsewhere from Thailand. The tropical-latitude populations of various Holarctic and Palaearctic species known from our inland waters are likely to represent glacial relicts as hypothesized by Segers (1996) while the reports of certain others at foot hills of Himalayas may be attributed to extension of the Himalayan mountain ranges as hypothesized by Sharma and Sharma (2014c).

Freshwater Rotifera of India revealed a large fraction of species (~ 37% of S) of regional distribution interest in the Indian sub-region with still an important fraction (~11%) characterized by distribution till this date restricted to NEI. These features thus highlighted importance of Eurotatoria vis-à-vis regional biogeography. Various members of this category included:

1. *Ascomorpha ecaudis* Perty, 1850
2. *A. saltans indica* Wulfert, 1966
3. *Ascomorphella volvocicola* (Plate, 1886)
4. *Brachionus bennini* Leissling, 1924
5. *B. dichotomus reductus* Koste & Shiel, 1980 *
6. *B. dimidiatus* Bryce, 1931
7. *B. donneri* Brehm, 1951
8. *B. falcatus reductus* Koste & Shiel, 1987*
9. *B. kostei* Shiel, 1983*
10. *B. leydigii* Cohn, 1862
11. *B. pterodinoides Rousselet*, 1913*
12. *B. rotundiformis* Tschugunoff, 1921
13. *B. sessilis* Varga, 1951
14. *Cephalodella gigantea* Remane, 1933
15. *C, intuta* Myers, 1924*
16. *C.megalocephala* (Glascott, 1893)
17. *C.misgurnus* Wulfert, 1937
18. *C. panarista* Myers, 1924
19. *C.ventripes* (Dixon-Nuttall, 1901)*
20. Co*lurella colurus* (Ehrenberg, 1830)
21. *C. oxycauda* Carlin 1939
22. C. *sanoamuangae* Chittapun, Pholpunthin & Segers, 1999
23. *Cyrtonia tuba* (Ehrenberg, 1834)
24. *Dipleuchlanis ornata* Segers, 1993*
25. *Euchlanis deflexa* Gosse, 1851
26. *Euchlanis meneta* Myers, 1930
27. *Euchlanis semicarinata* Segers, 1993*
28. *Eosphora anthadis* Harring & Myers, 1922
29. *E. najas* Ehrenberg, 1830
30. *Itura aurita* (Ehrenberg, 1830)
31. *Gastropus hyptopus* (Ehrenberg, 1838)
32. *G. minor* (Rousselet, 1892) *
33. *G. stylifer* Imhof, 1891
34. *Kellicottia longispina* (Kellicott, 1879)
35. *Keratella edmondsoni* Ahlstrom, 1943
36. *K. hiemalis* Carlin, 1943
37. *K. javana* Hauer, 1937*
38. *K. serrulata* (Ehrenberg, 1838)
39. *K. ticinensis* (Callerio, 1921)
40. *Lecane acanthinula* (Hauer, 1938)
41. *L. aeganea* Harring, 1914*
42. *L. arcuata* (Bryce, 1891)
43. *L. aspasia* Myers, 1917*
44. *L. batillifer* (Murray, 1913) *
45. *L. bifastigata* Hauer, 1938
46. *L .bifurca* (Bryce, 1892)
47. *L. blachei* Bērziņš, 1973
48. *L. braumi* Koste, 1988
49. *L. bulla diabolica* (Hauer, 1936)
50. *L. doryssa* Harring, 1914
51. *L. elasma* Harring & Myers, 1926
52. *L. elongata* Harring & Myers, 1926
53. *L. eswari* Dhanapathi, 1976
54. *L. galeata* (Bryce, 1892)
55. *L. glypta* Harring & Myers, 1926*
56. *L. haliclysta* Harring & Myers, 1926
57. *L. jaintiaensis* Sharma, 1987
58. *L. lateralis* Sharma, 1978
59. *L. latissima* Yamamoto, 1951
60. *L. levistyla* (Olofsson, 1917)
61. *L. ligona* (Dunlop, 1901)

62. *L. niwati* Segers, Kothetip & Sanoamuang, 2004*
63. *L. pawlowskii* Wulfert, 1966
64. *L. paxiana* Hauer, 1940
65. *L. perplexa* (Ahlstrom, 1938)
66. *L. pertica* Harring & Myers, 1926
67. *L. pusilla* Harring, 1914
68. *L. rhenana* Hauer, 1929*
69. *L. rhytida* Harring & Myers, 1926*
70. *L. rugosa* (Harring, 1914)
71. *L. ruttneri* Hauer, 1938
72. *L. schraederi* Wulfert, 1966
73. *L. scutata* (Harring & Myers, 1926)
74. *L simonneae* Segers, 1993
75. *L. sinuata* (Hauer, 1938)
76. *L. solfatara* (Hauer, 1938) *
77. *L. stokesii* (Pell, 1890)
78. *L. syngenes* (Hauer, 1938)
79. *L. tenuiseta* Harring, 1914
80. *L. undulata* Hauer, 1938*
81. *L. vasishti* Sharma, 1980
82. *L. verecunda* Harring & Myers, 1926
83. *Lepadella benjamini* Harring, 1916*
84. *L. bicornis* Vasisht & Battish, 1971
85. *L. biloba* Hauer, 1958
86. *L. costatoides* Segers, 1992
87. *L. dactyliseta* (Stenroos, 1898)
88. *L. desmeti* Segers & Chittapun, 2001*
89. *L. discoidea* Segers, 1993
90. *L. elongata* Koste, 1992*
91. *L. imbricata* Harring, 1914
92. *L. kostei* Wulfert, 1966
93. *L. latusinus* (Hilgendorf, 1889)*
94. *L. lindaui* Koste, 1981
95. *L. longiseta* Myers, 1934
96. *L. minoruoides* Koste & Robertson, 1983*
97. *L. nartiangensis* Sharma & Sharma, 1987*
98. *L. patella oblonga* (Ehrenberg, 1834) *
99. *L. patella persimilis* De Ridder, 1961
100. *L. quadricarinata* (Stenroos, 1898)
101. *L. quinquecostata* (Lucks, 1912)
102. *L. rhomboidula* (Bryce, 1890)
103. *L. triba* Myers, 1934
104. *L. vandenbrandei* Gillard, 1952*
105. *L. heterodactyla* Fadeew, 1925*
106. *Lophocharis naias* Wulfert, 1942
107. *Macrochaetus danneelae* Koste & Shiel, 1983*
108. *M. longipes* Myers, 1934
109. *M. subquadratus* Perty, 1850
110. *Mikrocodides chlaena* (Gosse, 1886)
111. *Monommata actices* Myers, 1930
112. *Monommata grandis* Tessin, 1890*
113. *Monommata longiseta* (O.F. Müller, 1786)
114. *Monommata maculata* Harring & Myers, 1930
115. *Mytilina michelangellii* Reid & Turner, 1988*
116. *M. mucronata* (O.F. Muller, 1773)
117. *Notholca labis* Gosse, 1887
118. *N. squamula* (O.F. Muller, 1786)
119. *N. striata* (Müller, 1786)
120. *Notommata aurita* (Müller, 1786)
121. *Notommata glyphura* Wulfert, 1935

122. *Notommata pachyura* (Gosse, 1886)
123. *Notommata pseudocerberus* De Beauchamp, 1908
124. *Notommata saccigera* Ehrenberg, 1830
125. *Notommata spinata* Koste & Shiel, 1991*
126. *Platyias leloupi* (Gillard, 1967)
127. *Proalides subtilis* Rodewald, 1930
128. *Proales decipiens* (Ehrenberg, 1832)
129. *P. fallaciosa* Wulfert, 1937
130. *P. indirae* Wulfert, 1966
131. *Rhinoglena frontalis* Ehrenberg, 1853
132. *Squatinella bifurca* (Bolton, 1884)*
133. *Taphrocampa annulosa* Gosse, 1851*
134. *T. selenura* Gosse, 1887
135. *Trichotria pocillum* (O.F. Muller, 1776)
136. *T. abilioi* Segers & Sarma, 1993*
137. *T. bidens* (Lucks, 1912) *
138. *T. brachyura* (Gosse, 1851)
139. *T. brazieliensis* (Murray, 1913)
140. *T. chattoni* (De Beauchamp, 1907)
141. *T. hollaerti* De Smet, 1990*
142. *T. iernis* (Gosse, 1887)
143. *T. insignis* (Herrick, 1885) *
144. *T. insulana* (Hauer, 1937) *
145. *T. kostei* Segers, 1993
146. *T. maior* Hauer, 1936*
147. *T. myersi* (Hauer, 1931)
148. *T. scipio* (Gosse, 1886)
149. *T. siamensis* Segers & Pholpunthin, 1997 *
150. *T. stylata* (Gosse, 1851)
151. *T. sulcata* (Jennings, 1894) *
152. *T. taurocephala* (Hauer, 1931) *
153. *T. tenuior* (Gosse, 1886)
154. *T. uncinata* (Voigt, 1902) *
155. *T. voluta* (Murray, 1913)
156. *Wolga spinifera* (Western, 1894)

* Species yet known to be restricted to northeast India (NEI)

Interestingly, nineteen taxa, originally described from India, are characterized by extension of their distribution ranges. This category included the following taxa:

1. *Adineta longicornis* Murray, 1906
2. *Ascomorpha saltans indica* Wulfert, 1966
3. *Brachionus donneri* Brehm, 1951
4. *B. durgae* Dhanapathi, 1974
5. *Floscularia tenuilobata* Anderson, 1889
6. *Habrotrocha angusticollis attenuata* (Murray, 1906)
7. *H. nodosa* (Murray, 1906)
8. *H. perforata* (Murray, 1906)
9. *Horaella brehmi* Donner, 1949
10. *Keratella edmondsoni* Ahlstrom, 1943
11. *Lecane bulla diabolica* (Hauer, 1936)
12. *L. eswari* Dhanapathi, 1976
13. *L. lateralis* Sharma, 1978
14. *Lepadella bicornis* Vasisht & Battish, 1971
15. *Philodina squamosa* Murray, 1906
16. *P. indica* Segers & Babu, 1999
17. *Ptygura stephanion* (Anderson, 1889)
18. *Rotaria mento* (Anderson, 1889)
19. *R. sordida fimbriata* (Murray, 1906)

Sharma (1991, 1996, 1998a) stressed lacunae on inadequate studies on detailed analysis of the rotifer diversity from different states of India notwithstanding the fact that the fauna is yet by no means adequately explored. This generalization holds valid even till date after time lapse of over 120 years since inception of the work by Anderson (1889). The regional investigations are altogether lacking except for the report of 238 species belonging to 50 genera and 23 families, making NEI one of the most specious and diverse region of India vis-à-vis Rotifera (Sharma and Sharma, 2014a). Even this status now stands updated with the report of nearly 280 species (BKS, unpublished). The state of Assam of NEI is most biodiverse with the report of 220 rotifer species (Sharma and Sharma, 2014a); 162 and 161 species are known from the hill states of Mizoram (Sharma and Sharma, 2015b) and Meghalaya (Sharma *et al.*, 2016), respectively; 162 species are enlisted from Manipur (Sharma *et al.,* 2016); 152 species are known from Tripura (Sharma and Sharma, 2000) while the rotifer faunas of Arunachal Pradesh and Nagaland are being investigated (BKS, unpublished) and that of Sikkim remained unexplored expect for the sole report of Murray (1906). Besides, the reports of 148 species from West Bengal (Sharma, 1998b) from eastern India and 177 species from Tamil Nadu (Sharma and Sharma, 2009) of south India deserved attention while the review from Jammu and Kashmir (Shah et al. 2015) is riddled with inherent inconsistencies to provide a reliable count of richness (BKS, unpublished). Ironically, the rotifer faunas of various other states of north, eastern, central, western and south India are yet highly under-explored. Interestingly, the sole study on freshwater rotifers off the Indian mainland referred to the report from south Andaman (Sharma, 2017); the findings indicated much scope of extending such a endeavor to freshwaters ecosystems of the Andaman and Nicobar as well as Lakshadweep Islands.

Eurotatoria is largely overlooked vis-à-vis ecosystem diversity in the Indian studies. Nevertheless, 220 species known (Sharma and Sharma, 2014a, 2014d) from the floodplains of the Brahmaputra river basin characterized these ecotones as one of the globally diverse rotifer habitats. Deepor Beel, a Ramsar site and an important floodplain lake of NEI, is individually ranked the globally important rotifer 'hot-spot' (Sharma, B.K. and Sharma, S., 2015c). This is followed by the report of 162 species (Sharma *et al.*, 2016) from Loktak Lake (another Ramsar site). Total richness (S value) of the two wetlands concurred with the report (Dumont and Segers, 1996) for 'All Taxa Biological Inventories (ATBI)' for the rotifer assemblages of temperate and subtropical lakes (S=123–210). The reports of 144 species (Sharma, 2014; Sharma *et al.*, 2015) from Majuli- the largest river island and 154 species from four beels of lower Assam (Sharma *et al.*, 2017) endorsed rich rotifer diversity of the Brahmaputra floodplains and highlighted the importance of the '*rotiferologist effect'* advanced by Fontaneto *et al*. (2012). Total richness known from the Brahmaputra floodplains is notably higher than the reports of 110 species (Arora and Mehra, 2003) from the backwaters of the river Yamuna at Delhi, 27 species from two floodplain lakes of Kashmir (Khan, 1987) and 38 species from four ox-bow lakes and nine floodplain lakes of South-eastern West Bengal (Khan, 2003). The richness is strikingly low (90 species) in the "seasonal" floodplains (*hoars*) of the Barak River basin of Assam (Sharma and Sharma, 2014a).

Lecanidae, the largest family of monogonont rotifers, is most biodiverse (89 species; ~21% of S) in inland waters of India. Brachionidae (46 species) > Lepadellidae (44 species) > Trichocercidae (36 species) > Notommatidae (32 species) collectively comprised an important fraction (~38 % of S). The biodiversity importance of five families of Eurotatoria broadly concurred with the reports from Thailand (Sa-Ardrit *et al.*, 2013) and the Oriental fauna (Segers, 2008). Interestingly, majority of the families, except Brachionidae, include predominantly littoral-periphytic taxa (Segers, 2001). Latitudinal variations are well known in the distribution of Rotifera (Green, 1972; De Ridder, 1981; Dumont, 1983; Segers, 1996) while Segers (2001) stressed the role of thermopiles in the fauna of Southeast Asia with significance of *Lecane* and *Brachionus*. The lecanid dominance compared well with the reports from Africa (Segers *et al.*, 1993, 1998), Thailand (Sa-Ardrit *et al.*, 2013) and Argentina (Jose de Paggi, 2001). More specific information is provided in the reviews on the Indian Lecanidae (Sharma and Sharma, 2014b), Brachionidae (Sharma and Sharma, 2014c) and Lepadellidae (Sharma and Sharma, 2015a). The significance of `tropic-centered' *Lecane* and *Brachionus*, large fraction of cosmopolitan species and occurrence of several pantropical and cosmotropical species imparted a general 'tropical character' to the rotifer fauna of India. This generalization is conformity with the composition of the tropical faunas from different parts of the globe (Pejler, 1977; Fernando, 1980; Dussart *et al.*, 1984; Segers, 1996, 2001, 2008).

TAXONOMIC STATUS

The Indian literature included several examples of taxonomic and nomenclature anomalies with 'sloppy and uncritical' descriptions of various taxa as indicated below:

Genus & species ***inquirenda***

The following taxa are affirmed as invalid vide Segers (2007) and, Jersabek and Leitner (2013):

Diplois daviesiae Gosse, 1886

Pseudoembata acutipoda Wycliffe & Michael, 1968

Nomen nudum

Four species proposed from India are categorized as *nomen nudum* in the absence of medatory taxonomic descriptions and illustrations:

Platyias dalensis: Dal Lake, Kashmir (Das & Akhtar 1976)

Lepadella bela: Uttrakhand (Sharma & Pant, 1985)

Lecane chandramohani sp. nov : Andhra Pradesh (source unknown?)

Lecane radhakrishnai sp. nov: Andhra Pradesh (source unknown?)

Of these, *Lepadella bela*, appearing in the species list from two lakes of Uttarakhand (Sharma and Pant, 1985), was designated as *nomen nudum* vide Sharma and Sharma (2015a). *Platyias dalensis* appeared in a report from Dal Lake, Kashmir (Das and Akhtar 1976) but to our knowledge it is never described till date. This statement also holds valid for *Lecane chandramohani* sp. nov and *L. radhakrishnai* sp. nov which appeared in the list of Karuthapandi *et al.* (2013) but yet remained un-described. The said three species are thus designated as *nomen nudum* and considered invalid.

Species ***inquirenda***

In all nine new species, described from India, are '*species inquirenda'* (refer: Segers, 2007):

Cephalodella wiszniewskii Edmondson & Hutchinson, 1934

Conochilus arboreus Rajendran, 1971

Conochilus madurai Michael, 1966

Lecane bidentata Dhanapathi, 1976

Lepadella triprojectus Sharma 1978

Lindia intermedia Dhanapathi and Rama Sarma, 2000

Polyarthra multiappendiculata Arora, 1962

Metopidia torquata, Anderson 1889

Sinantherina triglandularis Arora, 1963

Of these, Sharma (1978) described *Lepadella triprojectus* from West Bengal based on a single specimen (insufficient material). According to Jersabek and Leitner (2013), the three diagnostic tube-like projections are the result of a fungus infection (Chytridiomycota/Hyphochytridiomycota) and represent evacuation tubes of zoosporangia for the zoospores. We are well aware of limitation of "type material" and possibility of a fungal infection in particular and, hence, confirm this taxon as *species inquirenda* (Sharma and Sharma, 2015a).

Synonymized species / taxa

We emphasize on 'sloppy and uncritical' descriptions of new Indian taxa as highlighted by synonymized 15 new species and subspecies:

Brachionus caudatus var. *indica* Novotná-Dvořáková, 1963	= *B. ahlstromi* Lindeman, 1939
B. forficula var. *keralaiensis* Nayar & Nair, 1969	= *B. forficula* Wierzejski, 1891
Conochilus dossuarius var. *asetosus* Arora, 1962	= *Conochilus dossuarius* Hudson, 1885
Euchlanis brahmae Dhanapathi, 1976	= *Euchlanis triquetra* Ehrenberg, 1838
Lecane curvilinealis Arora, 1965	= *Lecane curvicornis* (Murray, 1913)
Lecane donnerianus Dhanapathi, 1976	= *Lecane ungulata* (Gosse, 1887)
Lecane dorsicalis Arora, 1965	= *Lecane luna* (Müller, 1776)
Lecane longidactyla Arora, 1965	= *Lecane curvicornis* (Murray, 1913)
Lecane neali Wulfert, 1966	= *Lecane crepida* Harring, 1914
Lecane paradecipiens Nayar, 1968	= *Lecane thalera* (Harring & Myers, 1926)
Lecane padespares Arora, 1965	= *Lecane curvicornis f. miamiensis* Myers, 1941
Lecane tesselata Arora, 1965	= *Lecane nitida* (Murray, 1913)
Lecane yamunensis Novotná-Dvořáková, 1963	= *Lecane papuana* (Murray, 1913)
Trichocerca tropis Hauer, 1937	= *Trichocerca voluta* (Murray, 1913)
Platyias longispinosus Arora, 1966	= *Platyias leloupi* (Gillard, 1967)

Attracted by morphological plasticity inherent in several rotifer taxa, the Indian workers have invariably designated infra-specific (sub) categories which do not warrant nomenclatural validity. We focus caution on uncritical usage of lower ranks while the status of certain such new names proposed from India is now indicated as hereunder:

Lecane luna f. *dorsicalis* Sharma, 1978	= *L. luna* (Müller, 1776)
Lecane crepida f. *bengalensis* Sharma, 1978	= *Lecane crepida* Harring, 1914
Lecane luna f. *dorsicalis* Sharma, 1978	= *Lecane luna* (Müller, 1776
Lepadella patella elongata Sharma & Sharma, 1987*	= Lepadella *patella* (O.F. Muller, 1773)
Lepadella patella oblongata Sharma & Sharma, 1999*	= *L. patella oblonga* (Ehrenberg, 1834)
Lepadella ovalis f. larga Sharma, 1978*	= *Lepadella discoidea* Segers, 1993

*refer Sharma and Sharma (2015a)

TAXONOMIC IMPEDIMENTS

The progress of biodiversity and biogeography of the Indian Eurotatoria is severely impaired by considerations highlighted below:

Poor taxonomic resolutions

The Indian literature is flooded with works explicating poor quality in context of global levels of Rotifera taxonomy. 'Poor illustrations' or 'lack of illustrations' or of micro-photographs in majority of works are impediments to enable an objective opinion on actual status of the recorded taxa. These aspects vis-à-vis new reports attract criticism on authenticity and render them invariably unverifiable. SEM studies, morphometric analysis and studies of trophi are largely ignored in spite of attention drawn on some aspects by Sharma and Michael (1980).

Incomplete species lists

Though routinely noticed in the Indian surveys, such inventories are handicap for biodiversity and ecosystem diversity while biogeography attempts based on these are vulnerable to criticism. The frequent overlooking identification of smaller due to difficulties of sorting and mounting, and adequate expertise is a prime concern of incomplete species inventories (BKS, personal communication).

Out-dated manuals

The rotifer workers from India frequently rely on works of Edmondson (1959), Needham and Needham (1962), Michael (1973), Tonapi (1980) and Battish (1992) which inevitably have current limitations to facilitate correct species delineations.

Insufficient literature updates

The global progress in Rotifera taxonomy have largely escaped attention of workers from India. Important global manuals for several have evaded attention for various reasons. This lacuna also holds valid for review works of the Indian origin.

Fuzzy species inventories

The fuzzy inventories and uncritical checklists are misleading. The lists of the rotifers from Wasim district of Maharashtra (Tayade and Dabhade, 2011), Andhra Pradesh (Karuthapandi *et al.,* 2013), Jammu & Kashmir (Shah *et al.,* 2015), and on the Indian rotifers (Dhanapathi, 2000) are classical examples of anomalous compilations that merit cautious use.

Lack of 'voucher / type-specimens'

Lack of voucher species or access thereof are of concern for the Indian Rotifera biodiversity assessment otherwise riddled with a concerning magnitude of unverifiable records. We extend also this concern to non-availability to certain type-specimens.

Inadequate expertise

With amateurs increasingly creating nomenclatural mess and spurious on-line journals publishing dubious reports, lack of taxonomic expertise is of prime importance.

Lack of biogeography considerations

The routine inventories without comments on nature and composition, and distribution of taxa are merely rendered as ad-hoc 'laundry lists.

Species lists vis-à-vis political boundaries

Changes in political boundaries and creation of newer states effect the rotifer inventories of Bihar, Jharkhand, Andhra Pradesh, Telegana and Uttarakhand etc. Changes in names of West Bengal (=Bengal) and Orissa (=Odisha) should appropriately be followed. Such changes certainly confuse international readers.

Collaborations apprehensions

'*National Identification Advisory Service for. Rotifera*' offered by the senior author (BKS) since the last three decades has received limited response. Our attempts to forge national collaborations or network invoked little success.

SCOPE OF ROTIFERA BIODIVERSITY

Notwithstanding the current assessment, the biodiversity and biogeography of the Indian Rotifera offers ample perspective for future investigators as indicated below:

Biodiversity update

The faunal diversity of the taxon vs. regional surveys, following analogy of Northeast Indian Rotifera and supported with extensive collections from diverse freshwater biotopes, merit future interest. The lacunae from various states of India need to be addressed.

Hot-spots and Ramsar site

The Himalayan and Western Ghat hot-spots offer excellent scope for faunal and biogeography explorations on Rotifera in view yet limited information. With

Deepor Beel and Loktak Lake-two Ramsar sites known as globally rich rotifer habitats, other (freshwater) Ramsar sites spread over scattered parts of India provide notable potential.

Conservation areas

The freshwater biotopes of conservation areas are yet poorly explored except for our preliminary reports from Nokrek Biosphere reserve, Meghalaya; and Kaziranga National park and Pobitora wildlife sanctuary of Assam. Various conservation areas of India deserve attention for the rotifer diversity.

Ecosystem diversity

The Indian Eurotatoria diversity offers great scope vis-à-vis floodplain lakes, small wetlands, lacustrine systems, lotic ecosystems, subterranean grout waters, and small lentic ecosystems and ephemeral waters which otherwise are under-explored in spite of interesting biodiversity traits.

Validation of taxa

This is a stupendous task as the Indian literature is loaded with dubious and anomalous reports without voucher specimens or illustrations to warrant validation.

Analysis of cryptic diversity

The report of several species-groups, the Indian populations need through analysis of their cryptic diversity with comprehensive 'morpho-taxonomy' based on SEM, functional morphology, embryology, trunk-limb morphology and head-pore studies as well as the male morphology. These efforts need to be supplemented with 'eco-systematic' and molecular studies.

Epiphytic, sessile and benthic rotifers

The most of the Indian workers analyze plankton samples while epiphytic, sessile and benthic rotifers provide ample scope to augment biodiversity of the phylum. The latter deserved attention using specific sampling techniques.

Bdelloidea rotifers

Often un-explored in majority of works from India, this group of rotifers deserved attention with specific sampling techniques.

Rotifera-aquatic macrophytes associations

This is much ignored aspect in the studies from India till date particularly from wetlands and thus provided scope for future investigations to document this interesting feature of Rotifera assemblages.

National reference collections

A national depository of Rotifera collections is essential for 'assessment and authentication' of faunal diversity than individual domains. Other institutional depositories, if any, must be designated in public domain to facilitate easy access.

Identification manuals / Hand-books

An 'authentic hand-book' or illustrative manual' to facilitate identification of Rotifera is long felt. The authors have initiated steps to bridge this gap.

Fauna of Indian volume

A fauna volume on Indian Rotifera desired priority attention; the write up has been initiated by the authors.

Trained human resources

Training programs and 'All Indian Coordinated project on Capacity Building in Taxonomy (AICOPTAX)', the Ministry of Environment, Forests & Climate change (Government of India) are vital for human resources development to promote research on Rotifera. The role of national and international specialists is useful to develop in such programs.

Conclusion

Rotifera have been casually documented in a large fraction of 'routine' Indian works over the last about 120 years rendering such sources as 'poor quality or ad-hoc' reports. The 'sloppy' descriptions, unconfirmed reports, fuzzy identifications, misidentifications and incomplete inventories, and erroneous local lists confound taxonomic progress. The validation of dubious records, analyses of cryptic diversity, and the intensive sampling of hitherto un-explored or under-explored parts and ecosystems of India are challenges with holistic biosystematics efforts integrating morpho-taxonomy, ecology and molecular systematic etc. With existing ecological heterogeneity, habitat diversity, biodiversity hot-spots and possibility of descriptions of new taxa and new records, we hypothesize still high diversity of the Indian Eurotatoria than known in this assessment. The development of taxonomic expertise, a national depositary, and national collaborative efforts are future keys to Rotifera biodiversity of India.

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GASTROTRICHA

Chapter 8

JASMINE PURUSHOTHAMAN[1]

ABSTRACT

Gastrotricha constitutes one of the most interesting groups of meiobenthic freshwater and marine invertebrates comprising about 823 species in the world. The present status of gastrotrichs studies in India is very less when compared to the world studies and the information about its diversity and density is scanty. About 24 species of fresh water gastrotrichs were recorded from India so far. They are mostly dominated by the genus Chaetonotus with the record of about 20 species.

Keywords: Gastrotricha, Freshwater, invertebrate

INTRODUCTION

Gastrotricha is a cosmopolitan phylum of aquatic and wet terrestrial invertebrates comprising about 823 described species (Kolicka, 2017). It constitutes one of the most interesting groups of meiobenthic freshwater and marine invertebrates. Gastrotrichs are microscopic, monophyletic, acoelomate unsegmented metazoan worms ranging from 50 µm to 3500 µm (Kisielewski, 1997, Hochberg and Litvaitis, 2000; Todaro *et al.,* 2006b). There are very small species, especially among *Paucitubulatina* of about 70 µm length. The longest gastrotrichs belong to the genus *Megadasys* and reach up to 3.5mm in length (Schmidt 1974). Gastrotrichs swim or crawl by means of their ciliated epidermis. They inhabit aquatic and wet terrestrial ecosystems from tropical to Polar Regions (Scourfield, 1897, Hochberg, 2005; Balsamo *et al*., 2008; 2009, Kieneke, 2010). Moreover there are reports of coexistence of gastrotrichs with insects and crustaceans in astatic water bodies and sediments in dark sea caves (Kisielewski, 1990, Todaro *et al.,* 2006a). In freshwater they are epiphytic or epibenthic and to some extent interstitial and semi-planktonic.

The body of gastrotrich is elongated, strap- shaped or fusiform or tenpin-shaped, small sized body (60-770µm) composed of three regions, a rounded head, an ovate trunk and a caudal furca formed by two adhesive tubes. The body is dorsally covered with a variety of cuticular structure as bristles, scales, spines etc., to withstand effects of abrasion in the habitat. The cuticle is thin, flexible and transparent. The head bears clusters of sensory cilia, several protective cuticular plates and the subepical mouth having a protrusible hook like structure. The ventral surface of the body is flattened and covered with patches of locomotory cilia for smooth gliding over solid substratum. A strong muscular pharynx, with a

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triradaiate lumen extends for about a third of the body length and is surrounded by a large bilobed brain. Adhesive tubes supplied with cement glands are used for adhesion to sand grains or vegetation. They are mostly hermaphrodites.In fresh water, gastrotrichs are either benthic or live among vegetations, and some species are swimming in the free water. A straight gut opens in to a sub terminal anus in the ventral side. At the sides of the anterior intestine two protonephridia is present and it emptying into two ventral pores. Two ovaries located in the posterior portion of the trunk (Remane 1936; Ruppert 1991). Functional testis are present in the marine forms such as Neodasyidae, Xenotrichulidae, Musellifer, but it is absent in freshwater species. Freshwater species all reproduce by apomictic parthenogenesis (Hummon 1984; Balsamo *et al.,* 1992).

Historical resume

The studies on Gastrotrichs were started from 18^{th} Century by Remane (1936) and Mecnikow (1865) introduced the name Gastrotricha. Initially, gastrotrichs were only reported from freshwater, until Schultze (1853) found the first marine species, *Turbanella hyaline* from the sandy samples of Island Neuwerk of North Sea. The first broad account of gastrotrich morphology was made by Zelinka (1889). Since then a large number of genera and species were described mainly from the European and North American coasts. The pioneering contribution of this group had given by Prof. Adolf Remane of the Kiel University, from North, Baltic and Mediterranean seas. The knowledge on gastrotrich diversity and distribution is still to be considered as fragmentary. Intensive studies have been done from Europe and South America than Africa, South East Asia and Australia (Balsamo *et al.,* 2008).

The first chaetonotids was described by Grunspan (1908) from Italy. Information on gastrotrich studies consists largely of notes on habitats and associated fauna. The reports of intertidal marine Gastrotricha during this period from the Central and South America were Remane (1953) described *Turbanella paliciosi* from El Salvador, along the Pacific coast of Central America; du Bois-ReymondMarcus (1952) reported the presence of the genus Thaumastoderma from Brazil, on the southern Atlantic coast of South America; and Dioni (1960) described *Turbanella corderoi* from Uruguay, also on the southern Atlantic coast of South America. Apart from field observations on the occurrence of various species of Gastrotrichs under measured conditions of temperature, salinity or oxygen, the only data reported were those of Hummon (1974) on lethal limits of several marine and brackish-water forms.

Studies on freshwater gastrotrichs from Brazil were done by Kisielewski (1990). 54 fresh water Gastrotricha species were reported from water logged areas of Bialoweiza forest, Poland (Kisielewski & Kisielewski 1986). In Europe, freshwater Gastrotricha studies have been carried out in Italy, France, Germany, Poland and Great Britain, whereas the information from other countries is still very poor (Balsamo *et al.,* 2008). In Denmark, only 2 freshwater species, viz., (*Chaetonotus larus* (Müller, 1773) and *Ichthydium podura* (Müller, 1773) have been reported An additional species, *Heterolepidoderma caudosquamatum* Grilli, Kristensen & Balsamo, 2009 was recently described from a brackish-water pond in the Copenhagen's docklands area (Grilli *et al.,* 2009). Grilli *et al*., (2010) recorded a total of 26 species of Gastrotricha belonging to the genera *Aspidiophorus*, *Chaetonotus*, *Haltidytes*, *Hetero lepidoderma*, *Ichthydium* and *Polymerurus* from Denmark freshwater bodies. Kawamura (1918) reported the first species, *Polymerurus nodicaudus* (Voigt, 1901) in Shinshu (Nagano Prefecture), Japan. Later, Saito (1973) reported 26 species in the ponds of Hiroshima Prefecture. Sudzuki (1971) reported 11 species in lakes around Mount Fuji (Yamanashi Prefecture) and Shigakogen (Nagano Prefecture). To date, about 46 gastrotrich species have been reported from the lakes, ponds, swamps and rice paddies of Japan (Suzuki & Furuyam 2013). Currently 224 freshwater species of Gastrotricha known so far from Europe (223 Chaetonotida + 1 Macrodasyida).

Gastrotricha is generally less studied phylum in India and information about its diversity and density is scanty. Annandale (1907) reported that among filamentous algae from ponds having the representative of Gastrotrichs which agrees very closely with the figure and description given by Zelinka (1889) on *Chaetonotus schulzei*. This is the first reference on Gastrotichs in Indian literature. Limited work has been carried out on freshwater gastrotrichs of the Indian subcontinent, Vanamala Naidu (1962), Dhanapathi (1976), Rao and Chandramohan (1977) and Sharma & Sharma (1987) reported on the occurrence of several known species of chaetonotid gastrotrichs from different freshwater habitats of India. Vanamala Naidu (1962) reported 3 species of gastrotrichs from the fresh water habitats of India. Visvesvara (1963) described two new species from Nagpur in Central India.Taxonomic account of seven species of gastrotrichs from West Bengal and adjacent areas were reported by Sharma (1980). Sharma & Sharma (1990) reported the occurrence of five species of freshwater Gastrotrichs from Meghalaya State, North-Eastern India. There are many areas within the Indian region which remain unexplored or under explored in marine, brackish and freshwater habitats, offering plentiful possibility to carry out taxonomic and ecological investigations on the gastrotrich fauna. Harkal & Mokashe (2013) reported the occurrence of *Polymerurus nodicaudus* and *Chaetonotus elegans* species of Gastrotricha in periphytic habitat of Kagzipura Lake, District Aurangabad, Maharashtra.

Methodology

Gastrotrichs may be collected by taking samples of sediments or vegetation. Water samples may be filtered with a 20μM net to avoid the contamination of other free living micro invertebrates. The filtered water will be collected in a sampling jar and preserved in 4% formalin. For quantitative work on sediment dwelling species, small diameter (2–5 cm) cores are preferable. For plant-dwelling forms, quantitative samples probably could be obtained by modifying sampling methods developed for macroinvertebrates to use very fine mesh and small sample volumes or subsampling. A modified Baermann funnel is useful for extracting chaetonotidians from pond sediments, but not successful in the case of dasydytids. living animals are preferable to preserved animals for many purposes, it often is desirable to extract the animals from the sample prior to preservation. Living gastrotrichs often are too active for critical observations to be made, so they must be slowed down by gently squeezing the animal. They can be slowed down by placing it in a viscous medium such as methylcellulose, or by narcotizing it with cocaine. If the sample must be preserved immediately, narcotize the animals with 1% MgCl2 for 10 min, and then fix them in 10% formalin with Rose Bengal. d'Hondt recommended using MS 222 (tricaine methanesulfonate), under the cover slip for narcotizing gastrotrichs. Gastrotrichs can also be cultured by using 0.1% malted milk, raw egg yolk, wheat grain infusion, and bakers yeast. It is difficult to extract or count the gastrotrichs from a sample. Gastrotrichs are handpicked and counted under a dissecting microscope. Samples will be mounted in glycerol and observed under compound microscope at high resolution for taxonomic identification.

Diversity

Gastrotrichs are one of the interesting groups of meiobenthic invertebrates with considerable abundance in both freshwater and marine habitats. However, the Gastrotricha still remains one of the most neglected groups of the animal kingdom. Our present knowledge of this group mainly based on the studies conducted in the areas of Europe, British Isles, and Northern continental Europe, Southern Europe and Indian coasts.Many areas are still remaining unexplored for this group.

The numbers of gastrotrich species at the global level are estimated about 823 extant species, based on the updated classification (Balsamo *et al*., 2015, Kolicka, 2017). However, many regions of the world remaining largely unexplored or under explored.

Within the Indian region, about 100 species were identified from 6 families of Macrodasyida and 3 families of Chaetonotida.The families of Chaetonotida represented viz., Chaetonotidae, Xenotrichulidae and Dasydytidae. Any further intensive explorations of marine and freshwater habitats are, however, likely to reveal the existence of more genera from this region. Little is known about the freshwater gastrotrichs of India, and so far only 23 species were reported (Sharma, 1980). The other studies of freshwater gastrotrichs are found in the scattered collections from Andhra Pradesh (Vanamala Naidu, 1962, Dhanapathi, 1976, Rao&Chandramohan, 1977), Nagpur in Central India (Visveswara, 1963, 1964).

The taxonomic composition and abundance of the gastrotrich genera and species occurring in this region are more or less in agreement with those known from other parts of the world.

Classification

The phylum is composed of two orders: Macrodasyida and Chaetonotida, with, 17 families, 65 genera and one genus *incertae sedis*. The order Macrodasyida represents with 358 species (+1 species *incertaesedis*) belonging to 10 families, and 35 genera. The order Chaetonotida includes 462 species belonging to 8 families and 31 genera (Balsamo *et al*., 2015; Kolicka, 2017). In gastrotrichs, 486 species are marine and 338 species are from freshwater. Only about 70 freshwater species have been found in psammic habitats, and less than 35 species are known from sediments of running waters. All species described from the families Dasydytidae and Neogosseidae, with about 50 species, are semipelagic or fully planktonic: the colonization of water column corresponds to specific, characteristic morphological adaptations (Kisielewski 1990, Balsamo *et al.,* 2008, Todaro *et al.,* 2013, Kånneby and Todaro 2015).

The order Macrodasyida includes all marine but two fresh water species (Balsamo *et al*., 2015; Kolicka, 2017). One freshwater species belongs to the family Redudasyidae that, however, also comprises a marine species. Another freshwater species has been assigned to the order as *incertae sedis* (*Marinellina flagellata*). The order Chaetonotida encompasses 130 marine, 338 freshwater species. Three families (6 genera) are exclusively marine (Neodasyidae, Muselliferidae, Xenotrichulidae), 4 (12 genera) are exclusively freshwater (Dasydytidae, Neogosseidae, Proichthydiidae, Dichaeturidae), and the largest family, Chaetonotidae, numbers marine and freshwater species (2 genera exclusively marine, 8 freshwater and 5 including marine, brackish-water and freshwater).

Macrodasyida presently represented by 35 genera belonging to 10 families namely, Dactylopodolidae, Lepidodasyidae, Macrodasyidae, Planodasyidae, Turbanellidae, Thaumastodermatidae, Cephalodasyidae, Redudasyidae, Xenodasyidae, Hummondasyidae.

The Chaetonotida are known to comprise 31genera belonging to 8 families, namely Chaetonotidae, Neodasyidae, Xenotriculidae, Dichaeturidae, Proichthydidae, Neogosseidae, Dasydytidae, Muselliferidae.

DISTRIBUTION

The gastrotrichs inhabit in all natural aquatic ecosystems of freshwater and marine habitat. Habitats with unpolluted conditions, favoured the colonization and evolution of a variety of species and sub species of gastrotrichs. Hitherto, only limited areas of the region were explored for this group. They are also known to inhabit from tropical to Polar Regions (Scourfield 1897; Hochberg 2005; Balsamo *et al.,* 2008; 2010; Todaro et al. 2009; 2011; Kieneke 2010). Gastrotrichs are considered cosmopolitan and have been reported, in the literature, from all continents except Antarctica (d'Hondt, 1971; Balsamo *et al*., 2008). There are reports of their distribution in astatic water bodies, sediments in the dark caves of the Sea (Todaro *et al.,* 2006a). Based on the updated classification, 823 species of Gastrotricha were known to the world. Of these, more than 50% are known to report in the area of Europe, British Isles, and Northern continental Europe and southern Europe. Total 24 sp. of gastrotrichs has been reported from various freshwater environments in India.

The freshwater gastrotrichs are mostly dominated by the genus *Chaetonotus* with the record of about 20 widely distributed species. Visvesvara (1963) described two new species from Nagpur and Central India. Faunistic surveys conducted in recent years at several areas however, indicated a remarkable decrease of this fauna both in their density and diversity. This is largely due to the increasing pollution of the habitats and degradation of the natural environment.

Endemism

Endemism of gastrotrichs are generally known about very fewer and it is difficult to mention due to the scarcity of studies and scattered reports from all over the world. Some percentage of endemism is generally known for the terrestrial gastrotrichs in insular ecosystems due to their isolation for long periods. Out of the 21 known genera, only 1genus *Planodasys* has been reported as endemic to the Indian region

.The endemicity in general is far greater in the highly thigmotactic Macrodasyida than in Chaetonotida, which are endowed with greater power of environmental tolerance, locomotion and dispersal. As a result, many species of the Chaetonotida have been reported as cosmopolitan in their distribution.

Biology

Gastrotrichs are a common component of the interstitial fauna of marine sands as well as of the freshwater periphyton and epibenthos. It includes about 823 species grouped into two orders: Macrodasyida, with 358 species, all of them are marine except two fresh water and Chaetonotida, with 462 species, of which only 150 are marine or brackish. Freshwater representatives mainly belong, to the order Chaetonotida (Balsamo & Todaro, 2002). Characteristic for this order is the tenpin-shaped body usually with a bifurcated posterior end bearing adhesive tubes. To date Chaetonotida include 29–30 genera of which Chaetonotus Ehrenberg, 1830 with more than 200 nominal species is the most numerous (Balsamo *et al.,* 2009).

In fresh water gastrotrichs, their habitats are subject to unpredictable variation, including drying. So, resistant egg types are seen in several species of the freshwater Chaetonotidae. In *Chaetonotus maximus* and *C. Multinensis* (Balsamo and Todaro, 1988a; Todaro and Balsamo, 1988), *Heterolepidoderma* sp. (Levy, 1984a, b), and *Lepidodermella squammata* (Hummon, 1984a), formation of the resting (opsiblastic) egg occurs prior to the formation of sperm, during the phase of parthenogenic egg production. Such resting eggs hatch into animals with the usual life history of parthenogenic egg production followed by hermaphroditism (Levy and Weiss, 1980; Levy, 1984a, b). An additional resting egg-type has also been found in the species of *L. squammata* and may represent the sexual egg (Levy and Weiss, 1980; Levy, 1984a); animals from such eggs have the usual life history (Levy, 1984a). Thus one egg of any type or one adult in parthenogenic reproductive phase can colonize.

Habitat

The fresh water gastrotrichs are epiphytic or epibenthic and to some extent they behave as interstitial or semi-planktonic. Gastrotrichs are also found occasionally on bryophytes. The Dichaeturidaeis a rare family that has been found in cisterns, in underground water, and among mosses (Remane 1936; Ruttner-Kolisko 1955). In a peat land complex in northern Italy, Balsamo *et al*., (1992) identified 21 species of gastrotrichs.

Threats

D. elongatus is an indicator species of fringes of severe organic pollution but even this species is absent from areas of its greatest severity (Hummon *et al.,* 1990). Reports also showed that the complete absence of gastrotrichs from the littoral sites of polluted environments is in hospitable habitats for this meiobenthic phylum.Till now no conservation measure as such has been undertaken to protect this meiobenthic phylum from lethal effects of potential pollution in the aquatic ecosystems. Due to the increasing pollution by anthropogenic activities most of the meiobenthicfauna will be vanished. Although the whole phylum is being threatened with increasing effects of habitat destruction and organic pollution in the environment, no qualitative or quantitative data are available on the percentage of decline of any species or varieties of populations of gastrotrichs from India. Due to these reasons, it is not possible to categorize any particular species of this group as threatened or endangered. There is also no published record of any introduced biodiversity for this phylum.

Conservation and Gaps in Research

Gastrotrichs are highly modified in morphology and living in the habitats of interstitial, marine and freshwater environments. Their morphological diversity has contributed largely to expand the knowledge on systematic zoology. Gastrotrichs are also used in a variety of experimental and interesting ecological investigations related to aquatic biology. As they are quite sensitive to ecological stress, they are being widely employed as indicators of pollution biology. Some of the species like *D. elongatus* can be considered as an indicator species of fringes of severe organic pollution but even this species is absent from areas of its greatest severity (Hummon *et al.,* 1990). Thus, the gastrotrichs both in marine and freshwater habitats offer ample scope for carrying out various types of investigations on taxonomy, biology, ecology, and distribution.The gastrotrichs constituting part of meiobenthos in aquatic ecosystems play an important role in their trophic cycle by forming food for larger animals and by contributing remarkably to the regeneration of nutrients after their death and disintegration. Hence, their mass decline in biomass will result not only in the loss of biological diversity, but also upsets the ecological balance of marine and freshwater eco systems. In these circumstances, this tiny organism has to be protected from pollution and habitat destruction. The present status of gastrotrichs studies in India is very less when compared to the world studies. So we have to give more importance to this less studied phylum.

Table 1. The number of family, genus and species of Phylum Gastrotrich present in the fresh water ecosystems of India

Phylum	**GASTROTRICHA**	**Indian Species**	
Order	Macrodasyida	**Fresh water**	
Family	Cephalodasyidae	-	-
	Dactylopodolidae	-	-
	Lepidodasyidae	-	-
	Macrodasyidae	-	-
	Planodasyidae	-	-
	Redudasyidae	-	-
	Thaumastodermatidae	-	-
	Turbanellidae	-	-
	Xenodasyidae	-	-
Order	Chaetonotida		-
Family	Neodasyidae		-
	Chaetonotidae	22	-
			Chaetonotus anomalus Brunson 1950
			Chaelonotus brevispinosus Zelinka 1889

Phylum	GASTROTRICHA	Indian Species	
			Chaetonotus caudalspinosus Visveswara 1964
			Chaetonotusformosus Stokes 1887
			Chaetonotus laterospinosus Visveswara 1964
			Chaetonotus longipinosus Stokes 1887
			Chaetonotus monobarbatus Visveswara 1964
			Chaetonotus novenarius Greuter 1917
			Chaetonotus octonarius Slokes 1887
			Chaetonolus schulzei Zelinka 1889
		-	Chaetonotus *sextospinosus* Visveswara 1964
			Chaetonotus similis Stokes 1887
			Chaetonotus spinulosus Slokes 1887
			Chaetonotus tachyneusticus Brunson 1948
			Chaetonotus trianguliformis Visveswara 1964
			Chaetonotus vulgaris Brunson 1950
			Icthydium auritum Brunson 1950
			Iclhydium minimum Brunson 1950
			Icthydium monolobum Brunson 1950
			Lepidodermella squarnutum (Dujardin 1841)
			Polymerurus magnus Visveswara 1963
			Polymerurus nodicaudus Voigt 1901
	Dasydytidae	1	*Stylochaela abarbila* Visveswara 1963
	Dichaeturidae	-	
	Muselliferidae		
	Neogosseidae	1	*Neogossea antennigera* (Goose 1857)
	Proichthydiidae	-	
	Xenotrichulidae	-	
		-	
Total		24	

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Chapter 9

NEMATODA

QUDSIA TAHSEEN

ABSTRACT

Nematodes, one of the important consumers and contributors in nutrient recycling are one of the affected taxa of freshwater ecosystems. As per the latest studies by Abebe *et.al.* (2008) freshwater nematodes constituted nearly two-thirds of the 19 orders, two-fifths of the 221 families and one-fifth of the nearly 1800 genera. Of the 27,000 nominal species, the freshwater species were about 1808 showing approximately 7% representation. In India, the diversity of freshwater nematode is represented by 422 species distributed in 119 genera and 57 families.

Key words: Nematoda, Enoplea, Chromadorea, Freshwater, India.

INTRODUCTION

Nematodes are primarily aquatic organisms that require a film of water for movement. They are regarded truly ubiquitous invertebrates which inhabit all types of habitats and comprise of 90% of metazoans (Mclntyre, 1971) numerically. These pseudocoelomate organisms are ranked second to insects with regard to their diversity, competence and impact on human society. Nematodes not only successfully colonize almost every geographic location including deserts, forests, lakes, rivers, marshes and deep oceans but can also survive in extreme habitats such as icebergs and hot springs. They even parasitise nearly all groups of animals and a wide variety of plants. Due to their diverse feeding habits, they can be categorized as animal parasitic, plant parasitic and free-living forms. The free-living species further represent four main trophic groups *viz*., bacteriophagous, mycophagous, omniphagous or predaceous in nature. Besides being parasites of animals and plants, nematodes form an important component of food web due to their crucial role in nutrient cycling as bacterivores and fungivores. Nematodes offer excellent biological tools due to their high species richness, abundance, short generation time, pervasiveness and tolerance, to monitor changes in environment and can serve useful models to study interactions between biodiversity and ecosystem functions (Moens et al. 2004).

Of the total described over 30,000 (26,642 species reported by Hugot *et al.,* 2001) of nematodes, approximately 50% are marine while the remaining 50% constitute the animal parasites (15%), plant parasites (10%) and soil and fresh water species (25%). Thus the share of fresh water species, seems to be too nominal keeping in view the vast fresh water areas of the world. Although in both lentic (Traunspurger,

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1996a, b, 2002) and lotic habitats (Danielopol, 1976; Anderson, 1992) nematodes are the most abundant representatives of meiofaunal communities, the taxonomic records on fresh water nematodes are relatively scanty and fractured and are still in the late alpha stage compared to the terrestrial forms. It is due to the fact that majority of the studies carried out so far on aquatic nematodes have been focused on the marine ones.

Fossil records

As nematodes are abundant today, they existed in enormous numbers in the past too; however, their fossil record is very limited due to their small size, soft bodies and concealed habitats. Nematode anatomy is rather simple without many conspicuous hard / sclerotized structures; hence the taxonomically diagnostic features are unlikely to be preserved in normal process of fossilization. Therefore, virtually all fossil nematodes that are taxonomically identifiable have been reported from amber (Poinar, 2011). Transparent amber does not occur in pre-Cretaceous strata and that constrains a reliable fossil record in the period. Palaeontological evidence can also include their fossilized behaviour such as the traces of life activity, locomotory patterns preserved in rocks (Fig. 2A). The early Carboniferous limestone of Montana and the late Carboniferous Mazon Creek sideritic concretions of Illinois yielded some aquatic fossils. The Mesozoic nematode, *Eophasma jurasicum* anticipated to exist in ocean in early Jurassic (Arduini *et al.,* 1983), was found preserved as pyritised remains in shale (Fig. 2B).

There are no fossil records of nematode parasites of vertebrates and most fossil evidences are of Mermithidae, the insect parasites. Balinski *et al*. (2013) presented a discovery of the oldest known traces of nematode-within-sediment activity from the Ordovician strata of China. These trace fossils are about 70 million years older than the oldest known nematode body fossil (Poinar *et al.,* 2008; Poinar, 2011). The fossil record of the enoplid nematode *Palaeonema* suggested its probable link with aquatic (marine and freshwater) ancestors. Another fossil representing a fresh water nematode *Cretacimermis libani*, is from 120-135 million year- old amber.

Historical Review

The oldest written record of nematodes is presumably of intestinal roundworm '*Ascaris*' in Chinese literature, about 4,690 years ago.. The scientists, Hippocrates (430 B.C.), Aristotle (384-322 B.C.), Magnus (1200-1280 A.D) also gave references of roundworms in their writings.

To enumerate the comprehensive history of taxonomy of all groups of freshwater nematodes would be difficult and beyond the scope of this chapter, therefore, some important landmarks in the history of taxonomy have been discussed. Freshwater nematodes are predominantly free-living forms belonging to families: Tobrilidae, Tripylidae, Chromadoridae, Cyatholaimidae, Ironidae, Rhabdolaimidae, Leptolaimidae, Monhysteridae and Plectidae. The first record of taxonomic studies on this group can be traced as early as in 1851 when Leidy described the first freshwater nematode, *Tobrilus longus*. Later, Bastian (1865) in his monograph, described 100 new species. He also described 22 new genera and placed free-living nematodes under family Anguillulidae by grouping them into continental (soil and freshwater inhabiting) and marine forms. Cobb (1918) reported hundreds of nematodes in the top three inches of a drinking water filter bed. Micoletzky's (1922) monograph listed 142 genera and 931 species with 58% marine and 42% continental species. Again in 1925, he gave a good account of free-living freshwater nematodes. Filipjev (1934) and Paramonov (1952) brought Nematology to maturity as a Zoological Science and gave hypothesis concerning nematode relationship, evolution and phylogenies besides offering sound classification which formed the basis of current classification of Nemata. A comprehensive record of free-living marine nematodes of Belgian coast was later published by De Coninck and Schuurmans Stekhoven (1933). 'Nematoda' was treated as a phylum with two classes, 'Phasmidia' and 'Aphasmidia' by Chitwood (1933, 1937). Later he replaced these names with Secernentea and Adenophorea and proposed new system of classification including both free-living and parasitic nematodes. His authoritative book (1950) '*An Introduction to Nematology*' is an important landmark in the history of Nematology.

Thorne's (1937, 1939, and 1949) monographs on Dorylaims, Cephalobidae and Tylenchida as well as his book (1961) '*Principles of Nematology*' are valuable contributions to the field of Nematology. Goodey's (1951) *'Soil and Freshwater Nematodes'* (revised in 1963), was the first book to provide a comprehensive account of free-living nematodes, including freshwater taxa. In 1960, Meyl gave the key to identification of free-living freshwater species of class Adenophorea and Secernentea. Gerlach and Riemann (1973, 1974) in '*Bremerhaven Checklist of Aquatic Nematodes'* included genera of aquatic (marine and limnetic) nematodes excluding the Dorylaimida. Afterwards, Ferris et al. (1973) reported freshwater genera from eastern North America while Tarjan et al. (1977) gave an illustrated key to nematodes found in freshwater habitats. Andrássy (1978) listed 170 genera containing 605 species of freshwater nematodes in a checklist for European inland waters while Tsalolikhin (1980, 1985) contributed a book on ecology and taxonomy of freshwater nematodes of European countries. Later, the free-living nematode fauna of the Netherlands and Italy were described and illustrated by Bongers (1988) and Zullini (1982) respectively. Andrássy (1976) in his book entitled, '*Evolution as a basis for the systematization of nematodes*', subdivided the nematodes into three subclasses: Torquentia, Secernentia and Penetrentia. Lorenzen (1981) published the revised classification of the Adenophorea while Jacobs (1984) presented a classification scheme including animal parasites, free-living and phytoparasitic nematodes of continental and marine origin. Andrássy, the legendry nematologist, made significant contributions to nematode taxonomy by describing a large number of genera and species. Since 1952 till 2012, in his numerous publications, he published keys to identification, proposed and raised higher taxa, amended and put forth classification schemes and authored a number of books on the subject including '*Klasse Nematoda'* (1984) based on the diagnosis of nematodes of Araeolaimida, Enoplida, Chromadorida, Monhysterida, and Rhabditida. In the same year, Jacobs listed 117 genera and 327 species of freshwater nematodes from Africa. Later a revised classification of phylum Nematoda based on molecular as well as traditional systematics has been worked out by Blaxter *et al.* (1998) and De Ley and Blaxter (2002). Later, Esser and Buckingham (1987) reported 133 genera and 160 species of free-living nematodes occupying freshwater habitats in North America. The workers *viz*., Hoeppli (1926), Hoeppli and Chu (1932), Gagarin and Lemsina (1982), Nicholas and Stewart (1984) and Ebsary (1985), Ocaña and Zullini (1988), Zullini (1988), Oca***ñ***a (1991), Nicholas (1993), Alekseev and Linnik (1995), Alekseev (1996) and Tsalolikhin (1979, 1998) also published on fresh water nematodes. Gagarin (1993, 2000, 200l), described nematodes of Russia and its adjoining countries. Abebe and Coomans (1995; 1996a,b,c,d,e,f; 2002) reported new freshwater species from Ethiopia. Doucet and Doucet (1999) provided an updated checklist of soil and freshwater nematodes from continental Argentina while a checklist of free-living freshwater nematodes from South Africa was given by Heyns (2002). Recently Abebe et al. (2006) in their book *"Freshwater Nematodes*: *Ecology and Taxonomy"* gave up to date comprehensive information on the fresh water nematodes, with emphasis on their biogeography and ecology.

Various scientists who worked exclusively on freshwater bodies include Hirschmann (1952), Schiemer et al. (1969), Biro (1973), Nalepa and Quigley (1983), Prejs and Lazarek (1988), Pehofer (1989), Anderson (1992), Prejs (1977a, b; 1993), Traunspurger (1991; 1992; 1996a, b; 2000), Traunspurger and Weischer (1993), Särkkä (1995), Beier and Traunspurger (2001, 2003a, b). However, these studies largely envisaged largely the ecological aspects *viz*., nematodes number, distribution, abundance, biomass with respect to sediments depth etc. Over the last decade a lot of studies have been made on freshwater meiofauna that led to the publication of comprehensive monographs in a special issue of Freshwater Biology (2000, volume 44) and several books on the theme, such as Freshwater Meiofauna (Rundle *et al*., 2002); Freshwater nematodes: ecology and taxonomy (Abebe *et al*., 2006) and Meiobenthology (Giere, 2009). Some scientists who worked on the functional status and resource utilization of nematode meiofauna are Beier *et al*. (2004), Traunspurger and Bergtold (2006), Moens et al. (2006), Muschiol et al. (2008), Spieth *et al*. (2011), Weber and Traunspurger, 2014). Nematodes were also proposed to be models for testing ecological theories (Reiss *et al*., 2010). (De Mesel *et al*., 2004; Hohberg and Traunspurger, 2005; Pascal *et al*., 2008; Evrard *et al*., 2010; Steel *et al*., 2013; Heidemann *et al*., 2014) and their community structure was considered a powerful tool to study freshwater pollution (Heininger *et al*., 2007; Höss *et al*., 2011; Hägerbäumer *et al*., 2015) due to anthropogenic intervention.

Nematology in India started in the mid twentieth century but the major focus was on the plant parasitic nematodes due to their importance in agriculture. Most of the faunal work on nematodes was done on terrestrial nematodes. Fresh water nematodes were virtually ignored in most survey reports except few sporadic records by Ali and Suryavanshi, and Khera. A general reason for the neglect of nematodes in faunal studies concerns difficulties with their minute size, techniques for isolation and adequate characterization and identification. The freshwater nematodes of India have been explored the least and the work particularly on taxonomy of the free-living nematodes is relatively scanty. Ali et al. (1969-1973) described free-living nematode species from Maharashtra while Khera (1965-1975) described free-living nematode species from Rajasthan state.

Jairajpuri and Ahmad (1992) and Ahmad and Jairajpuri (2010) in their respective publications on Dorylaimida and Mononchida included many species reported from soil but having also been reported from aquatic habitats. A number of papers were published on the reproductive biology and taxonomy of free-living nematodes by Ahmad and Jairajpuri (1979-1982) and Tahseen and coworkers (1988-2015) from Aligarh. Tahseen and coworkers (2005, 2006) also explored the nematode fauna of wetland Keoladeo National Park, Shekha Jheel, Aligarh and Keetham lake , Agra and reported good number of new and known species. In view of their rich biodiversity and unexplored status, the freshwater habitats offer an array of species that still lie unknown and uninventoried. In this chapter we try to have an overview of the fresh water nematodes of India.

METHODOLOGY FOR STUDYING FRESHWATER NEMATODES

Collection and processing of samples

Samples may be collected from ponds, ditches, drains and canals, lakes, rivers and streams with a record of the geographical coordinates at the collection site. The sampling devices *viz*., dredges, worm nets, bottom scrapers, mud suckers, sledge trawls and planktonic nets (Fig. 1C) may be used. The water and mud samples may be collected in special sampling containers (Fig. 1A, B) and then passed through a series of sieves (Fig. 1D) with pore size ranging from 0.4 mm to 40 um. Rocks and other submerged material can be washed with a water spray or by vigorous shaking or brushing.

The mud and slurry samples can be processed using Cobb's (1918) sieving and decantation and modified Bearman's funnel techniques (Fig. 1G). After 24 hours a small amount of water holding extracted nematodes can be taken from the stem of funnel into a cavity block. For coastal and mud samples, extraction trays can be used where sample can be placed on a wire mesh lined with tissue paper with water in the tray touching its base (Fig. 1F).

Fixation and preservation: The nematodes extracted from processed samples, can be examined under the Stereoscopic Zoom Microscope (Olympus – SZX12) with a range of magnifications for their generic identification. For their future use, the extracted nematodes can be fixed in hot Formaline: Acetic Acid fixative (8 ml of Formaline (commercial formaldehyde 40%), 2 ml of glycerol and 90 ml of distilled water) and kept for 24 h before their further use. For dehydration, the nematodes can be transferred to a mixture of glycerol and alcohol (95 parts of 30% alcohol + 5 parts of glycerol) and then placed in a desiccator (Fig. 1H) containing anhydrous Calcium Chloride. In about 3-4 weeks, the nematodes can be dehydrated (Seinhorst, 1959) and ready to be mounted.

The wax ring method of De Maeseneer and D' Herde (1963) for mounting and sealing of the nematodes, can be used. A secondary sealing with nail polish is done to prevent drying or dissolution of wax by immersion oil. For an in depth study, the mounted nematodes are viewed under compound microscope and measured using ocular micrometer, drawn using drawing tube and photographed using a digital camera mounted on the Microscope.

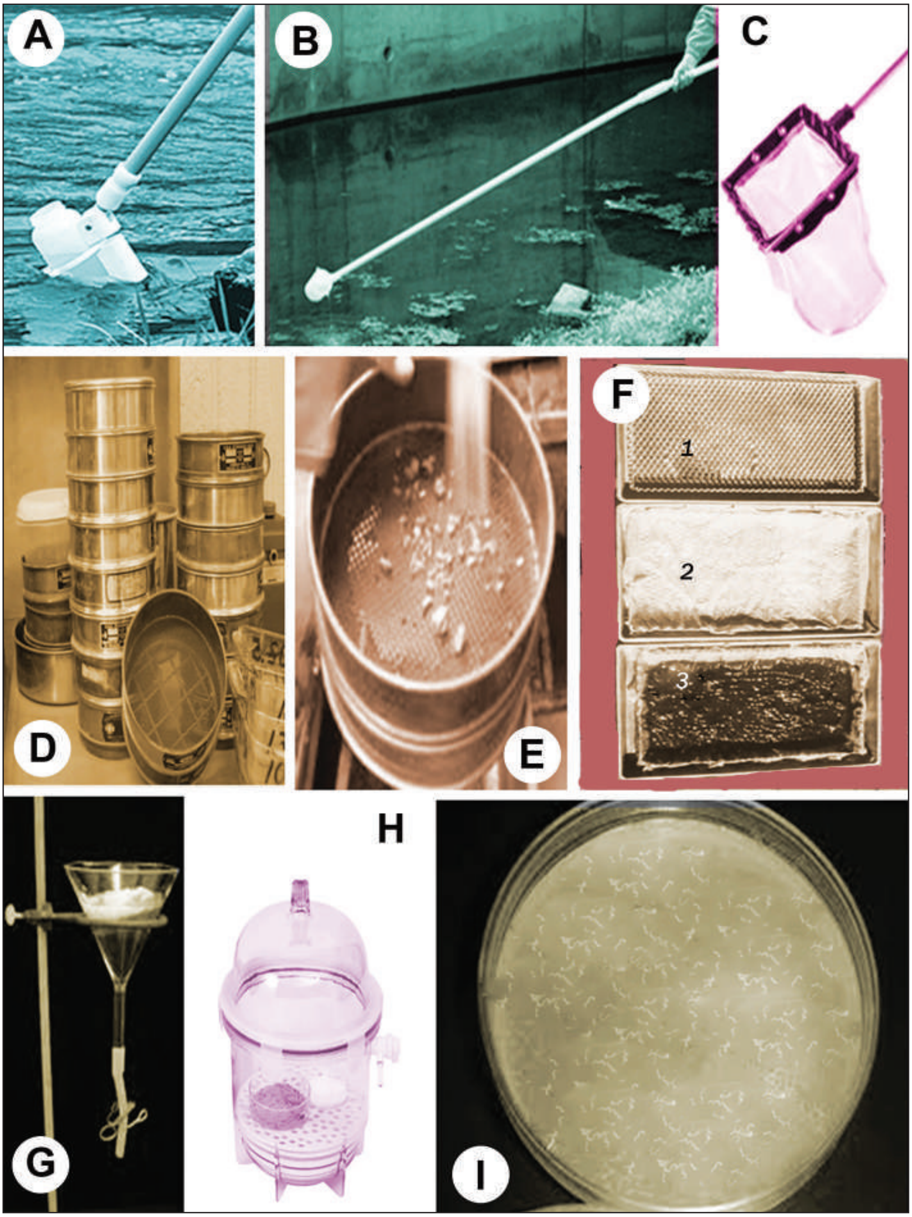

Fig. 1. A, B, C: Sampling devices; D: Sieves of different pore size; E: Sieving of water samples; F: Tray method for processing coastal/moist sediment samples; G: Baerman's funnel technique; H: Desiccator for dehydration of nematodes; I: Culture plate with nematode population

Scanning Electron Microscopy

For scanning electron microscopy, the specimens can be fixed in 2% glutaraldehyde, post-fixed in 2% osmium tetroxide, dehydrated in an ethanol series and critical-point dried using CO_2. The nematodes are mounted on double-sided adhesive tape being placed on a stub and coated with 10nm gold before observing at 10 kV under a scanning electron microscope.

Diversity of freshwater nematodes (from the Global perspective)

Fresh water nematode diversity is difficult to quantify correctly because of scanty efforts devoted to study these habitats, in general. Often the identification may not be up to the mark and remain unverified because of lack of voucher specimens of most of the taxa reported in ecological studies. Further there may not be absolute extraction of nematodes from samples due to presence of some lethargic/ inactive species or those showing seasonality, quiescence or cryptobiosis. Some workers who worked on fresh water nematodes and listed them from different regions of the world include Traunspurger (2000), Michiels and Traunspurger (2005), Abebe *et al*. (2006), Hodda (2006), Abebe *et al*. (2008), Antofica and Poiras (2009),Traunspurger *et al*. (2012), Flach *et al*. (2012) and Traunspurger *et al*. (2015). As per recently proposed classification scheme of De Ley and Blaxter (2004), the Phylum Nematoda is divided into Class Chromadorea and Enoplea which are further splitted into 3 subclasses, 19 orders and 221 families. According to Andrássy's (1999) old scheme of classification, the census of nematodes showed Rhabditida to be the most diverse taxon of the freshwater habitats. Abebe *et al*. (2008) carried out the difficult task of estimating the region-wise as well as total global diversity of fresh water nematodes and concluded that freshwater nematodes constituted nearly two-thirds of the 19 orders, two-fifths of the 221 families and one-fifth of the nearly 1800 genera. Of the 27,000 nominal species, the freshwater species were about 1808 showing approximately 7% representation (Abebe *et al*., 2008).

Table 1. Global representation of freshwater nematode taxa (after Abebe *et al*., 2008)

Nematode Taxa	Family	Genus	Species
ENOPLEA			
Enoplida	8	19	79
Triplonchida	6	27	140
Dorylaimida	16	103	610
Mononchida	5	20	99
Mermithida	2	52	417
CHROMADOREA			
Chromadorida	4	9	36
Desmodorida	1	1	7

Nematode Taxa	Family	Genus	Species
Desmoscolecida	3	5	9
Monhysterida	4	14	114
Araeolaimida	1	1	8
Plectida	6	13	125
Rhabditida	19	55	164
Total	**75**	**319**	**1808**

The data in Table 1 has been extracted from the work of Abebe and coworkers published in 2008 and taxa may show changed/ increased number with more freshwater species being reported in the intervening period, however, the trend of representation of taxa may not drastically change but remain more or less same.

Diversity of freshwater nematodes (from Indian perspective)

There is often a very fine line of demarcation existing between the freshwater and soil-inhabiting nematodes and in most cases there is virtually none. In view of the sporadic and limited studies on Indian freshwater nematodes (Table 2), the task of assembling all information on this group is not an easy one. However, we are in the process of compiling a catalogue on Indian freshwater species of nematodes. The species-wise listing of freshwater nematodes will be beyond the scope of this chapter. Nevertheless, some of the commonly found fresh water taxa are, hereby, reported which are of common occurrence to these habitats besides some degree of terrestrial representation. The nematodes belonging to Dorylaimida have the highest representation in freshwater habitats whereas members of Order Rhabditida show greatest diversity and adaptability and occur in all possible habitats. The genera *Acrobeles, Acrobeloides, Cephalobus, Chiloplacus, Mesorhabditis, Panagrolaimus, Panagrellus, Pelodera, Protorhabditis, Rhabditis, Rhabditella, Teratorhabditis, Butlerius, Fictor, Mononchoides* and *Oigolaimella* have been reported from freshwater bodies. In Plectida (Fig. 2C-J), the freshwater genera reported from Indian waters are *Anaplectus*, *Chiloplectus, Choronogaster*, *Cylindrolaimus, Ereptonema, Plectus*, *Rhabdolaimus Tylocephalus, Udonchus* and *Wilsonema*. Monhysterids (Fig. 4A-F) demonstrate diverse feeding habits and are predominantly aquatic with greater percentage reported from marine ecosystems. However, the genera commonly found in freshwater include *Eumonhystera, Geomonhystera, Hoffmaenneria, Monhystera* and *Monhystrella*. Chromadorida (Fig. 4G-J), the order of largely marine nematodes, with punctated cuticle and conspicuous amphids are represented by few freshwater forms. The genera *Achromadora, Chromadorita, Chromadorina,* and *Punctodora* have species recorded from freshwater habitats. Some representatives of Orders Enoplida (Fig. 7A-F) and Triplonchida (Fig. 5A-G) have been reported from freshwater *viz*., *Cryptonchus, Halalaimus, Ironus, Onchulus, Prismatolaimus, Tobrilus, Tripyla, Tripylina,* and *Trischistoma***.**

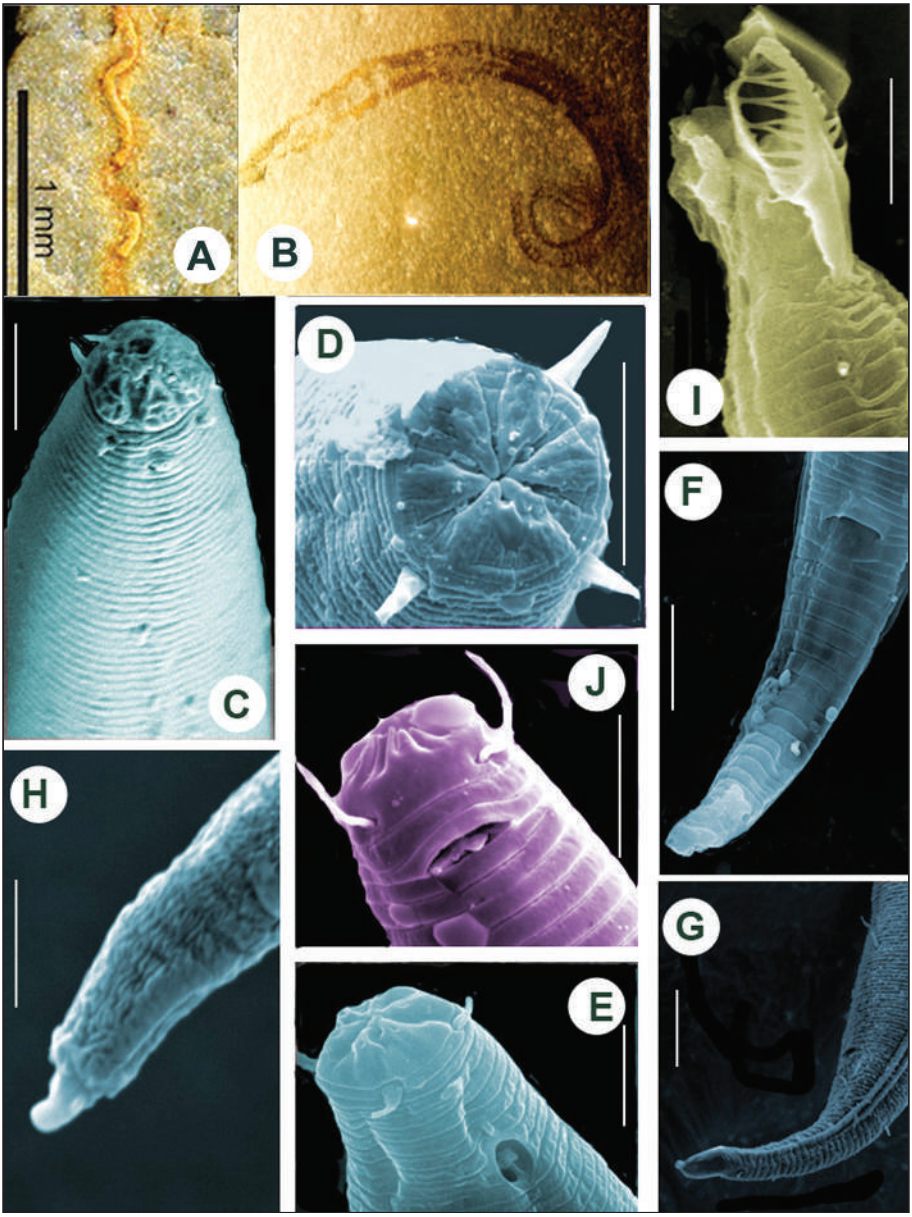

Fig. 2. A: fossil evidence of activity (locomotion) after Balinski & Sun (2015); B: *Eophasma jurasicum* Source: https://commons.wikimedia.org/wiki/File; Order: Plectida. B, D: *En face* view of *Plectus parvus* Bastian, 1865; C, E: Anterior body region of *P. parvus* Bastian, 1865; F, G, H: Tail region of *Plectus geophilus* de Man, 1880; I: Anterior body region of *Neotylocephalus inflatus* (Yeates, 1967) Holovachov *et al*., 2003; J: Anterior body region of *Chronogaster typicus* (De Man, 1921) (Scale bar= 10 µm).

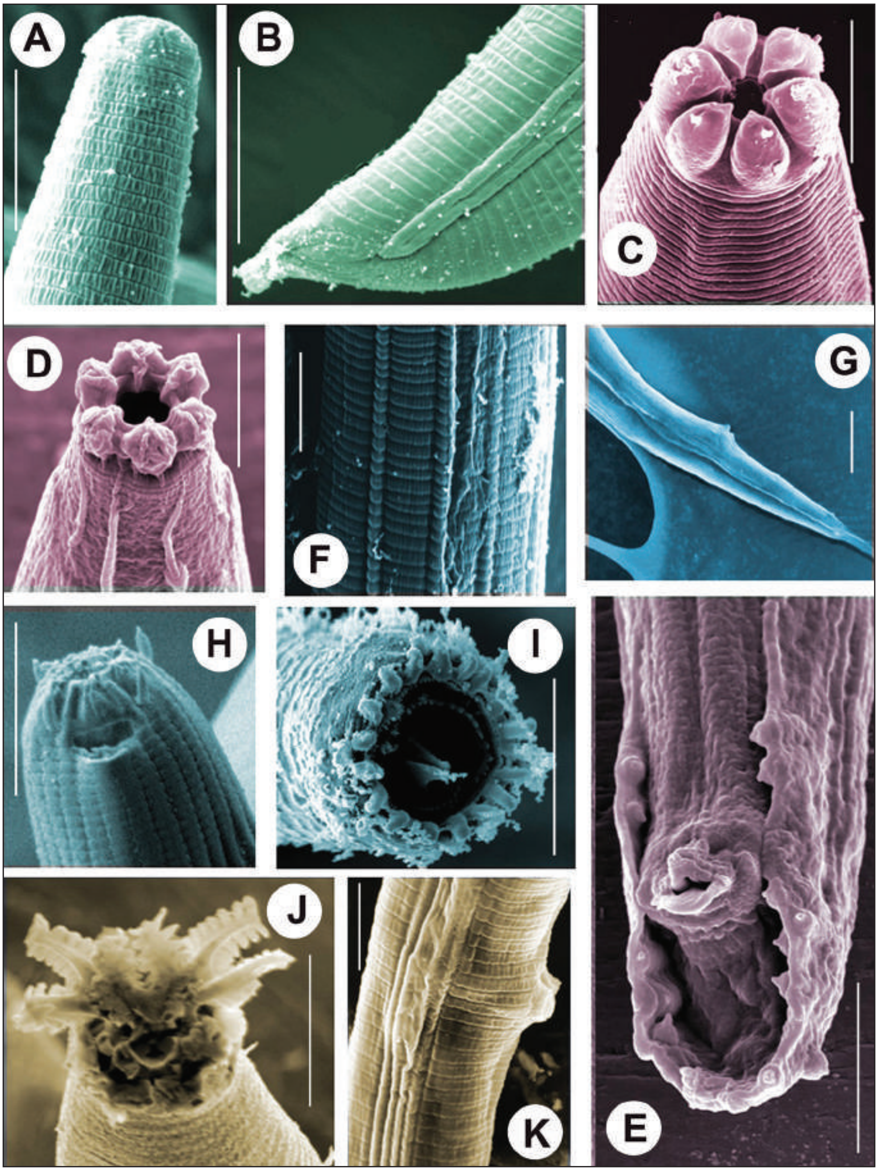

Fig. 3. Order: Rhabditida; Suborder: Tylenchina. A: Anterior body region of *Helicotylenchus pseudorobustus* (Steiner, 1914) Golden 1945; B: Tail region of *Helicotylenchus pseudorobustus* (Steiner, 1914); Suborder: Rhabditina. C: Anterior body region of *Pelodera aligarhensis*; D: Anterior body region of *P. aligarhensis* Tahseen *et al.*, 2014; E: Tail region of Rhabpanus uniquus Tahseen *et al.,* 2012; Suborder: Diplogastrina. F: Longitudinal body ridges in *Diplogastrellus* sp.; G: Tail region in *Diplogastrellus* sp; H: Anterior body region in *Oigolaimella longicauda* (Claus, 1862); I: Anterior body region in Fictor composticola Khan *et al.*, 2008; Suborder: Cephalobina. J: Anterior body region of *Acrobeles complexus* Thorne 1925; K: Vulval region of *A. complexus* Thorne 1925 (Scale bar= 10 µm).

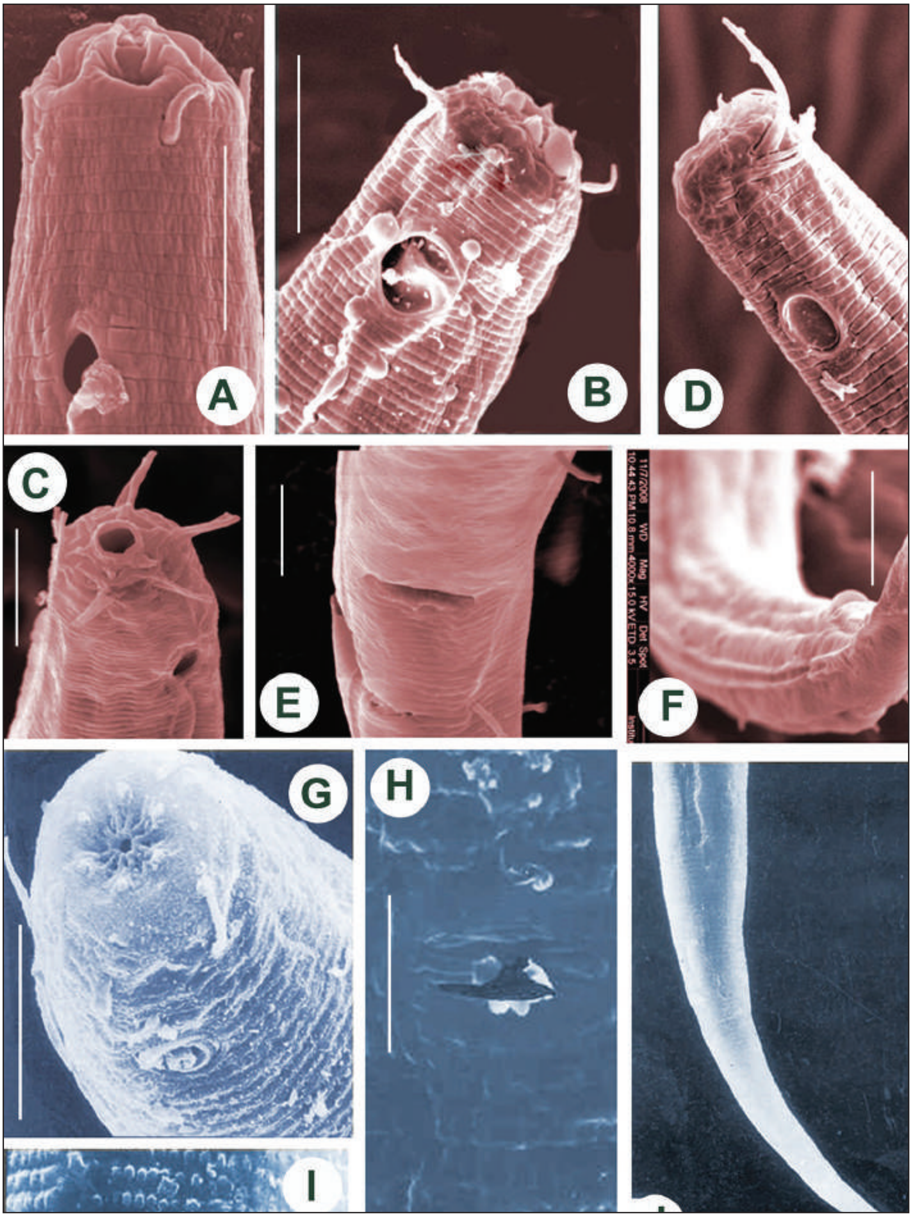

Fig. 4. Order: Monhysterida. A: Anterior body region of *Monhystrella kerryi* Khan *et al*., 2005; B Anterior body region of *Monhystera rolandi* Khan and Tahseen, 2006; C: Anterior body region of *Geomonhystera glandulata* Khan and Tahseen, 2006; D: Anterior body region of *Hoffmaenneria keoladeoensis* Khan *et al*., 2005; D, E: Vulval body region of *G. glandulata* Khan and Tahseen, 2006; F: Tail region of *H. keoladeoensis* Khan *et al*., 2005; Order: Chromadorida. G: Anterior body region of *Achromadora indica* Tahseen, 2001; H: Vulval region of *A. indica* Tahseen, 2001; I, J: Body punctuations and tail region in *A. indica* Tahseen, 2001, respectively (Scale bar= 10 µm).

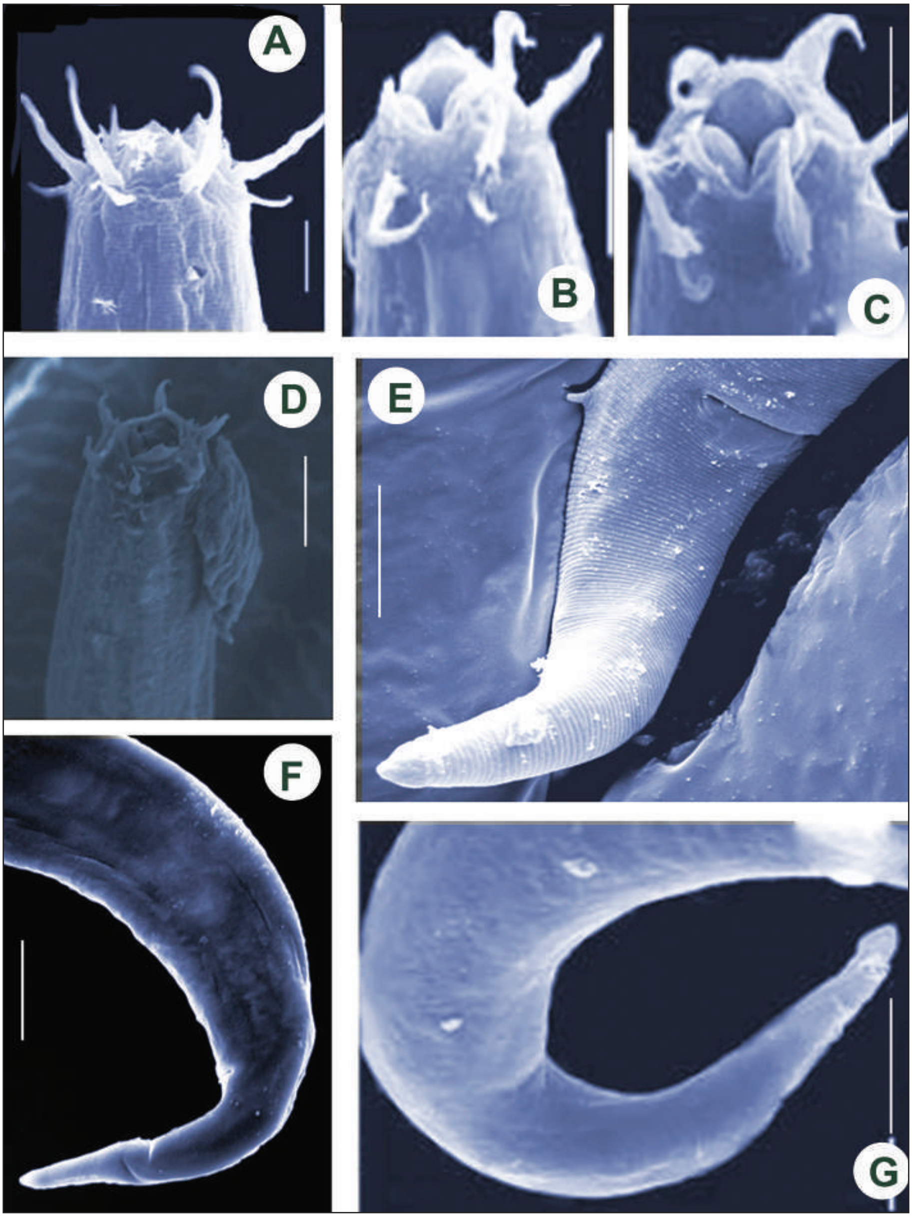

Fig. 5. Order: Triplonchida. A: Anterior body region in *Tripylina ymyensis* Tahseen and Nusrat, 2010; B, C: Anterior body region in *T. valiathani* Tahseen and Nusrat, 2010; D: Anterior body region in *Tripylina* sp.; E-G: Tail region in *Tripylina* spp. (Scale bar= 10 µm).

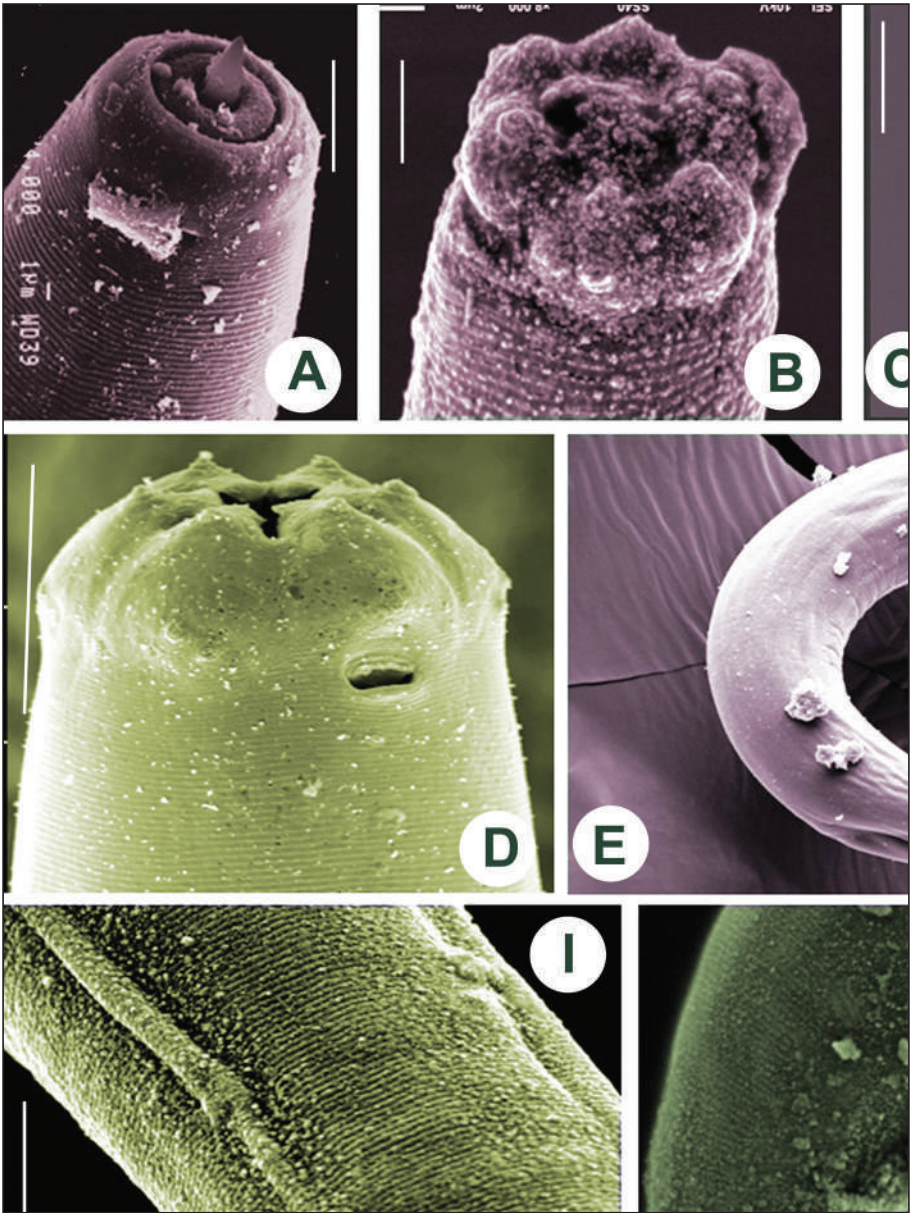

Fig. 6. Order: Dorylaimida. A: Anterior body region in *Paractinolaimus macrolaimus* (de Man, 1880) Meyl, 1957; B: Anterior body region in *Labronema papillatum* Khan, Ahmad & Jairajpuri, 1995; C: Tail region in *Tylencholaimus* sp. E: Male tail region in *Laimydorus* sp.; J: Vulval region in *L. papillatum* Khan, Ahmad & Jairajpuri, 1995; Order: Mononchida. D: Anterior body region in *Mononchus aquaticus* Coetzee 1968; I: Fine cuticular striations in *M. aquaticus* Coetzee 1968; Tail region in *Mylonchulus lacustris* (Cobb, 1915) Andrássy, 1958 (Scale bar= 10 µm).

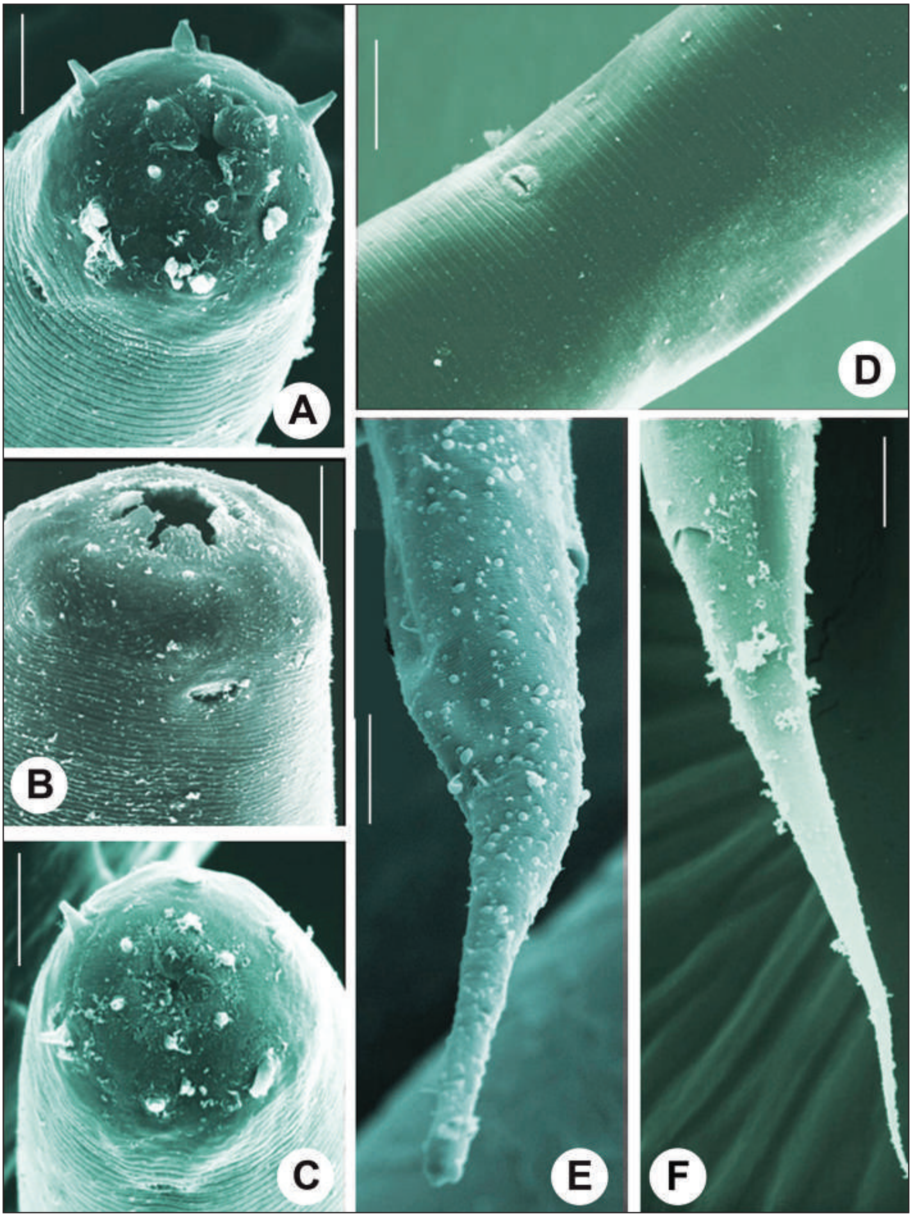

Fig. 7. Order: Enoplida. A, B, C: Anterior body region in *Brevitobrilus dimorphicus* Tahseen *et al*., 2009; Vulval region in *Prismatolaimus lacustris* Tahseen *et al*., 2006; E: Tail region in *B. dimorphicus* Tahseen *et al*., 2009; F: Tail region of *Ironus dentifurcatus* Argo and Heyns, 1972 (Scale bar= 10 µm).

Table 2. A tentative representation of freshwater nematode taxa from India (extracted from the published literature)

Nematode Taxa	Family	Genus	Species
ENOPLEA			
Enoplida	3	3	16
Triplonchida	5	10	12
Dorylaimida	14	39	218
Mononchida	5	9	35
Mermithida	2	2	6
CHROMADOREA			
Chromadorida	2	5	9
Desmodorida	1	1	1
Desmoscolecida	0	0	0
Monhysterida	2	8	15
Araeolaimida	1	1	8
Plectida	2	6	22
Rhabditida	20	35	80
Total	57	119	422

Classification

Of the orders of Nematoda, only Rhabditida seems to have the widest habitat range although its representation in marine environment is negligible (Table 2). The orders Dorylaimida and Mononchida are solely confined to inland habitats hence not found in estuarine or marine environments. Dry or xeric habitats may show occurrence of orders Dorylaimida and Rhabditida whereas the presence of Mononchida is negligible. The Orders Monhysterida, Araelolaimida, Plectida and Enoplida are of common occurrence in all types of aquatic environments and even in the moist soils. However, Chromadorida and Desmodorida show a very limited presence in moist soils. Desmoscolecida is a purely aquatic taxon.

Distribution

The nematodes form an important biotic component of lotic habitats in abundance and diversity, yet they are relatively less explored. Due to variation in water flow rates, organic enrichment, sediment granulometry, physical characteristics and chemistry of sediments, the lotic environments show differences in species composition, diversity and abundance (Hodda, 2006). Fresh water nematodes of shallow water bodies are often faced with periods of drying hence they show an inherent ability of quiescence and may undergo anhydrobiosis in response to water stress (Wharton, 1986; Womersley and Ching, 1989). Such characteristic also seems to be common in nematodes of Polar Regions (Pickup and Rothery, 1991; Wharton and Barclay, 1993; Wharton, 2004). Many freshwater nematodes particularly Cephalobs show anhydrobiosis although the trait may remain unexpressed in relatively stable habitats. Fresh water habitats may also show variation in food resources hence the species largely are omnivores, non-specialized microbial feeders or predators and often show food storage abilities for long time survival. Some crystalline structures in the of nematodes inhabiting the extreme habitats were earlier considered to be food storage sites (Bird *et at,* 1991) but were later declared to be involved with detoxifying mechanism for sulphides. Rhabditida and Mermithida have adopted the phoretic behaviour and get associated with insects for dispersal under adverse conditions. Very often the nematodes in lotic habitats are apparently occasionally or even accidentally found in either the sediments or the water column. Springs have relatively stable conditions and those with lower ionic content show higher abundance and species richness. Limnetic systems are relatively less variable in water characteristics and most limnetic genera are found to be either ubiquitous or have a widespread distribution (Andrássy, 1978; Jacobs, 1984). Some species show very short generation time and specialized adaptations for efficient dispersal in colonizing and exploiting eutrophic environments (Hodda, 2006). The limnetic habitats often show oxygen stress. Oxygen is taken up fast for the decomposition of the organic matter in these habitats (Zinabu and Taylor, 1989). In temperate and arctic regions, the lakes freeze for a long period in winters and the organisms therein face oxygen shortage. Therefore, among nematodes, the facultative anaerobes like *Tobrilus gracilis* withstanding anoxic conditions may be common in these habitats (Schiemer and Duncan 1973). In Lake Baikal too, the dominant groups are tobrilids (Tsalolikhin, 1975; Shoshin, 1999). Monhysterids are also found to be adapted to such anoxic environment (Jacobs and Heyns, 1990). A dorylaim, *Eudorylaimus andrassyi* has been reported (Hodda, 2006) to survive in the anaerobic situation, reproduce and increase its population in deeper part of the lake.

Endemism

Endemism cannot be worked out with context to Indian nematode fauna due to paucity of biogeographical data on freshwater nematodes. Unless substantial information is available on these nematodes, endemism cannot be established with certainty.

Adaptations of fresh water nematodes

Nematodes represent the most abundant metazoans in freshwater habitats. They can reach densities of up to 11.4 million/m^2 in fresh water habitats (Michiels and Traunspurger, 2005). Their adaptations to fresh water environment are reflected in many ways. Besides having a strong protective cuticle (often annulated) and hypodermis maintaining a high turgor pressure, most of the fresh-water nematodes are around 0.5-2 mm long having slender, spindle-shaped bodies with enhanced swimming abilities. Most aquatic nematodes possess long filamentous tails and propel themselves faster by their whipping action. They are also characterised by having conspicuous sense organs compared to their terrestrial counterparts. Most peripheral sense organs including lip sensilla and somatic sensilla are long, setiform. In several groups, numerous additional setae may be found. Amphids are bilaterally symmetrical structures and can be spiral, circular or cyathiform in fresh water forms demonstrating great taxonomic value. Being the inhabitants of an environment having dim or insufficient light, these nematodes have pigment bodies associated with the anterior pharynx, generally referred as eyespots or ocelli. The crystalline inclusions (crystalloids) in the bodies of fresh water monhysterids and enoplids are thought to be part of a detoxification mechanism for hydrogen sulphide, the generally toxic end product of respiration. Some structures found in fresh water nematodes are the stretch receptors (metanemes) as well as cephalic organs. The buccal cavity or stoma shows great diversity in form and structure, reflecting different feeding habits of these nematodes. The pharynx is accordingly modified and may be cylindrical or with one or two muscular expansion/s called pharyngeal bulb/s. The intestine is usually a simple straight tube not dissimilar to their terrestrial counterparts and is generally taxonomically unimportant. The excretory system mainly serves as osmoregulatory organ. Fresh water nematodes excrete nitrogenous wastes in the form of ammonia or urea. In absence of a specialized respiratory system, the nematodes exchange gases though the body surface and usually are aerobic in habit with exception of deep lake nematodes which survive in oxygen stress. The number and structure of ovaries along with other genital components, though taxonomically important, do not show much difference from those found in terrestrial nematodes and are largely meant to distinguish between major taxonomic groups (Lorenzen, 1981, 1994). Likewise the position of vulva varies from middle (e.g., members of Tobrilidae, Plectidae etc.) to posterior (e.g., monhysterids) in aquatic nematodes. The male nematodes may possess one (monorchic) or two (diorchic) testes irrespective of the habitat but largely depending on the taxa they belong to. Typically, the cuticularised spicules and a gubernaculum though important taxonomic characters, are not habitat-specific. However, the tail shape is a character showing specificity to the aquatic habitats as most nematodes show long tails usually with fine termini. If the tail terminus is bluntly-rounded, it is often supplemented with a spinneret- the outlet for caudal glands' sticky secretion that helps in anchorage to an object or substratum. This phenomenon of nictation is commonly found in fresh water nematodes.

Threats

Ecological services are compromised due to aquatic ecosystems being severely altered or destroyed at a rate much faster than they are being restored. The maintenance of freshwater ecosystems is essential for sustenance of biotic resources. According to UNESCO's report, Populations of freshwater species were reduced by half between 1970 and 2005. India with only 2.4% of the world's land area, represents 11-12% of biodiversity hotspots of the world. Despite the vastness of Indian habitats, the list of known indigenous species of nematodes is merely up to 3000 (unpublished), out of which majority are the plant parasites holding importance in agriculture. The non parasitic nematode fauna is relatively unexplored and undocumented. This is because of our apparent unawareness and apathy towards our own biodiversity wealth. Our ignorance towards the existing biodiversity is reflected in the limited use of our biodiversity resources. Many of species facing habitat loss are likely to become extinct before being known to science. Particularly, species with restricted ranges are vulnerable to these threats.

The increasing pollution and contamination of environment is a thing of concern as it also is a greater driver of biodiversity loss. The soil or water pollution directly affects the nematode diversity and can be studied using nematode models. The mushrooming industries have opened up job avenues but at the same time they have loaded our environment with various obnoxious chemicals and xenobiotics. Of the biodiversity wealth, many freshwater ecosystems are least surveyed and appear more threatened than the terrestrial ecosystems due to faulty practices such as creation of dams, water diversion, overexploitation besides water pollution. Therefore, there is an urgent need of taxonomic surveys facilitating species inventorization of the freshwater ecosystems of the country before they disappear from the scene.

Conservation and Human significance

Nematodes are quite important organisms of the earth ecosystem. They are the causative agents of a large number of diseases to humans, live stock and other animals bringing morbidity as well as mortality. They cause huge losses to agriculture and horticulture globally due to infesting a wide variety of plants. Not only forming the important component of the food chains of a complex web, the nematodes have also been recognized as excellent experimental models (*Caenorhabditis elegans, Panagrellus redivivus and Pristionchus pacificus*) in biological research particularly on the aspects of developmental genetics and ageing. Nematodes have now been used as bioindicators in environment monitoring programmes replacing several bacteria and animal models; thus providing a cost-effective strategy for testing pollutants of different categories in different habitats due to their ubiquity and resilience and specificity to various pollutants (Faupel et al. 2012). Ecological concepts based on coexistence of species sharing the same resource have potential uses for more effective biological control. The widespread degradation of freshwater ecosystems has to be stopped and a variety of management techniques should be used to restore these systems to a more natural and sustainable state in order to prevent continued loss of biodiversity, ecosystem functioning, and ecological integrity.

Gaps in research

Realizing India's rich biological heritage our ignorance towards the existing nematode species is enormous due to their microscopic size and hidden nature. With latest researches, the importance of nematode has been dawned on us in all walks of life. Besides being parasites of animals and plants, the nematodes form an important component of food web due to their important role in nutrient cycling as bacterivores and fungivores. The aquatic nematodes in general and the fresh water nematodes in particular are the groups which need much attention of taxonomists but studies made on these groups are fragmentary. Although several studies have been made on the taxonomy of soil and fresh water nematodes in the past but they are too few to make any difference due to vastness of the area with remote and unexplored habitats. With a huge unaccounted biodiversity in the freshwater systems, the societal need of taxonomy is greater than ever but the resources supporting taxonomy are becoming scarcer (Wilson, 1985; Wheeler et al. 2004; Evenhuis, 2007) thus impeding the process of conservation. The decreasing numbers of taxonomists, lesser number of taxonomic centers and inadequate taxonomic training have their fall out on effective management of our biodiversity wealth. The identification and taxonomic placement need to follow a holistic approach to have comprehensive information about a species and its functional status in the environment. A more complete knowledge of freshwater nematodes and subsequently their positions in food webs may be potentially beneficial to risk assessment and managerial approaches. Thus the inclusion of free-living nematodes in the simulation models of freshwater food webs may help to disentangle pathways describing the "small-scale" control of some key ecological processes (Majdi and Traunspurger, 2015).

Expertise (India and Abroad)

In India, initially the studies in Nematology began with the taxonomic aspects with plant parasitic nematodes and free-living soil inhabiting nematodes in focus. Institutes busy in Nematological research are largely focusing on non taxonomic aspects. The taxonomic studies that too on freshwater nematodes, with special reference to wetlands, have been mostly conducted by the author and to some extent by Prof. Irfan Ahmad and Prof. Wasim Ahmad of Section of Nematology, Department of Zoology, Aligarh Muslim University, Aligarh, Uttar Pradesh.

Indian scientists who have expertise in taxonomy of nematodes are:

Prof. H.K. Bajaj (Retd.), Department of Nematology, Haryana Agricultural University, Hisar

Dr. Uma Rao, Department of Nematology, Indian Agricultural Research Institute, New Delhi

Prof. S. Subramanian, Department of Nematology, Centre for Plant Protection Studies, Tamil Nadu Agricultural University, Coimbatore,

There are a good number of experts working in the field of Nematology in various Nematology Departments in Bihar, Gujarat, Himachal Pradesh, Orissa, Karnataka, Kerala, Tamil Nadu, Uttar Pradesh etc. but largely they have been focusing on non taxonomic themes and on management issues.

Some of the active international experts, who have dealt or presently dealing with the taxonomy of freshwater nematodes, are:

Prof. Walter Traunspurger, University of Bielefeld, Morgenbreede 45 D-33615 Bielefeld, Germany

Prof. Walter Sudhaus, Institut für Biologie/Zoologie, AG Evolutionsbiologie, Freie Universität, D-14195 Berlin, Germany.

Prof. Aldo Zullini, Dept. of Biotechnology & Biosciences, University of Milano -Bicocca (Italy)

Prof. Howard Ferris, Dept. of Entomology and Nematology, UC Davis, US

Dr. David H.A. Fitch, Dept. of Biology, New York University, New York, US

Dr. Oleksandr Holovachov, Dept. of Zoology, Swedish Museum of Natural History, Stockholm, Sweden

Dr. Paul De Ley, Nematology Dept., University of California, Riverside, US

Dr. Eyualem Abebe, Elizabeth City State University, Elizabeth city, North Carolina, US

Dr. M.R. Siddiqi, 24 Brantwood Road, Luton, England, UK

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Chapter 10

BRYOZOA

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ABSTRACT

Bryozoa are also known as polyzoa, ectoprocta or moss animals are small benthic aquatic invertebrates growing as colonies of connected zooids on submerged substrates. A total of 94 species of Bryozoans placed under 24 genera, 10 families and two classes are known worldwide. The Indian fauna comprises a total of 22 species under 13 genera and 6 families belonging to two classes namely Gymnolaemata and Phylactolaemata.

Key words: Bryozoa, Gymnolaemata, Phylactolaemata, Freshwater, India.

INTRODUCTION

Bryozoa are also known as polyzoa, ectoprocta or moss animals that play an important role in water quality monitoring and palaeolimnological research and for controlling their growth as foulers (Swami *et al.,* 2014). They are small benthic aquatic invertebrates growing as colonies of connected zooids on submerged substrates and feed on suspended organic particles which they capture with a whorl of ciliated tentacles or lophophore (Massard & Geimer, 2008). They inhabit many aquatic environment like ponds, reservoirs, lakes, streams found stuck to the surface of any substratum like aquatic weeds, logs, stones, bricks, etc., and they also live together in the form a colony, and are generally yellowish-brown, pinkish-brown, dark-brown, reddish-brown, green or black in color (Samanta, 1999, Mitra, 2016).

Review of literature

Annandale (1906, 1911) and Annandale and Kemp (1912) studied the freshwater bryoazoans in India and made a significant contribution to the Indian freshwater Bryozoa. After that nearly fifty years there were no further information of this group. Roonwal (1969) restarted the work on Indian freshwater Bryozoans which was followed by many significant workers like Rao (1961, 1972, 1973, 1976, 1991), Rao *et al.* (1962, 1978, 1979, 1985), Srivastava (1981, 1985) and Chaubey *et al*. (1985). Samanta (1998, 1999, 2000, 2003, 2005) reported the occurrence of freshwater bryozoans from West Bengal, Meghalaya, Tripura, Sikkim and Andhra Pradesh. Kalita and Goswami (2005) reported 5 species of freshwater bryozoans from the Deepar wetland near Guwahati Assam. Again Samanta (2007) has

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investigated the distribution bryozoans in Uttar Pradesh and reported 5 species. Mitra and Pattanayak (2013) reported *Plumatella javanica* Karepelin, from Arunachal Pradesh. Mokashe *et al.* (2015) recorded *Swarupella divina* for the first time from India.

Global and Indian Diversity (Table. 1 and 2)

Of the estimated 5700 or even 8000 extant species of bryozoans, only a small number are found in freshwater habitats (Massard & Geimer, 2008). The freshwater Bryozoa comprises two classes namely Gymnolaemata and Phylactolaemata at global level both of them have 5 families each and the former class comprises 20 species under 8 genera whereas the latter includes 74 species under 16 genera. A total of 94 species of Bryozoans placed under 24 genera, 10 families and two classes are known worldwide. Massard & Geimer (2008) made a detailed analysis of the global freshwater bryozoans and their study shows that among the seven major zoogeographical realm the oriental region has highest species number (Table. 2). The Indian fauna comprises a total of 22 species under 13 genera and 6 families of the two classes. Out of the 20 species of Gymnolaemata 3 species are available in India and out of 74 species of Phylactolaemata 19 species are available in India (Table. 1).

Table 1. Global and Indian Distribution

Class/Family	World		India	
	Genera	Species	Genera	Species
Class **Gymnolaemata** Allman, 1856 (5 Families)	**8**	**20**	**2**	**3**
Family Victorellidae Hincks, 1880	4	8	1	1
Family Pottsiellidae Braem, 1940	1	1	-	-
Family Paludicellidae Allman, 1885	1	2	-	-
Family Arachnidiidae Hincks, 1877	1	1	-	-
Family Hislopiidae Jullien, 1885	1	8	1	2
Class **Phylactolaemata** Allman, 1856 (5 Families)	**16**	**74**	**11**	**19**
Family Fredericellidae Hyatt, 1868	2	6	1	1
Family Plumatellidae Allman, 1856	9	59	6	14
Family PectinatellidaeLacourt, 1968	1	1	2	2
Family Cristatellidae Allman, 1856	1	1	-	-
Family Lophopodidae Rogick, 1935	3	7	2	2
Total	**24**	**94**	**13**	**22**

Table 2. Zoogeographical distribution

Class/Family	PA		NA		NT		AT		OL		AU		PAC		WORLD	
	G	Sp.	G	Sp.	G	Sp.	G	Sp.	G	Sp.	G	Sp.	G	Sp.	G	Sp.
Gymnolaemata Allman, 1856 5F; 8G; 20sp.	6	10	4	4	4	6	2	2	3	8	2	2	-	-	8	20
Victorellidae Hincks, 1880	3	5	2	2	1	1	1	1	1	2	1	1	-	-	4	8
Pottsiellidae Braem, 1940	-	-	1	1	1	1	-	-	-	-	-	-	-	-	1	1
Paludicellidae Allman, 1885	1	1	1	1	1	2	-	-	1	1	1	1	-	-	1	2
Arachnidiidae Hincks, 1877	1	1	-	-	-	-	1	1	-	-	-	-	-	-	1	1
Hislopiidae Jullien, 1885	1	3	-	-	1	2	-	-	1	5	-	-	-	-	1	8
Phylactolaemata Allman, 1856 5F; 16g; 74sp.	13	34	9	28	6	24	8	20	14	39	4	14	1	2	16	74
Fredericellidae Hyatt, 1868	2	4	1	4	1	3	1	2	2	4	1	2	-	-	2	6
Plumatellidae Allman, 1856	6	24	4	20	3	19	6	14	9	30	2	11	1	1	9	59
Pectinatellidae Lacourt, 1968	1	1	1	1	1	1	-	-	1	1	-	-	-	-	1	1
Cristatellidae Allman, 1856	1	1	1	1	-	-	-	-	-	-	-	-	-	-	1	1
Lophopodidae Rogick, 1935	3	4	2	2	1	1	1	4	2	4	1	1	-	-	3	7
Total	19	44	13	32	10	30	10	22	17	47	6	16	1	2	24	94

Source: Table slightly modified after Massard & Geimer, 2008.

PA: Palaearctic; NA: Nearctic; NT: Neotropical; AT: Africotropical; OL: Oriental; AU: Australasian; PAC: Pacific Oceanic Islands

SYSTEMATIC LIST OF INDIAN FRESHWTER BRYOZOA

Phylum BRYOZOA Ehrenberg, 1831

Class GYMNOLAEMATA Allman, 1856

Order CTENOSTOMATA (or CTENOSTOMATIDA) Busk, 1852

Family HISLOPIIDAE Jullien, 1885

Genus ***Hislopia*** Carter, 1858

1. *Hislopia prolix* Hirose and Mawatari, 2011

(=*Hislopia lacustris*: Annandale, 1911 (vide Jung *et al*., 2017))

2. *Hislopia moniliformis* (Annandale, 1911)

Family VICTORELLIDAE, Hincks, 1880

Genus ***Victorella*** Saville Kent, 1870

3. *Victorella pavida* Saville Kent, 1870

Class PHYLACTOLAEMATA Allman, 1856

Family FREDERICELLIDAE Hyatt, 1868

Genus ***Fredericella*** Gervais, 1838

4. *Fredericella sultana* (Blumenbach, 1779)

Family PLUMATELLIDAE Allman, 1856

Genus ***Afrindella*** Annandale, 1912

5. *Afrindella tanganyikae* (Rousselet,1907) (=*Plumatella tanganyikae* of Annandale, 2011)

Genus ***Plumatella*** Lamarck, 1816

6. *Plumatella bombayensis* Annandale, 1908 (?)
7. *Plumatella emarginata* Allman, 1844
8. *Plumatella casmiana* Oka, 1907
9. *Plumatella fruticosa* Allman, 1844
10. *Plumatella javanica* Kraepelin, 1906
11. *Plumatella repens* (Linnaeus, 1758)
12. *Plumatella ganapati* Rao, Agrawal, Diwan & Shrivastava, 1985

Genus ***Hyalinella*** Jullien, 1885

13. *Hyalinelladiwanensis* Rao, Agrawal, Diwan & Shrivastava, 1985
14. *Hyalinella punctata* (Hancock, 1850)

Genus ***Rumercanella*** Hirose and Mawatare, 2011

15. *Rumarcanella vorstmani* (Toriumi, 1952)

Genus ***Stolella*** Annandale, 1909

16. *Stolellaindica* Annandale, 1909

Genus ***Swarupella*** Srivastava, 1981

17. *Swarupella andamanensis* (Rao, 1961)
18. *Swarupella divina* Wood *et al.,* 2006

Family LOPHOPOPIDAE Rogick, 1935

Genus ***Asajirella*** Oda & Mukai, 1989

19. *Asajirella gelatinosa* (Oka, 1891)

Genus ***Lophopodella*** Rousselet, 1904

20. *Lophopodella carteri* (Hyatt, 1866) (=*Stolellahimalayanus* Annandale, 1911)

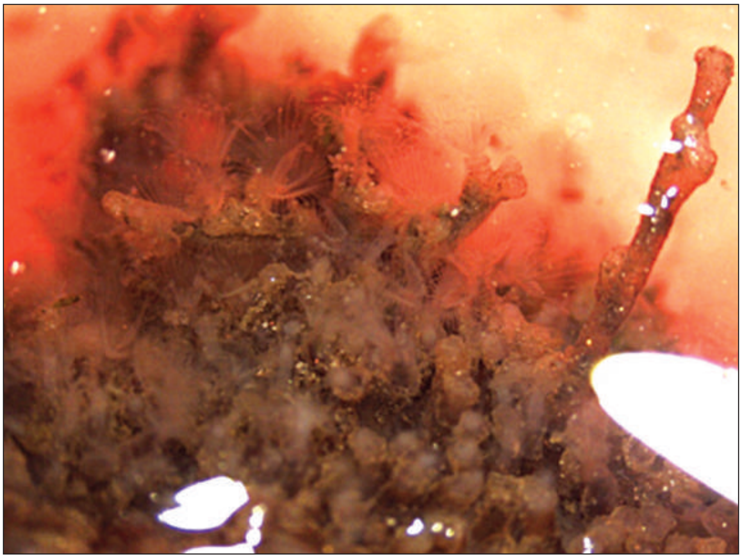
Family PECTINATELLIDAE Lacourt, 1968

Genus ***Pectinatella*** Leidy, 1851

21. *Pectinatellaburmanica* Annandale, 1908

Genus ***Varunella***

22. *Varunella indorana* Wiebach, 1974



Plumatella fruticosa Allman, 1844

Reproduction and Life History

(Source: http://www.ucmp.berkeley.edu/bryozoa/bryozoalh.html)

Bryozoans can reproduce both sexually and asexually. Asexual reproduction occurs by budding off new zooids as the colony grows, and is this the main way by which a colony expands in size. If a piece of a bryozoan colony breaks off, the piece can continue to grow and will form a new colony. In some bryozoan species, colonies largely die off in the winter and regenerate the following summer. Freshwater bryzoans can also reproduce asexually by forming masses of cells surrounded by chitinous valves. These cell masses, known as statoblasts, remain dormant for some time and can withstand drying and freezing; when conditions are favorable, the statoblasts germinates and forms a new zooid.

Most bryozoans are hermaphroditic, with individuals containing both ovaries and testes; however, these may not be at the same state of maturity at the same time. Some species shed both eggs and sperm directly into the water where they fuse, but the majority of species brood their eggs, within the zooecium or in special chambers known as ovicells, and capture free-swimming sperm with their tentacles to fertilize the eggs. The fertilized eggs divide and develop into free-swimming larvae, which escape from the brood chamber and swim away. These larvae eventually settle on a suitable substrate and metamorphose into a new zooid, which becomes the parent zooid, or ancestrula, of a new bryozoan colony.

Significance of Freshwater Bryozoans

Wood (2005) investigated the pipeline menace of Freshwater Bryozoans and his observation and suggestion to control this fouling agent is as follows. Under certain conditions, conduits carrying unfiltered water from lakes or rivers eventually become lined with bryozoans, hydroids, sponges, and many other organisms. By blocking the conduit or clogging end use devices, these nuisance animals impose serious economic costs. Bryozoans are probably the most common among the fouling animals. Three factors that hamper control efforts are (1) dormant bodies (statoblasts or hibernaculae) that tolerate harsh physical and chemical treatments; (2) regeneration of bryozoan colonies from pockets of living tissue; (3) easy dispersal of bryozoans through air and water. Control measures must take into account the species involved, their source, their accessibility, the end use of the water, and the seasonal conditions in which the problem occurs. Wood *et al.* (2006) identified *Pomacea canaliculata* an invasive species of snail is a voracious predator of phylactolaemate bryozoans.

Gap Area

The studies on the freshwater bryozoans is very limited and scanty and at present very limited and very little attention is given to this group. The status of certain freshwater Bryozoan species are not clear so a taxonomic revision of this group is essential. It becomes very rare to see taxonomists who are working in this group and most of the earlier workers are superannuated. The authors are not experts of this group and the present work is merely a compilation of information for study purpose, based on the published research articles and information available online. More young researchers should come forward to study these poorly studied freshwater bryozoans.

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Chapter 11

ANNELIDA : POLYCHAETA

SANTANU MITRA AND SUBHRENDU S. MISHRA

ABSTRACT

Review of literature on freshwater polychaete fauna of India reveals occurrence of 41 species belonging to 25 genera in 15 families. Nereididae is the most diverse family with 5 genera and 11 species. Some species, considered primarily as estuarine component, are able to survive in pure freshwater conditions also. Very few species are able to adapt lentic freshwater ecosystems, like ponds or lakes. A comprehensive list of freshwater polychaetes of India is provided herewith.

Key words: Polychaeta; Annelida; freshwater.

INTRODUCTION

Polychaetes, commonly called as 'brittle worms', are non-monophyletic groups of animals belonging to the phylum Annelida. This is one of the major invertebrate communities of marine ecosystems. They are usually the most abundant animals living in sand and mud substratum of seas hore. There are several marine forms which have penetrated to brackish water of estuarine ecosystems and also survive in pure freshwater systems, but unable to breed there while others have adapted significantly to remain for their entire life-span in freshwater. Polychaetes are considered an important faunal component in any ecosystem, exhibiting a short life span with a high secondary production. This group is established as an important link by the food chain; they play a leading role in demersal fishery as they are consumed by many bottom feeding fishes.

However, systematics and ecological studies of polychaetes are comparatively very poor than those of other major groups of animals. The global diversity of polychaetes is about 14000 species, where as only about 320 species have been reported from Indian waters (Misra, 1995; Pati *et al*., 2015). No comprehensive report on 'Freshwater Polychaetes' has been brought out from India, except for some stray reports (Dutta Munshi *et al*., 1989, Nesemann *et al*., 2004, Mitra & Roy, 2010, Mitra *et al.,* 2011). The present work is an attempt towards preparing a check list of all the polychaetes that live in freshwater habitats in India as only scattered information is currently available on this group. This comprehensive checklist may serve as an essential database for ecological and taxonomical works on the benthic fauna of this group in any freshwater bodies. Information was compiled and collated based on the review of the literature on polychaete fauna in different lentic and lotic freshwater systems found all along and across India, as well as personal field experience of the present author.

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Historical Resume

Wesenberg-Lund (1958) initiated the listing of typical non-marine polychaetes around the world by reporting 43 species, comprising 31 purely fresh water species. Glasby and Timm (2008) were the first to review comprehensive global data on the diversity of freshwater polychaetes which yielded enlisting of 168 species under 70 genera and 24 families though not more than 2% of all the species of polychaetes found in the world. Later Glasby *et al.* (2009) updated it by cataloguing 197 species representing 78 genera and 26 families of which the family Nereididae dominated comprising 61 species.

Willey (1908) described a new species *Spio bengalensis* from the brackish water ponds of Canning in Sunderban delta, which was the first work on non-marine polychaetes in India, till the pioneering work of Southern (1921) providing a comprehensive account of the polychaetes of brackish waters in India. In this work, he even mentioned about some polychaetes that could live in pure fresh water conditions. Fauvel (1932, 1953) in his studies on Polychaetes of Indian waters mentioned only 47 brackish-water species out of the total 283 polychaetes species known from India. Misra (1995) contributed a more detailed account on the non-marine polychaetes from several brackish water ecosystems in India and reported 167 species of polychaetes under 38 families, with comments on salinity tolerance of those species. There are several reports on estuarine polychaetes that can also tolerate freshwater conditions (Southern 1921; Misra 1995).

Table 1. Freshwater polychaete diversity in India and World

Family	No. of Genus in World	No. of Genus in India	No of species in the world	No of species in India
Capitellidae	6	3	4	4
Maldanidae	1	1	1	1
Orbinidae	1	1	1	1
Paraonidae	1	0	1	0
Pisionidae	1	0	1	0
Nereididae	17	5	55	11
Pilargidae	1	1	1	1
Goniadidae	1	1	1	1
Nephtyidae	2	2	3	2
Phyllodocidae	1	1	1	1
Eunicidae	1	1	1	1
Histriobdellidae	1	0	10	0
Lumbrineridae	1	1	2	2

Family	No. of Genus in World	No. of Genus in India	No of species in the world	No of species in India
Onuphidae	1	0	1	0
Sabellidae	8	1	22	1
Serpulidae	2	1	5	2
Cirratulidae	2	0	2	0
Sternaspidae	2	1	3	1
Ampharetidae	6	0	6	0
Terebellidae	1	0	1	0
Spionidae	11	4	17	5
Aeolosomatidae	3	1	27	7
Nerillidae	1	0	1	0
Protodrilidae	1	0	1	0
Potamodrilidae	1	0	1	0
TOTAL	74	25	169	41

Diversity

A thorough review of literature on the polychaetes and other aquatic annelid fauna of the freshwater ecosystems of India reveal the occurrence of 41 species belonging to 25 genera and 15 families (Table 2). Family-wise Global and Indian diversity of freshwater polychaetes are compared in Table 1. The family Nereididae is the most diverse, with 5 genera and 11 species, followed by family Spionidae, with 4 genera and 5 species. Family Aeolosomatidae, earlier considered as freshwater oligochaete, is now treated under Polychaeta (Glasby and Team 2008; Glasby *et al.,* 2009). Some species, primarily considered as estuarine component, are revealed to be able to survive in pure freshwater condition also. A few species can thrive in lentic freshwater ecosystems, like ponds or lakes. All the 7 species of Aeolosomatidae are very specialists in lentic and lotic freshwater bodies. Among the typical polychaetes, *Namalycastis indica* and *Micronephtys oligobranchia* found in the Yamuna river about 1600 km from the Ganges delta, at the elevation of 70-100 m above sea level (Glasby and Timm, 2008). *Namalycastis indica* was reported from several pond ecosystems of India located at far distances from sea-coast (Roy and Nandi 2008; Mitra and Misra, 2012, Roy and Nandi, 2012). Mitra and Roy (2010) reported *Lumbrineris psedobifilaris* from a freshwater bhery at the East Kolkata wetlands of West Bengal, which is interestingly a new addition to the Global list of freshwater polychaetes (Glasby *et al.,* 2009). Dutta Munshi (1989) initiated a very important work, the ecological study of freshwater polychaetes in the Ganges River, but such studies were not carried out in other major rivers or in any large freshwater system in the country.

Table 2. Systematic List of the Freshwater Polychaetes of Indian Waters

Phylum ANNELIDA Lamarck, 1809

Class POLYCHAETA Grube, 1850

Order SCOLECIDA *sensu* Rouse and Fauchald, 1997

Family CAPITELLIDAE Grube, 1862

Genus ***Capitella*** Blainville, 1828

1. *Capitella capitata* (Fabricius, 1970)

Genus ***Heteromastus*** Eisig, 1887

2. *Heteromastus filiformes* (Claparede, 1864)
3. *H. similis* Southern, 1921

Genus ***Parheteromastus*** Monro, 1937

4. *Parheteromastus tenuis* Monro, 1937

Family MALDANIDAE Malmgren, 1867

Genus ***Euclymene*** Verrill, 1900

5. *Euclymene annandalei* Southern, 1921

Family ORBINIIDAE Hartman, 1942

Genus ***Scoloplos*** Baainville, 1828

6. *Scoloplos marsupialis* Southern, 1921

Order PHYLLODOCIDA Dales, 1962

Family NEREIDIDAE Blainville, 1818

Genus ***Dendroneriedes*** Southern, 1921

7. *Dendronereides gangetica* Misra, 1999
8. *D. heteropoda* Southern, 1921

Genus ***Dendronereis*** Peters, 1854

9. *Dendronereis aestuarina* Southern, 1921

Genus ***Namalycastis*** Hartman, 1959

10. *Namalycastis fauveli* Rao, 1981
11. *N. indica* (Southern, 1921)
12. *N. meraukensis* (Horst, 1918)

Genus ***Neanthes*** Kinberg, 1865

13. *Neanthes chilkaensis* (Southern, 1921)
14. *N. glandicincta* (Southern, 1921)
15. *N. meggitti* (Monro, 1931)
16. *N. reducta* (Southern, 1921)

Genus ***Tylonereis*** Fauvel, 1911

17. *Tylonereis fauveli* Southern, 1921

Family PILARGIDAE de Saint-Joseph, 1899

Genus ***Sigambra*** Muller, 1858

18. *Sigambra constricta* (Southern, 1921)

Family GONOIADIDAE Kinberg, 1866

Genus ***Glycinde*** Muller, 1858

19. *Glycinde oligodon* Southern, 1921

Family NEPHTYIDAE Grube, 1850

Genus ***Nephtys*** Cuvier, 1817

20. *Nephtys polybranchia* Southern, 1921

Genus ***Micronephthys*** Friedrich, 1939

21. *Micronephthys oligobranchia* (Southern, 1921)

Family PHYLLODOCIDAE Oersted, 1843

Genus ***Hypereteone*** Bergstrom, 1914

22. *Hypereteone barantollae* (Fauvel, 1932)

Order EUNICIDA Fauchald, 1977

Family EUNICIDAE Berthold, 1827

Genus ***Marphysa*** Quatrefages, 1866

23. *Marphysa gravelyi* Southern, 1921

Family LUMBRINEREIDAE Malmgren, 1867

Genus ***Lumbrineris*** Blainville, 1818

24. *Lumbrineris bilabiata* Misra, 1999
25. *L. pseudobifilaris* Fauvel, 1932

Order SABELLIDA Fauchald, 1977

Family SABELLIDAE Latreille, 1825

Genus ***Potamilla*** Malmgren, 1866

26. *Potamilla leptochaeta* Southern, 1921

Family SERPULIDAE Rafinesque, 1815

Genus ***Ficopomatus*** Southern, 1921

27. *Ficopomatus macrodon* Southern, 1921

28. *F. uschakovi* (Pillai, 1960)

Order TEREBELLIDA *sensu* Rouse and Fauchald, 1997

Family STERNASPIDAE Carus, 1863

Genus ***Sternaspis*** Otto, 1820

29. *Sternaspis costata* Marenzeller, 1879

Order SPIONIDA *sensu* Rouse & Fauchald, 1997

Family SPIONIDAE Grube, 1850

Genus ***Polydora*** Bosc, 1802

30. *Polydora ciliata* (Johnston, 1838)

31. *P. hornelli* Willey, 1905

Genus ***Prionospio*** Malmgren, 1867

32. *Prionospio cirrifera* Wiren,1833

Genus ***Paraprionospio*** Caullery, 1914

33. *Paraprionospio pinnata* (Ehlers, 1901)

Genus ***Pseudopolydora*** Czerniavasky, 1881

34. *Pseudopolydora kempi* (Southern, 1921)

Order AELOSOMATIDA (inserte sedis)

Family AEOLOSOMATIDAE Beddard, 1895

Genus ***Aeolosoma*** Ehrenberg, 1828

35. *Aeolosoma beddardi* Michaelsen, 1900

36. *A. headleyi* Beddarad, 1888

37. *A. hemprichi* Ehrenberg, 1831

38. *A. hyalinum* Blunke, 1967

39. *A. niveum* Leydig, 1865

40. *A. travancorense* Aiyer, 1926

41. *A. viride* Stephenson, 1913

Importance of Polychaetes

Polychaetes serve as food for bottom-feeding fin- and shell fishes. They are used as 'bait organisms' in sport fishery. Polychaetes are important food resource in aquaculture for Crustacea as they provide correct balance of PUFA that is very essential for maturation and egg production of shrimps; they often consume *Eunice viridis* as food. Polychaetes are now-a-days used as indicator species of pollution in EIA (Environment Impact Assessment) studies as considerable importance is established to their presence or absence in the aquatic systems. They also play a key role in recycling of nutrients between pelagic and benthic realms; sometimes these animals are used as toxicological test organisms. Some polychaetes are being used to remove organic wastes from aquaculture systems.

Scope of studies

Polychaetes are one of the most important components of marine benthic community, but in freshwater systems though their diversity and density of populations are not high, their occurrence or absence has of significance as indicator species implying the health of the habitat environment. Investigations on this group for diversity documentation works in the freshwater ecosystems of India have not been adequately attempted. It is very much needed to have systematic surveys along the major freshwater bodies i.e. rivers, lakes and other small and big water bodies to investigate and study the diversity of polychaetes and also their ecological role in these aquatic systems.

Fig. 1. *Lumbrinereis bilabiata*

Fig. 2. *Heteromastus filiformes*

Fig. 3. A group of polychaete worm (belonging to Nereidae, Lumbrinereidae and Capitellidae)

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Chapter 12

ANNELIDA : OLIGOCHAETA (MICRODRILI)

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ABSTRACT

The present document recognises 71 species of Oligochaetes placed under 20 genera and one family freshwater environments of India. Taxonomic studies of freshwater oligochaetes in India are sporadic and their diversity and distribution in several states is not known yet. Since they are indicators of health of aquatic bodies, besides being food source for benthic organisms, a thorough systematic exploration and inventory of oligochaetes of various acquatic habitats in poorly explored states are needed on priority basis.

Key words: Oligochaeta, Annelida, Freshwater, Diversity, India.

INTRODUCTION

The oligochaetes are elongate and segmented animals with no appendages belonging to Phylum Annelida. The first segment, called prostomium, is smooth and conical without any sensory organ, while remaining segments are with a few bristles or chaetae. A few anterior segments with numerous sensory glands are modified into clittelum, important for reproduction. Oligochates are either burrowing or aquatic in habit. About half of the Annelids are placed in subclass Oligochaeta. They were also termed as Clitellata that include all segmented animals possessing a clitellum. However, paraphyly of clitellates has been confirmed by molecular analyses (Siddall *et al*., 2001) and Clitellata has become synonymous with "Oligochaeta" (Martin *et al.,* 2008) by separating monophyletic leeches and branchiobellids.

The oligochaetes were classified by Benham (1890) into two convenient groups on the basis of their body size and habitat preferences: Microdrili (small, mainly aquatic worms, including primarily terrestrial family Enchytraeidae), and Megadrili (larger, mostly terrestrial worms and their aquatic representatives). Martin *et al.* (2008) estimated about 1,700 valid species of globally known aquatic oligochaetes. Of these about 1100 spp. inhabit freshwater, 600 are known from marine environment and around 100 species are living in ground water. Family Enchytraeidae include nearly one-third of globally valid 676 species inhabiting aquatic habitats. Michaelsen (1928) combined orders Oligochaeta and Hirudinea into class Clitellata on the basis of their close affinities. Though Oligochaeta Grube, 1850 being older name than Clitellata Michaelsen, 1928, the latter was explicated with the objective to include Hirudinea that follows the priority principle for phylogenetic taxon names (Rouse and Fauchald, 1995).

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Oligochaetes generally comprise of 50% of the benthic macro-invertebrate communities in Indian lakes, rivers and streams, at least 10% of the benthic community in estuaries near-shore, coastal areas etc., and 40% terrestrial, freshwater and marine oligochaetes. They form an integral component of aquatic communities throughout the world. This group largely contributes to diet of bottom feeding omnivores. Many studies have focused on the use of freshwater oligochaetes as indicator of trophic condition, environmental health and their impact on sediment structure. Correct identification of oligochaetes is necessary for bio-assessment of any aquatic environment. The aim of the present communication is to provide a brief state of art report of freshwater oligochaetes of India and scope of the studies for this particular group of animals.

Review of work

Stephenson (1930) authored one of the major reviews of Oligochaeta, but this was primarily as an overview of the zoology of this group, not as taxonomic reference. Subsequently, Sperber (1948) published the most comprehensive contribution to the taxonomy of Naididae. Brinkhurst and Jamieson (1971) compiled voluminous information on systematics and taxonomy of aquatic oligochaetes of the world. Brinkhurst and Wetzal (1984) added the supplement to it with the global review, and provided an annotated list of described or revised freshwater oligochaetes. Further, Brinkhurst (1986) provided guide to the freshwater oligochaetes of the world as a supplement to previous publications.

Annandale (1905) was the pioneer to put forth a note on Indian oligochate, and described an aquatic oligochate, *Chaetogaster bengalensis,* from India. Stephenson (1907 a & b) and Michaelson (1909) were next to him to work on Indian freshwater oligochaete fauna. Stephenson had done an extensive work covering most of the geographical range of India, leading to documentation of the fist compilation on oligochaete fauna of India (Stephenson, 1923), followed by few other notable contributions till 1931 (Stephenson, 1924, 1925, 1926, 1931). Aiyer (1929) gave an account of aquatic olegochaeta from Travancore following the work of Cognetti (1911).

In the latter half of 20th century, K.V. Naidu devoted to the study of aquatic oligochaetes and his five-decade-long research along with co-workers was compiled in the form of *"The Fauna of India and the adjacent countries - Aquatic Oligochaeta"* (Naidu, 2005). Our knowledge on Aquatic Oligochaetes of India is mainly based on this comprehensive work.

The present list of aquatic oligochaetes of India is largely based on Naidu (2005). Species referred under family Microchaetidae in Naidu (2005) are regarded as aquatic representatives of megadril oligochaetes, assigned under family Almidae, and are not included in the present list. Similarly, species listed in the family Aeolosomatidae are also excluded following recent observations (Rouse and Fauchald, 1995). A total of 106 aquatic Oligochaeta species has been listed by Singh *et al.* (2009), including Aeolosomatids and other Asian species that are not recorded from Indian Territory.

Species Diversity

Classification of Oligochaeta is in a state of instability due to considerable ongoing studies using molecular and morphological data. The systematic position of the family Aeolosomatidae is uncertain. However, it has been excluded from the present list, as it is included under freshwater polychaetes (Rouse and Fauchald, 1995; Glasby *et al*., 2009). Primarily terrestrial microdril family Enchytraeidae, that is represented by 18 species under 7 genera in India is also excluded from the purview of this communication. The present document recognises 71 species of oligochaetes placed under 20 genera in one family as purely aquatic in habit. The list of species known from India is provided hereunder (Table 1).

Table 1. Systematic List of freshwater oligochaetes of India

Phylum ANNELIDA

Class CLITELLATA

Subclass OLIGOCHAETA

Order TUBIFICIDA

Family NAIDIDAE

Subfamily NAIDINAE

Genus ***Chaetogaster*** von Baer, 1827

1. *Chaetogaster cristallinus* Vejdovsky, 1883
2. *Chaetogaster diaphanous* (Gruithuisen, 1828)
3. *Chaetogaster diastrophus* (Gruithuisen, 1828)
4. *Chaetogaster langi* Bretscher, 1896
5. *Chaetogaster limnaei bengalensis* Annandale, 1905
6. *Chaetogaster limnaei limnaei* von Baer, 1827

Genus ***Nais*** Müller, 1773

7. *Nais andhrensis* Naidu & Naidu, 1981
8. *Nais andina* Cernosvitov, 1939
9. *Nais barbata* Müller, 1773
10. *Nais bretscheri* Michaelsen, 1899
11. *Nais communis* Piguet, 1906
12. *Nais elinguis* Müller, 1773
13. *Nais simplex* Piguet, 1906
14. *Nais variabilis* Piguet, 1906

Genus ***Slavinia*** Vejddovsky, 1883

15. *Slavinia appendiculata* (d'Udekem, 1855)

Genus ***Stylaria*** Lamarck, 1816

16. *Stylaria fossularis* Leidy, 1852

Genus ***Haemonais*** Bretscher, 1900

17. *Haemonais waldvogeli* Bretscher, 1900

Genus ***Branchiodrilus*** Mich., 1900

18. *Branchiodrilus hortensis* Stephenson, 1910
19. *Branchiodrilus semperi* (Bourne, 1890)

Genus ***Dero*** Oken, 1815

20. *Dero cooperi* Stephenson, 1932
21. *Dero digitata* (Müller, 1773)
22. *Dero dorsalis* Ferronière, 1899
23. *Dero indica* Naidu, 1962
24. *Dero nivea* Aiyer, 1929
25. *Dero obtusa* d'Udekem, 1855
26. *Dero palmata* Aiyer, 1929
27. *Dero pectinata* Aiyer, 1929
28. *Dero plumosa* Naidu, 1962
29. *Dero raviensis* (Stephenson, 1914)
30. *Dero sawayai* Marcus, 1943
31. *Dero zeylanica* Stephenson, 1913

Genus ***Aulophorus*** Schmarda, 1861

32. *Aulophorus carteri* Stephenson, 1931
33. *Aulophorus flabelliger* Stephenson, 1931
34. *Aulophorus furcatus* (Müller, 1773)
35. *Aulophorus gravelyi* Stephenson, 1925
36. *Aulophorus hymanae* Naidu, 1963
37. *Aulophorus indicus* Naidu, 1963
38. *Aulophorus michaelseni* Stephenson, 1923
39. *Aulophorus moghei* Naidu & Srivastava, 1980
40. *Aulophorus tonkinensis* (Vejdovsky, 1894)

Genus ***Allonais*** Sperber, 1948

41. *Allonais gwaliorensis* (Stephenson, 1920)
42. *Allonais inaequalis* (Stephenson, 1911)
43. *Allonais paraguayensis paraguayensis* (Michaelsen, 1905)
44. *Allonais pectinata* (Stephenson, 1910)
45. *Allonais rayalaseemensis* Naidu, 1963

Genus ***Stephensoniana*** Cernosvitov, 1938

46. *Stephensoniana trivandrana* (Aiyer, 1926)

Genus ***Pristina*** Ehrenberg, 1828

47. *Pristina aequiseta* Bourne, 1891
48. *Pristina biserrata* Chen, 1940
49. *Pristina breviseta* Bourne, 1891
50. *Pristina evelinae* Marcus, 1943
51. *Pristina foreli* (Piguet, 1906)
52. *Pristina longiseta longiseta* Ehrenberg, 1828
53. *Pristina proboscidea* Beddard, 1896
54. *Pristina sperberae* Naidu, 1963
55. *Pristina synclites* Stephenson, 1925

Genus ***Pristinella*** Brinkhurst, 1985

56. *Pristinella acuminata* (Liang, 1958)
57. *Pristinella jenkinae* (Stephenson, 1931)
58. *Pristinella menoni* (Aiyer, 1929)
59. *Pristinella minuta* (Stephenson, 1914)

Subfamily TUBIFICINAE

Genus ***Tubifex*** Lamarck, 1816

60. *Tubifex tubifex* (Müller, 1774)

Genus ***Limnodrilus*** Claparède, 1862

61. *Limnodrilus claparedianus* Ratzel, 1868
62. *Limnodrilus hoffmeisteri* Claparède, 1862

Genus ***Monopylephorus*** Levinsen, 1884

63. *Monopylephorus limosus* (Hatai 1898)
64. *Monopylephorus parvus* Ditlevsen, 1904

Genus ***Bothrioneurum*** Stolć. 1888

65. *Bothrioneurum iris* Beddard 1901

Genus ***Branchiura*** Beddard, 1892

66. *Branchiura sowerbyi* Beddard, 1892

Genus ***Aulodrilus*** Bretscher 1899

67. *Aulodrilus pectinatus* Aiyer, 1928
68. *Aulodrilus pigueti* Kowalewski, 1914
69. *Aulodrilus pleuriseta* (Piguet, 1906)

Genus ***Telmatodrilus*** Eisen, 1979

70. *Telmatodrilus multiprostatus* Brinkhurst, 1971

Genus ***Alexandrovia*** Hrabe, 1962

71. *Alexandrovia onegensis* Hrabe, 1962

Distribution

Singh *et al*. (2009) reviewed the freshwater oligochaeta of India and provided information on distribution of all Indian genera in various parts of the world and in different states of India. But species-specific distribution data are lacking owing to absence of work from most of the regions of the country. Although, Stephenson (1907-1931) and Naidu (1956-2005) studied Indian fauna of freshwater oligochates, many regions of the country still remain unexplored. However, a few more publications can be traced in recent years pertaining to record of freshwater oligochaetes from southern states of India. Ragi and Jaya (2014) studied oligochaetes from selected ponds of Tiruvananthapuram district, Kerala. Naveed *et al.* (2014) provided a preliminary account of aquatic oligochaetes from eastern Tamil Nadu. Hegde and Sreepada (2014), and Vineetha *et al*. (2015) worked on oligochaetes of a few paddy fields of Karnataka and Kerala, respectively. Biswas and Mandal (2006) gave an account of freshwater oligochates of urban habitats of Kolkata. The Zoological Survey of India published the state fauna series with reports of 45 species, including terrestrial forms from Odisha (Julka et al., 1989); 27 species from West Bengal (Mukhopadhyay, 1999a); 6 species from Meghalaya (Mukhopadhyay, 1999b); 7 species from Tripura (Mukhopadhyay, 2000); 3 species from Sikkim (Mukhopadhyay, 2003); 9 species from Uttarakhand (Biswas and Mandal, 2010) and 31 species from Karnataka (Biswas and Mandal, 2013). Paliwal (2014) recorded *Branchiura sowerbyi* from Himalayan foothills in Himachal Pradesh.

Significance

Besides being a food source for almost all groups of aquatic organisms and a principle biotic component among the macro-zoobenthos community, freshwater oligochaetes function as intermediate host of Myxosporidians which cause a serious parasitic problem for the freshwater fishes. Further, thorough surveys of various states are needed systematically, which will add up more information on species composition and their distribution data to the existing knowledge of Indian freshwater oligochaetes besides helping us in understanding the life cycle of myxosporidians infecting fishes. Oligochaetes play an important ecological role in sediments, improving the fertility of soil by the process of bioturbation through their burrowing activity and so, are useful in environmental risk assessment (Chapman, 2001; Egeler and Römbke, 2007). Their presence or absence and density in an aquatic environment can also be taken into consideration as an indicator of health of the environment.

Discussions

Studies on the taxonomy of freshwater oligochaetes are sporadic in India and, therefore, only scattered information is available from discrete localities. The present checklist suggests there are 71 species of freshwater oligochaetes under 20 genera and one family. The states, namely, Jammu & Kashmir, Andhra Pradesh, Punjab, West Bengal, Uttar Pradesh, Maharashtra, Karnataka, Kerala and Tamil Nadu only have so far been explored, and that too in a very unsystematic way only. The poorly explored states are Himachal Pradesh, Uttarakhand, Delhi, Haryana, Rajasthan, Gujarat, Odisha, Madhya Pradesh, Bihar, Chhattisgarh, Jharkhand, Arunachal Pradesh, Sikkim, Assam, Manipur, Nagaland, Meghalaya, Tripura, Mizoram and Goa. Thus, there is a lot of scope for taxonomic studies of this group in these states. A thorough systematic exploration and inventory of oligochaetes of various aquatic habitats in poorly explored states are the dire need of the present time.

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Chapter 13

ANNELIDA : HIRUDINEA (LEECHES)

C.K. MANDAL AND SUBHRENDU S. MISHRA

ABSTRACT

About 700 species of leeches (Annelida: Hirudinea) are known from the world, whereas only 70 species have so far been recorded from India. Most of the leeches inhabit freshwater ecosystems. As many as 55 species under 24 genera and 5 families are recorded from the freshwater bodies of India and 36 of them are endemic.

Key words: Freshwater, Leeches, Distribution, Medicinal, Parasite.

INTRODUCTION

Mention of leeches in India is well traced in ancient literatures. Leeches were called as 'Jalaukas' or 'Jalauka' in the medicinal work of Sushruta and in the epic of Mahabharata. The name normally means "having water as its home", derived from 'jala' (=water) and 'okas' (=home). The nomenclature of leech in Sanskrit is believed to have come from the language of aboriginals.

Majority of leeches inhabits freshwater bodies, while their number in land and marine water is comparatively less. Freshwater leeches (Hirudinea) are mainly predatory and parasitic annelids with terminal suckers (Anterior and Posterior) for attachment, locomotion and feeding. They are closely related to the Oligochaetes and the epizoic Branchiobdellidae in possession of suckers, median genital orifice at clitellum region, and analogous jaws in the absence of setae. Leeches are hermaphrodite annelids with reduced parapodia and setae. They are recognized as an important macro invertebrate group of versatile habits and since the time immemorial, they have been playing significant role for the existence of human beings in this planet. Most of the leeches are blood-suckers on vertebrates or invertebrates, while others are mainly predators and rarely scavengers. They are characteristically modified for procuring and digesting their peculiar food, which consists typically of mammalian blood and animal fluid of smaller annelids, snails, insect larvae, and organic ooze. As predators and parasites, they occupy intermediate position in the food chain and trophic structure. Their exclusion from the environment is likely to affect the whole ecosystem. Leeches do not destroy crops, fruits or vegetation etc., but are very important so far as regulation of size and shape of the invertebrate communities is concerned. They are called blood suckers due to their blood-sucking habit as their food. It anaesthetizes the area of the host body by saliva and suck blood preventing clot by the help of hirudin

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secretion. Mouth, proboscis, or three jaws of some group are used to penetrate the body of the host to suck blood from the host body. High degree of adaptability to a wide range of environmental factors has made them adopt diverse ecological niches. The medicinal uses and venomous qualities of leeches have made them eye-catching and raised human curiosity to know about them.

Historical resume

Before 1900: In ancient Indian works, particularly in *Sushruta-Samhita* (600 BC) leeches were classified into two distinct groups, viz., venomous and non-venomous, with six types in each group, Krishna, Karuura, Alagarda, Indrayudha, Samudrika and Gochandana in the first group and Kapilas, Pingalas, Shankhamukhis, Musikas, Pundarimukhis and Savavikas in later group. Although, Linnaeus (1758) initiated naming of leeches in the world (8 species in one genus, *Hirudo*), the work of Blanchard (1897) can be treated as the base work on leeches from Indian region.

Between 1900 and 1947: Harding (1920) and Kaburaki (1921a) worked on the leach fauna of Chilka Lake, a brackish water lagoon in Odisha. Kaburaki (1921b) studied some leeches in the collection of Indian Museum. Harding (1924) further described 3 species of aquatic leeches from India. Moore (1924) reported one new species of leech from Srinagar. Harding and Moore (1927) provided a comprehensive account of leeches comprising 51 species from the Indian subcontinent. Bhatia (1930; 1934; 1939; 1940) contributed further to the study of Indian leeches mainly from Kashmir.

After 1947: Baugh (1960a, b) worked on Indian Rhynchobdellid leeches. Bhatt (1961) studied fresh water leeches from Nainital district (U.P.). Basu (1967) worked on leeches of Pulicat Lake. Dr. M. Chandra has contributed considerably towards study of leeches in India and all his work was consolidated (Chandra, 1991) as a '*Handbook on the leeches of India*'. This work enlisted 54 species belonging to 25 genera and five families including 9 terrestrial species and 10 marine species. In recent past, eight new species of freshwater leeches have been described from India (Mandal 2004b; 2004d; 2013a; 2013b 2015a; 2015b; Naesmann *et al*., 2007; Nesemann and Sharma, 2012).

Diversity

Throughout the world, more than 700 species of leeches have been known. Sket and Trontelj (2008) listed 680 species in 91 genera and many more are described thereafter. According to them, there are more than 480 species inhabit freshwaters. Mandal (2004a) enlisted 62 species of leeches from Indian waters including terrestrial and marine forms. Naesmann *et al*., (2007) and Nesemann and Sharma, (2012) contributed towards recording leeches from Gangetic Plain of Bihar with description of two new species. As per the recent update, 70 species (about 10% of world diversity) have so far been recorded from India. However, only 55 species belonging to 25 genera and 5 families were recorded from freshwater bodies of India (Table-1). Photographs of some representative leeches are provided in plates I-II.

Distribution

Freshwater leeches are usually found in stagnant waters, where water remains throughout the year, with aquatic plants and normally parasitic over aquatic fauna.

Very few species are found in running water. The distributional map of leeches of India is based on scattered reports only. Table-1 gives distributional records of freshwater leeches known from India. Many states have not been explored properly. Leech fauna of only three states, Jammu and Kashmir, Rajasthan and West Bengal, are well-studied.

Table 1. Freshwater leeches and their distribution

Sl. No.	Name of the Species	Distribution		Endemic to India
		India (States)	Abroad	
Family PISCICOLEDAE				
1.	*Ozobranchus shipleyi* Harding, 1909	Odisha; West Bengal	Sri Lanka; Pakistan	
2.	*Piscicola caeca* Kaburaki, 1921	Odisha	--	Endemic
3.	*Piscicola olivacea* Harding, 1920	Jammu & Kashmir; Odisha	Soochow (China).	
4.	*Pontobdellina macrothela* (Schmarda, 1861)	Odisha	Australia; China; Jamaica; Sumatra; Sri Lanka; New South Wales.	
5.	*Pterobdella amara* Kaburaki, 1921	Odisha	--	Endemic
6.	*Zeylanicobdella arugamensis* De Silva, 1963	Tamil Nadu	Sri Lanka; Malaysia	
Family GLOSSIPHONIDAE				
7.	*Batracobdella hardingi* Baugh, 1960	Bihar; Jammu & Kashmir	--	Endemic
8.	*Batracobdella lobata* (Bhatia, 1934)	Jammu & Kashmir	--	Endemic
9.	*Batracobdella mahabiri* Baugh, 1960	Madhya Pradesh	--	Endemic
10.	*Batracobdella reticulata* Kaburaki, 1921	Himachal Pradesh; Jammu & Kashmir; Maharashtra; Punjab	--	Endemic
11.	*Glossiphonia annandalei* Oka, 1921	Bihar; Odisha	--	
12.	*Glossiphonia complanata complanata* (Linnaeus, 1758)	Jammu & Kashmir	Japan, U.S.A.; Europe	Endemic
13.	*Glossiphonia cruciata* Bhatia, 1930	Jammu & Kashmir	--	Endemic
14.	*Glossiphonia heteroclita* (Linnaeus, 1761)	Bihar; Rajasthan; West Bengal	North America; Europe; Myanmar	

Sl. No.	Name of the Species	Distribution		Endemic to India
		India (States)	Abroad	
15.	*Glossiphonia weberi weberi* Blanchard, 1897	Andhra Pradesh; Assam; Bihar; Jammu & Kashmir; Madhya Pradesh; Odisha; Rajasthan; Tamil Nadu; Uttar Pradesh; West Bengal	Pakistan, Nepal, Sumatra; Myanmar	
16.	*Helobdella nociva* Harding, 1924	Himachal Pradesh; Jammu & Kashmir; Karnataka; Odisha; Rajasthan; West Bengal	--	Endemic
17.	*Helobdella stagnalis* (Linnaeus, 1758)	Jammu & Kashmir; Himachal Pradesh	Canada; U.S.A.; Paraguay	
18.	*Hemiclepsis bhatiai* Baugh, 1960	Bihar; Jammu & Kashmir	--	Endemic
19.	*Hemiclepsis marginata asiatica* Moore, 1927	Himachal Pradesh; Jammu & Kashmir; Meghalaya; Rajasthan; Uttar Pradesh; West Bengal	U.S.A; Paraguay; Andes; western Asia	
20.	*Hemiclepsis marginata marginata* Muller, 1774	Andhra Pradesh; Bihar; Karnataka; Madhya Pradesh; Maharashtra; Odisha; Rajasthan; Tamil Nadu; Uttar Pradesh; West Bengal;	Europe, Nepal; Western Asia	
21.	*Hemiclepsis viridis* Chelladurai, 1934	Kerala	--	Endemic
22.	*Hemiclepsis chharwardamensis* Mandal, 2013	Jharkhand	--	Endemic
23.	*Paraclepsis praedatrix* Harding, 1924	Andhra Pradesh; Assam; Bihar; Haryana; Himachal Pradesh; Karnataka; Maharashtra; Rajasthan; West Bengal	--	Endemic
24.	*Paraclepsis gardensi* Mandal, 2004	West Bengal	--	Endemic

Sl. No.	Name of the Species	Distribution		Endemic to India
		India (States)	Abroad	
25.	*Paraclepsis joraparienssis* Mandal, 2013	Jharkhand; Rajasthan	--	Endemic
26.	*Paraclepsis vulnifera* Mandal, 2013	Himachal Pradesh; Jammu & Kashmir; Maharashtra; Rajasthan; Tamil Nadu	--	Endemic
27.	*Placobdella ceylanica* (Harding, 1909)	Madhya Pradesh; Odisha; West Bengal	--	Endemic
28.	*Placobdella emdae* Harding, 1920	Bihar; Himachal Pradesh; Maharashtra; Odisha; Rajasthan; West Bengal;	--	Endemic
29.	*Placobdella fulva* Harding, 1924	Bihar; Rajasthan; West Bengal	Java, Sumatra	
30.	*Placobdella harasundarai* Mandal, 2004	West Bengal	--	Endemic
31.	*Placobdella horai* Baugh, 1960	West Bengal	--	Endemic
32.	*Placobdella indica* Baugh, 1960	Bihar; Jammu & Kashmir		Endemic
33.	*Placobdella undulata* Harding, 1924	Himachal Pradesh; Jammu & Kashmir; Rajasthan; West Bengal	--	Endemic
34.	*Placobdella gauripurensis* Mandal, 2013	West Bengal	--	Endemic
35.	*Placobdella godavariensis* Mandal, 2013	Maharashtra	--	Endemic
36.	*Theromyzon mathati* Bhatia, 1939	Jammu & Kashmir	--	Endemic
37.	*Theromyzon sexoculata* (Moore, 1898)	Manipur	Siberia (Russia)	
Family ERPOBDELLIDAE				
38.	*Barbronia weberi* (Blanchard, 1897)	Andhra Pradesh; Himachal Pradesh; Jammu & Kashmir; Madhya Pradesh; Rajasthan; Uttarakhand; West Bengal;	--	Endemic
39.	*Erpobdella octoculata* (Linnaeus, 1758)	Jammu & Kashmir.	Pakistan; Europe; Palestine	

Sl. No.	Name of the Species	Distribution		Endemic to India
		India (States)	Abroad	
40.	*Foraminobdella heptamerata* Kaburaki, 1921	Tamil Nadu	--	Endemic
41.	*Herpobdelloidea lateroculata* Kaburaki 1921	Assam; Madhya Pradesh; Maharastra; Manipur; Odisha; Rajasthan; West Bengal	--	Endemic
42.	*Nematobdella indica* Kaburaki, 1921	Himachal Pradesh; Madhya Pradesh; Maharashtra; Punjab; Rajasthan; Uttar Pradesh; West Bengal	--	Endemic
	Family SALIFIDAE			
43.	*Odontobdella krishna* Nesmann & Sharma 2012	Bihar	--	Endemic
44.	*Salifa biharensis* Nesmann et al., 2004	Bihar	--	Endemic
	Family HIRUDIDAE			
45.	*Dinobdella ferox* (Balanchard, 1896)	Himachal Pradesh; Manipur; Sikkim; Uttar Pradesh; West Bengal.	China; Myanmar; Sri Lanka; Taiwan; Thailand	
46.	*Dinobdella notata* Moore, 1927	Tamil Nadu	--	Endemic
47.	*Haemopis indicus* Bhatia, 1940	Jammu & Kashmir	--	Endemic
48.	*Hirudo asiatica* Balanchard, 1896	Uttar Pradesh	Afghanistan	
49.	*Hirudo birmanica* (Blanchard, 1894)	Andhra Pradesh; Assam; Bihar; Himachal Pradesh; Karnataka; Manipur; Nagaland; Odisha; Rajasthan; Sikkim; Uttar Pradesh; West Bengal;	Nepal; Pakistan; Sri Lanka; Thailand	
50.	*Myxobdella annandalei* Oka, 1917	Tamil Nadu	--	Endemic
	Family POECILOBDELLIDAE			

Sl. No.	Name of the Species	Distribution		Endemic to India
		India (States)	Abroad	
51.	*Poecilobdella granulosa* (Savigny, 1820)	Andhra Pradesh; Assam; Bihar; Gujarat; Himachal Pradesh; Madhya Pradesh; Maharashtra; Manipur; Odisha; Punjab; Rajasthan; Uttar Pradesh; Tamil Nadu; West Bengal;	--	Endemic
52.	*Poecilobdella javanica* (Wahiberg, 1856)	Assam; Manipur; Jammu & Kashmir; West Bengal	Sri Lanka; Java; Sumatra; Malaysia; Myanmar; Philippines.	
53.	*Poecilobdella manillensis* (Lesson, 1842)	Andhra Pradesh; Assam; Bihar; Karnataka; Kerala; Madhya Pradesh; Maharashtra; Odisha; Tamil Nadu; Uttar Pradesh; West Bengal	Pakistan, Sri Lanka, Myanmar; Borneo; Malayasia, Philippines; China	
54.	*Poecilobdella viridis* Moore, 1927	Himachal Pradesh; Jammu & Kashmir; Kerala; Tamil Nadu; Uttar Pradesh	--	Endemic
55.	*Whitmania laevis* (Baird, 1869)	Manipur.	Myanmar, China, Formosa ; Japan	

Endemism

Mandal (2004c) gave an account of the endemic leech fauna of India. At present, out of 55 species so far known from freshwaters of India, 36 species (about 65.5% total species known) seems to be endemic to India (Table-1). Majority of them belongs to the Jammu and Kashmir state probably for the extensive study of leech fauna from that state.

Conservation and significance

There are not much conservation issues with regard to leech fauna of India. However, destruction of habitats leads to depletion of leech population, coupled with extensive exploitation of aquatic resources which are supposed to be food source for leeches. On the other hand, leeches are of medicinal use by local people from time immemorial. The ancient Ayurvedic compendium, '*Sushruta-Samhita*', narrates the use of leeches in medicine, dating back to 2500 years ago. Currently, the bio-active anticoagulant and anti-inflammatory substances derived from leeches are attracting medical and pharmaceutical attention (Sohn *et al*., 2001;

Whitaker *et al.*, 2004) and even therapeutic use of leeches in osteoporosis is also documented (Pilcher, 2004).

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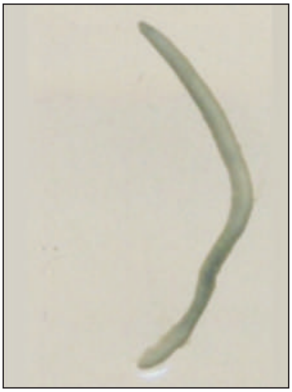
PLATE I

Paraclepsis jorapariensis

Placobdella emydae



Barbronia weberi

Hemiclepsis marginata asiatica

Glossiphonia weberi

Placobdella debkuntai

Paraclepsis jorapariensis (sucker)

Paraclepsis jorapariensis (whole body)

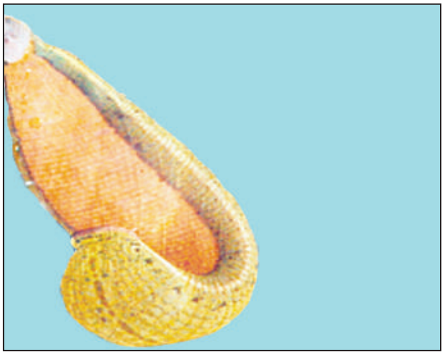
PLATE I

Poecilobdella granulosa

Herpobdelloidea lateroculata

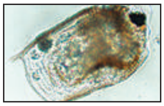
Hemiclepsis marginata marginata

Hemiclepsis chharwardamensis



Poecilobdella manillensis

Chapter 14



CRUSTACEA : BRANCHIOPODA (CLADOCERA)

B.K. SHARMA AND SUMITA SHARMA

ABSTRACT

Cladocera taxonomy is experiencing notable global changes because of advancements on levels of taxonomic refinements, validity of taxa, cosmopolitanism vs. regional endemism, vicariance, equivalence and inherent problems in several faunal works from different biogeographic regions. The status of Indian freshwater Cladocera is confounded with poor taxonomic resolutions, 'sloppy' descriptions, fuzzy identifications, nomenclatural anomalies, *species inquirenda, reports inquirenda*, lack of 'voucher specimens' for validation, incomplete inventories and above all taxonomic expertise. The revalidation of known Indian taxa concurrent with global taxonomic standards, indiscriminate 'ad-hoc' listing of ambiguous species and analysis of cryptic diversity in species-groups vs. molecular systematics are critical issues. Keeping in view these impediments, we attempt to assess the current diversity status of freshwater Cladocera, based on our taxonomic understanding of over three and half decades, and the critical evaluation of the published reports. An annotated list of 131 species known from inland waters of India is compiled with several indicated as "*sensu lato*"; the list is deemed to be provisional pending possible re-validation of all the Indian taxa. The nature and composition of freshwater Cladocera of India is analyzed with reference to interesting elements, biogeography and taxonomic anomalies. Various impediments hampering progress of cladoceran diversity are focused and the future biodiversity scope of the taxon is indicated. The intensive surveys vis-à-vis ecosystem diversity from unexplored or under-explored parts of India in general and the Himalayan region and Western Ghats 'hot-spots' merit biodiversity and biogeography interest.

Key words*:* composition, distribution, taxa, state-of-art, taxonomy.

INTRODUCTION

Cladocera or `Water fleas' are a group of small-sized, mostly microscopic branchiopods representing one of the most primitive groups of lower Crustacea. They inhabit almost all types of continental freshwaters and occur more abundantly in ephemeral and perennial lentic environs colonizing the littoral weedy margins while certain species are adapted to the benthic and subterranean environs. They form an integral link in aquatic food-webs; contribute significantly to biological productivity and energy flow in aquatic ecosystems due to rapid turnover rates;

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serve as ideal tools for environmental toxicology and bioassay studies; and serve as 'guide-forms' in paleo-limnological endeavors.

Cladocera taxonomy has progressed through a long history of more than three centuries of global contributions. The recent advances in this group coupled with application of molecular techniques have ushered in a new era of Cladocera biodiversity with higher levels of morpho-species delineations. The developments since 1980's have transformed our understanding of many old sloppily characterized species that left the present-day taxonomists with a large burden of 'hardly usable descriptions' (Dumont and Negrea, 2002). Even at the recent levels of progress, many of morpho-species have remained incompletely described and little is known about correct geographical limits of many others; the last aspect has resulted in a strong debate on 'cosmopolitanism' vis-à-vis regional endemism' (Frey, 1987a; Hudec, 1991; Sinev, 1999, 2001, 2011, 2012, 2016; Van Damme and Dumont, 2008a; Petrusek et al. 2004; Kotov and Taylor, 2010; Van Damme et al. 2011) in this group of Entomostracous Crustacea.

The systematic studies on Indian freshwater Cladocera were initiated by Baird (1860) and the status of their progress was traced by Sharma and Michael (1987), Michael and Sharma (1988), Sharma (1991) and Chatterjee *et al.* (2013). Fauna volume on Indian Cladocera (Michael and Sharma, 1988) proved useful identification for over two decades but now itself needed a future revision in light of current global taxonomic trends. The faunal diversity of the taxon is yet fairly known only from the states of West Bengal (Sharma 1978; Sharma and Sharma, 1985; Venkataraman, 1999), Meghalaya (Sharma and Sharma, 1999; Sharma, 2008), Tripura (Venkataraman and Das, 2000) Assam (Sharma and Sharma, 2008, 2013, 2014; Sharma and Sharma, 2014), Manipur (Sharma and Sharma, 2009, 2010) and to some extent from Bihar (Sharma and Sharma, 2001). Undoubtedly, species inventories from these states even required a critical re-appraisal in light of the recent progress in Cladocera taxonomy.

This communication is an attempt to assess the existing status of biodiversity of freshwater Cladocera of India vis-à-vis its composition and richness, interesting elements, nomenclatural; anomalies and taxonomic ambiguities. Various impediments compounding taxonomy in India are discussed and lacunae deserving future attention are highlighted.

MATERIALS AND METHODS

The present appraisal is based on analysis of our samples collected, during the last four decades, from distant localities scattered over different states of north, northeast, east and south India, as well as our earlier works and evaluation of the Indian literature. The collections were made from the littoral and semi-limnetic / limnetic regions of different ecosystems by towing plankton net (# 50 µm) and were preserved in 5% formalin. All collections were screened individually with a Wild-stereoscopic binocular microscope; various cladocerans and their disarticulated appendages were mounted in polyvinyl alcohol-lactophenol mixture and were observed with a Leica DM 1000 image analyzer fitted with drawing-tube. The different species were identified following Smirnov (1971, 1976, 1992, 1996), Michael and Sharma (1988), Korovchinsky (1992), Sharma and Sharma (1999), Sharma and Sharma (2008), Orlova-Bienkowskaja (2001), Korinek (2002) and Benzie (2005). We took into account notable progress in taxonomy of the subfamily Aloninae that has resulted in separation of several new genera (Dumont and Silva-Briano, 2000; Van Damme and Dumont, 2008a, 2008b; Van Damme et al. 2009, 2010, 2011; Sinev, 2016).

RESULTS

An annotated list of 131 species belonging to 47 genera, eleven families and four orders, examined from freshwater environs of India is provided.

Super-class CRUSTACEA

Class BRANCHIOPODA

Super-order CLADOCERA (*s. str.*)

Order CTENOPODA

Family SIDIDAE

Subfamily SIDIINAE

1. *Diaphanosoma brachyurum* (Lieven, 1848) s. lat*
2. *Diaphanosoma celebensis* Stingelin, 1900
3. *Diaphanosoma dubium* Manuilova, 1964
4. *Diaphanosoma excisum* Sars, 1885*

   Syn.: *Diaphanosoma excisum* var. *longiremis* Ekman, 1904
   Diaphanosoma excisum var. *stingelini* Jenkin, 1934
   Diaphanosoma paucispinosum Brehm, 1933
5. *Diaphanosoma sarsi* Richard, 1895*
6. *Diaphanosoma senegal* Gauthier, 1951*

   Syn.: *Diaphanosoma hydrocephalus* Brehm, 1952 .
   Diaphanosoma senegalensis Gauthier, 1951;
   Diaphanosoma siddharthii Rao, Padmaja & Naidu, 1998
7. *Diaphanosoma tropicum* Korovchinsky, 1998*
8. *Diaphanosomama volzi* Stingelin, 1805*

   Syn.: *Diaphanosoma aspinosum* Chiang, 1956
9. *Latonopsis australis* (Sars, 1888) s. lat*

   Syn.: *Latona tiwari* Biswas, 1964
   Latonopsis narenderi Rane, 1985
10. *Pseudosida sazalyi* Daday, 1898*
11. *Sarsilatona serricaudata* (Sars, 1901) s.lat.

    Syn.: *Latonopsis fasciculata* Daday, 1905
12. *Sarsilatona cf. fernandoi* (Rane, 1983) *

    Syn.: *Latonopsis fernandoi* Rane, 1983
13. *Sida crystallina* (O. F. Muller, 1776) s. lat*

Family HOLOPEDIDAE

14. *Holopedium gibberum* Zaddach, 1855 s.lat

Order ANOMOPODA

Family DAPHNIIDAE

Subfamily DAPHNIINAE

15. *Ceriodaphnia cornuta* Sars, 1885*
16. *Ceriodaphnia dubia* Richard, 1894 s.lat.
17. *Ceriodaphnia laticaudata* (P E Muller, 1776) *
    Syn.: *Ceriodaphnia reticulata* var. *kuerzii*' Stingelin
18. *Ceriodaphnia pulchella* Sars, 1862
19. *Ceriodaphnia quadrangula* (O. F. Muller, 1776)
20. *Ceriodaphnia reticulata* (Jurine, 1820)
    Syn: Ceriodaphnia reticulata var. *serrata* Sars
21. *Daphnia* (*Ctenodaphnia*) *carinata* King, 1853 s.lat *
    Syn.: *Daphnia* (*Ctenodaphnia*) *longicephala* Hebert, 1977
    Syn.: *Daphnia sarojae* Rane, 1986
22. *Daphnia* (*Ctenodaphnia*) *cephalata* King.1853 s. lat*
    Syn.: *Daphnia* (*Ctenodaphnia*) *hypsicephala* Daday, 1911
23. *Daphnia* (*Ctenodaphnia*) *fusca* Gurney, 1906
24. *Daphnia* (*Ctenodaphnia*)*magna* Straus, 1820*
25. *Daphnia* (*Ctenodaphnia*) *similis* Claus, 1876 s. lat*
    Syn.: *Daphnia madhuriae* Rane & Jarfi, 1990
    Daphnia sarojae Rane, 1986
26. *Daphnia* (*Ctenodaphnia*) *similoides* Hudec, 1991
27. *Daphnia* (*Ctenodaphnia*) *tibetana* (Sars, 1903)*
28. *Daphnia (Daphnia) obtusa* Kurz, 1874 emend. Scourfield,1942 s. lat
29. *Daphnia* (*Daphnia*) *pulex* Leydig, 1860*
30. *Daphnia (Daphnia) longispina* O. F. Muller, 1776 s. lat
31. *Daphnia* (*Daphnia*) *lumholtzi* Sars, 1885*
    Syn.: *Daphniopsis sumanae* Rane, 1985
32. *Simocephalus* (*Aquipiculus*) *heilongjiangensis* Shi & Shi, 1994*
33. *Simocephalus* (*Coronocephalus*) *serrulatus* (Koch, 1841) *
    Syn.: *Simocephalus surekhae* Rane, 1985
34. *Simocephalus (Echinocaudus) acutirostratus* (King, 1853) *
    Syn.: *Simocephalus vidyae* Rane, 1983
    Simocephalus vidyae gajareae Rane, 1986
35. *Simocephalus* (*Echinocaudus*) *exspinosus* (De Geer, 1778)*
    Syn.: *Simocephalus vamani* Rane, 1985
    Simocephalus (*Echinocaudus*) *australiensis* (Dana, 1852)

36. *Simocephalus* (*Simocephalus*) *elizabethae* (King, 1853)*
37. *Simocephalus* (*Simocephalus*) *mixtus* Sars, 1903*
38. *Simocephalus* (*Simocephalus*) *vetuloides* Sars, 1898*

Subfamily SCAPHOLEBERINAE

39. *Scapholeberis kingi* Sars, 1888

Family BOSMINIDAE

40. *Bosmina* (*Bosmina*) *longirostris* (O. F. Muller, 1776) s.lat.*
41. *Bosmina* (*Eubosmina*) *coregoni* Baird, 1857 s.lat.
42. *Bosmina* (*Liederobosmina*) *meridionalis* Sars, 1904 s.lat.
43. *Bosmina* (*Bosmina*) *tripurae* Korinek, Saha & Bhattacharya, 1999*

    Syn.: *Bosmina (Bosmina) cornuta* (Jurine, 1820)

    Bosmina (Sinobosmina) japonica Poppe & Richard, 1890
44. *Bosminopsis deitersi* Richard, 1895*

    Syn.: *Bosminopsis devendrai* Rane, 1984

Family MOINIDAE

45. *Moina belli* Gurney, 1904
46. *Moina brachiata* (Jurine, 1820)*

    Syn.: *Moina rectirostris* (Jurine, 1820)
47. *Moina dubia* Guerne & Richard, 1892
48. *Moina hemanti* Padhye & Dumont (2014)
49. *Moina macrocopa* (Straus, 1820) s lat.*

    Syn.: Moina banffyi Daday, 1883

    Moina easu Brehm, 1936

    Moina ganapatii Brehm, 1963

    Moina flagellata Hudendorff, 1876
50. *Moina micrura* Kurz, 1874*

    Syn.: *Moina dodhui* Rane, 1987

    Moina easu Brehm, 1936
51. *Moina oryzae* Hudec, 1987
52. *Moina weismanni* Ishikawa, 1896
53. *Moinodaphnia macleayi* (King, 1853)*

Family MACROTHRICIDAE

54. *Macrothrix laticornis* (Fischer, 1857) s. lat.*
55. *Macrothrix odiosa* (Gurney, 1907)*

    Syn.: *Guernella odiosa* (Gurney, 1916)

    Macrothrix capensis monodi Gauthier, 1930
56. *Macrothrix spinosa* King, 1853*

    Syn.: *Macrothrix goeldi* Richard, 1897

57. *Macrothrix triserialis* (Brady, 1886)*
Syn.: *Macrothrix chevreuxi* Guerne & Richard, 1892
Macrothrix shadini Mukhamediev, 1963
58. *Grimaldina brazzai* Richard, 1892*
59. *Guernella raphaelis* Richard, 1892*
Syn.: *Guernella ceylonica* Daday, 1898 Brehm (1953)
60. *Streblocerus serricaudatus* (Fischer, 1849) s.lat.*

Family ILYOCRYPTIDAE

61. *Ilyocryptus bhardwaji* Battish, 1981
62. *Ilyocryptus spinifer* Herrick, 1882*
Syn.: *Ilyocryptus halyi* Brady, 1886

Family EURYCERCIDAE

63. *Eurycercus (Eurycercus) lamellatus* (O. F. Muller, 1776) s. lat.*
64. *Eurycercus* sp.

Family CHYDORIDAE

Subfamily ALONINAE

Tribe ALONINI s. str.

65. *Acroperus angustatus* Sars, 1863*
66. *Acroperus harpae* (Baird, 1834) s. lat.*
67. *Alona affinis* (Leydig, 1860) s.lat.*
68. *Alona cambouei* de Guerne et Richard, 1893
69. *Alona guttata* Sars, 1862* s.lat
Alona guttata var. *tuberculata* Kurz, 1875*
70. *Alona intermedia* Sars, 1862 s.lat.
71. *Alona kotovi* Sinev, 2012*
72. *Alona pulchella* King, 1853*
73. *Alona quadrangularis* (O. F. Muller, 1776) s lat*
74. *Alona sarasinorum* Stingelin 1900
Syn.: *Alona taraporevalae* Shirgur & Naik, 1977*
75. *Anthalona harti harti* Van Damme, Sinev et Dumont, 2011
76. *Camptocercus australis* Sars, 1896*
77. *Camptocercus rectirostris* Schoedler, 1862
78. *Camptocercus uncinatus* Smirnov, 1973*
Syn.: *Camptocercus latikae* Rane, 1985
79. *Camptocercus cf. vietnamensis* Sinev, 2012
80. *Celsinotum macronyx* (Daday, 1898) *
Syn.: *Indialona jabalpurensis* Rane, 1983

81. *Coronatella anodonta* (Daday, 1905)
82. *Coronatella rectangula* (Sars, 1862) s lat*
83. *Coronatella monacantha* (Sars, 1901) s.lat.*
    Coronatella monacantha tridentata (Stingelin, 1905)
84. *Euryalona orientalis* (Daday, 1898) *
85. *Flavalona cheni* (Sinev, 1999) *
86. *Graptoleberis testudinaria* (Fischer, 1854) s. lat.*
    Syn.: *Graptoleberis testudinaria nathsagarensis* Rane 2005
87. *Karualona karua* (King, 1853)*
88. *Kurzia brevilabris* Rajapaksa & Fernando,1986*
89. *Kurzia latissima* (Kurz, 1875) s lat.*
90. *Kurzia longirostris* (Daday, 1898)*
91. *Leberis diaphanus* (King, 1853) s. lat.*
92. *Leberis punctatus* (Daday, 1898)
    Alona davidi punctata (Daday, 1898) ,
93. *Leydigia (Neoleydigia) acanthocercoides* (Fischer, 1854) s.lat.*
94. *Leydigia* (*Neoleydigia*) *ceylonica* (Daday, 1898)
    Leydigia (Neoleydigia) *australis ceylonica* Daday, 1898
95. *Leydigia (Neoleydigia) ciliata* (Gauthier, 1939)*
    Syn.: *Leydigia anakammaroi* Durga Prasad et al. 1985
    Leydigia ciliata melghatensis Rane, 2005
96. *Leydigia* (*Leydigia*) *leydigi* (Schoedler, 1863) s.lat.
97. *Leydigiopsis pulchra* Van Damme & Sinev, 2013 S.
98. *Notoalona globulosa* (Daday, 1898)*
99. *Ovalona cambouei* (Guerne & Richard, 1983) Sinev, 2015
100. *Oxyurella singalensis* (Daday, 1898)*
    Syn.: *Oxyurella lindbergi* Brehm, 1953
    Oxyurella sangramsagari Rane, 1984
101. *Oxyurella tenuicaudis* (Sars, 1862) s.lat.

Tribe INDIALONINI Kotov, 2000

102. *Indialona ganapati* Petkovski, 1966 ex. Kotov, 2000

Subfamily CHYDORINAE

103. *Alonella (Alonella) clathratula* Sars, 1896*
104. *Alonella* (*Alonella*) *excisa* (Fischer, 1854) s. lat.*
105. *Alonella* (*Alonella*) *exigua* (Lilljeborg, 1853)
106. *Alonella* (*Nanalonella*) *nana* (Baird, 1850)*
107. *Chydorus angustirostratus* Frey, 1982*

108. *Chydorus eurynotus* Sars, 1901 s.lat.*

109. *Chydorus invaginatus* Frey, 1982

110. *Chydorus parvus* Daday, 1898*

Syn.: *Chydorus robustus* Stingelin, 1905

111. *Chydorus pubescens* Sars, 1901s.lat.*

112. *Chydorus reticulatus* Daday, 1898*

113. *Chydorus sphaericus* (O. F. Muller, 1776) s.lat.*

114. *Chydorus ventricosus* Daday, 1898*

Syn.: *Chydorus brehmi* Biswas, 1966

115. *Dadaya macrops* (Daday, 1898)*

116. *Disparalona caudata* Smirnov, 1996*

117. *Disparalona hamata* Birge, 1879 s. lat*

Syn.: *Pleuroxus hamulatus* Birge, 1910

118. *Disparalona rostrata* (Koch, 1841) s.lat.

119. *Dunhevedia crassa* King, 1853*

Dunhevedia crassa ciliocaudata (Sovinsky, 1891)

Syn.: *Dunhevedia interrupta* Brehm, 1936

120. *Dunhevedia serrata* Daday, 1898*

121. *Ephemeroporus barroisi* (Richard, 1894) s.lat.*

122. *Picripleuroxus denticulatus* Birge, 1879 s.lat.*

123. *Picripleuroxus laevis* Sars, 1862 s. lat.*

124. *Picripleuroxus quasidenticulatus* (Smirnov, 1996)*

125. *Picripleuroxus similis* Vavra, 1900 s. lat.*

126. *Pleuroxus aduncus* (Jurine, 1829) s. lat.

Syn.: *Pleuroxus aduncus bhigawarensis* Rane, 2002

127. *Pleuroxus annandalei* (Daday, 1908)

128. *Pleuroxus trigonellus* (O. F. Muller, 1776) s. lat.

129. *Pseudochydorus globosus* (Baird, 1843) s. lat*

Order ONYCHOPODA

Family POLYPHEMIDAE

130. *Polyphemus pediculus* (Linne, 1761) s. lat

Super-order LEPTODORIDA

Order HAPLOPODA

Family LEPTODORIDAE

131. *Leptodora kindtii* (Focke, 1844) s. lat

* observed in our collections from different parts of India

A breakup of the cladoceran taxa recorded till date from India is indicated in Table 1.

Table 1. Family-wise breakup of Indian freshwater Cladocera

Family/ taxon	Species	Genera
Order CTENOPODA		
Family SIDIDAE	13	05
Family HOLOPEDIDAE	01	01
Order ANOMOPODA		
Family DAPHNIIDAE		
Subfamily DAPHNIINAE	24	03
Subfamily SCAPHOLEBERINAE	01	01
Family BOSMINIDAE	05	02
Family MOINIDAE	09	02
Family MACROTHRICIDAE	07	04
Family ILYOCRYPTIDAE	02	01
Family EURYCERCIDAE	02	01
Family CHYDORIDAE		
Subfamily CHYDORINAE	27	09
Subfamily ALONINAE	38	17
Order ONYCHOPODA		
Family POLYPHEMIDAE	01	01
Order HAPLOPODA		
Family LEPTODORIDAE	01	01
Total	131	48

DISCUSSION

Composition and richness

The present assessment of diversity of freshwater Cladocera of India revealed 131 species with a number of them represented as "*sensu lato*" (species complexes). The speciose Indian fauna comprised ~ 19.0% of ca. 700 species known globally (Kotov, 2011); the global estimate is expected to be much higher in light of recent taxonomic studies. Our report provided significant update to the earlier Indian lists of 87, 93, 90,109, 102 and 97 species by Fernando and Kanduru (1984), Sharma and Michael (1987), Michael and Sharma (1988), Sharma (1991), Battish (1992) and Murugan et al. (1998), respectively. Further, the present report concurred with 133 freshwater taxa listed (Chatterjee *et al.,* 2013) from India (*vide infra*) based on 'the literature available' ('secondary data'). We, however, caution against over-emphasis on an 'uncritical and erroneous' report of 187 freshwater species *vide* Raghunathan and Suresh Kumar (2003) riddled with unconfirmed and anomalous taxa, and duplicate entries. Interestingly, all eleven families of freshwater Cladocera and 47 genera known from India characterize rich and diverse nature of the taxon in inland waters of this country.

Sharma (1991) indicated inadequate studies on diversity of the taxon from different states of India; this generalization still holds valid with regards to the current state-of-art of investigations. Our initiative from northeast India (NEI) culminating in high richness (75 species) from Assam state (Sharma and Sharma, 2014) is of special biodiversity value. The importance of this rich diversity merits attention particularly in view of a conservative estimate of occurrence of up to 60 – 65 cladoceran species from tropical and subtropical parts of India (Fernando and Kanduru, 1984; Sharma and Michael 1987). This is followed by the reports of 58 species from Meghalaya (Sharma and Sharma, 1999; Sharma, 2008), 56 species from Manipur (Sharma and Sharma, 2009, 2010) and 50 species from Tripura (Venkataraman and Das, 2000; BKS, unpublished) while we are yet analyzing the collections from the states of Mizoram, Nagaland and Arunachal Pradesh of NEI. In addition, 56 and 60 species are examined from West Bengal (Sharma, 1978; Venkataraman, 1999) and Jammu & Kashmir (BKS, unpublished), respectively while Padhye and Dumont (2014a, 2014b) together reported 51 species from the Western Ghats of Maharashtra and Goa. The 'uncritical and erroneous' lists of 87 species from Tamil Nadu (Raghunathan and Suresh Kumar, 2002) and 54 species from Rajasthan (Sharma et al. 2012) indicated reasonably lower valid species (BKS, unpublished). The cladocera diversity from other states of India in general and from the Himalayan region and Western Ghats biodiversity 'hot-spots' in particular is yet inadequately known. We recommend critical re-appraisal of 'ad-hoc' diversity known from the mentioned states concurrent with global Cladocera taxonomy. In general, we attribute the existing localized Indian faunal works to the *cladocerologist effect* drawing an analogy to the *rotiferologist effect* advanced by Fontaneto *et al*. (2012).

The biodiversity of the Indian Cladocera lagged distinctly on investigations on ecosystem diversity except for our useful findings from the floodplain lakes (*beels*) of the Brahmaputra basin of Assam and *pats* of Manipur from NEI. The former are characterized by the richest diversity (75 species) known till date from any part of India, and of South and SE Asia (Sharma. and Sharma, 2014) which, in turn, is hypothesized to their habitat diversity and environmental heterogeneity of the sampled *beels*. This salient feature is affirmed by our report of 58 species (Sharma and Sharma, 2013) from Deepor Beel (a Ramsar site) categorizing this floodplain wetland as the richest freshwater ecosystem of Asia for Cladocera diversity. The report of 55 species (Sharma and Sharma, 2014) from the floodplain lakes (beels) of Majuli river island, upper Assam as well as 54 species (BKS, unpublished) from certain beels of lower Assam our reiterated remarks on ecosystem diversity of the floodplains of the Brahmaputra river basin. The environmental heterogeneity of floodplains of Assam, Deepor beel (Sharma and Sharma, 2012), and Majuli wetlands beel (Sharma and Sharma, 2014), is endorsed by our results on their globally speciose and diverse Rotifera assemblage (Sharma and Sharma, 2005; Sharma and Sharma, 2008, 2013). A relatively low richness (56 species) was observed in our collections from the floodplains of Iral, Imphal and Thoubal river basins of Manipur state of NEI (Sharma and Sharma, 2010) with the report of 51 species (Sharma and Sharma, 2009) from Loktak Lake, Manipur- another Ramsar site. Our reports from Assam and Manipur wetlands are, however, distinctly higher than the record of only 9 species from 65 wetlands of 24-Parganas district (Nandi *et al.,* 1993) and 36 species from 20 wetlands of South eastern West Bengal (Khan, 2003); 39 species from 30 wetlands of the Keoladeo National Park, Rajasthan (Venkataraman, 1992) and 29 species from 25 wetlands of Melaghat Tiger reserve, Maharashtra (Rane, 2005). Some of these differences are due to inadequate sampling and incomplete species inventories due to inadequate expertise.

Interesting taxa

Contrary to remarks of Michael and Sharma (1988) and Sharma (1991) and in light of recent information on biogeography of the taxon, we recognize a number of interesting elements of Indian Cladocera. These are assigned to the following categories:

(a) Indian endemics: *Indialona ganapati, Moina hemanti* and *Moina oryzae*;

(b) Australasian species: *Daphnia* (*Ctenodaphnia*) *cephalata*, *Disparalona caudata, Simocephalus (Echinocaudus) acutirostratus, Leberis diaphanus;*

(c) Indo-Malaysian species: *Alona kotovi, Celsinotum macronyx, Flavalona cheni, Oxyurella singalensis, Kurzia brevilabris* and *Sarsilatona cf. fernandoi*;

(d) Oriental endemics: *Alona sarasinorum*, *Chydorus angustirostratus*, *Chydorus reticulatus*, *Chydorus invaginatus*, *Diaphanosoma tropicum*, *Ilyocryptus bhardwaji*, and *Leydigia* (*Neoleydigia*) *ceylonica*;

(e) Asian endemics: *Daphnia* (*Ctenodaphnia*) *similoides*, *Daphnia* (*Ctenodaphnia*) *tibetana* and *Pleuroxus annandalei*;

(f) Indo-Ethiopian species: *Leberis punctatus;*

(g) Vietnam, Hainan, Malaysia, India: *Camptocercus cf. vietnamensis;*

(h) Thailand, Cambodia, South Vietnam, India: *Leydigiopsis pulchra;*

(i) Africa and tropical Asia: *Leydigia (Neoleydigia) ciliata* and *Notoalona globulosa;*

(j) Palearctic: *Acroperus angustatus*, *Disparalona rostrata* s.lat. *Holopedium gibberum* s.lat., *Kurzia latissima*, *Picripleuroxus laevis* s. lat. and *Polyphemus pediculus*;

(k) Holarctic: *Leptodora kindtii*;

(l) Others: *Chydorus parvus* (Ethiopian and Indo-Malayan regions), *Moina dubia* (Africa and Asia) and *Oxyurella tenuicaudis* (Europe and India).

The members of the stated categories imparted distinct biodiversity value to Indian Cladocera. The Australasian elements depicted an interesting affinity between cladoceran faunas of India, SE Asia and Australia. A better understanding of the Cladocera of tropical and subtropical regions and that of their geographical limits has helped in recent delineation of the Indo-Malaysian elements in the Indian fauna (Sharma and Sharma, 2014). Of these, *Alona kotovi*, a conger of *A. quadrangularis*, is considered as a connecting link between South American and Australasian Chydoridae (Sinev, 2012). The presence of various Oriental, Asian and India endemics is another biodiversity important feature. The interesting *Indialona ganapati*, allocated to new tribe Indialonini, was believed to be an extremely specialized taxon with a series of advanced characters which were considered to have originated after the separation of Indialonini from the main branch of the Aloninae (Kotov, 2000). Further, Kotov (loc cit.) linked this transformation to a reduction in body size and transition to a planktonic mode of life; the later mode is un-characteristic of many chydorids and only few species could temporarily penetrate the plankton of some reservoirs (Fryer, 1968; Smirnov, 1971).

The occurrence of Neotropical *Leydigiopsis* in Assam state of NEI (Sharma and Sharma, 2007, 2012) and SE Asia is a remarkable example of 'tropical Amphi-Pacific disjunction' (Van Damme and Sinev, 2013) and this genus is represented by one species *i.e., L. curvirostris* in India. We propose re-examination of specimens of the later in light of the possibility of occurrence of its Indo-Chinese congener *Leydigiopsis pulchera* described recently from Thailand and Vietnam (Van Damme and Sinev, 2013) or its undescribed close relative. *Moina hemanti,* another interesting Gondwanian member of tropical Amphi-Pacific group has its closest relative *Moina dumonti* occurring in Mexico and Cuba (Kotov et al., 2004; Padhye and Dumont, 2014a). As per Padhye and Dumont (loc cit.), molecular analysis suggested closeness of *M. hemanti* to *Moinodaphnia* with the possibility of the former forming a genus of its own with another Indian endemic of its clad (*M. oryzae*). In addition, sub-tropical specimens of *Eurycercus* sp. (Sharma and Michael, 1987), observed so far from certain wetlands of the states of Meghalaya and Manipur of NEI (BKS, unpublished), are of biodiversity value; we are yet not able to assign these to any taxon because of limited material.

In general, the available information indicated that highly speciose Cladocera from NEI region of the Himalayan 'hot-spot' is characterized by several biogeographically interesting elements (BKS, unpublished) in contrast to low richness and fewer interesting taxa reported (Padhye and Dumont, 2014b) from the Western Ghats of Maharashtra and Goa. More intensive collections from the later 'hot-spot' are yet desired to affirm these remarks or otherwise.

TAXONOMIC STATUS

The Indian literature is flooded with indiscriminate species lists riddled with identification errors rendering them useless or artificially inflating their richness. Such reports required critical scrutiny to avoid nomenclature anomalies and we categorize our remarks as:

A. 'Species *inquirendae*' and synonymized new taxa

Many cladoceran taxa from the tropics have an uncertain identity (Kotov *et al.*, 2013) with Southern Asia still trailing in validly described species. Our remarks reiterate this generalization.

In all nine new species, described from India, are '*species inuirenda'* (refer: Kotov, 2011):

Alona ladacensis Brehm, 1936

Alona dhilloni Battish, 1981

Camptocercus kapuri Battish, 1981

Daphnia katrajensis Rane, Jafri & Rafiq, 1992

Daphnia newporti Baird, 1860

Daphnia psittacea Baird, 1860

Diaphanosoma chandramohanii Rao, Padmaja & Naidu, 1998b

Holopedium ramasarmi Rao, Padmaja & Naidu, 1998a

Leydigia hardingi Nayar, 1971

We emphasize on 'sloppy and uncritical' descriptions of new Indian taxa as highlighted by synonymized 20 new species and four new subspecies; these included 12 species and one new subspecies synonymized by the authors (Sharma and Sharma, 1990):

Alona taraporevalae Shirgur & Naik, 1977 = *Alona sarasinorum* Stingelin 1900

Bosminopsis devendrai Rane, 1984* = *Bosminopsis deitersi* Richard, 1895

Camptocercus latikae Rane, 1985* = *Camptocercus uncinatus* Smirnov, 1973

Daphnia sarojae Rane, 1986* = *Daphnia* (*Ctenodaphnia*) *carinata* King, 1853

Daphnia madhuriae Rane & Jarfi, 1990 = *Daphnia* (*Ctenodaphnia*) *similis* Claus, 1876

Daphniopsis sumanae Rane, 1985 = *Daphnia* (*Daphnia*) *lumholtzi* Sars, 1885

Diaphanosoma hydrocephalus Brehm, 1952 = *Diaphanosoma senegal* Gauthier, 1951

Diaphanosoma siddharthii Rao, Padmaja & Naidu, 1998 = *Diaphanosoma senegal* Gauthier, 1951

Graptoleberis testudinaria nathsagarensis Rane 2005 = *Graptoleberis testudinaria* (Fischer, 1854)

Indialona jabalpurensis Rane, 1983* = *Celsinotum macronyx* (Daday, 1898)

Latona tiwari Biswas, 1964* = *Latonopsis australis* (Sars, 1888) ?

Latonopsis narenderi Rane, 1985* = *Latonopsis australis* (Sars, 1888)

Leydigia anakammaroi Durga Prasad *et al.,* 1985 = *Leydigia ciliata* (Gauthier, 1939)

Leydigia ciliata melghatensis Rane, 2005 = *Leydigia ciliata* (Gauthier, 1939)

Moina dodhui Rane, 1987* = *Moina micrura* Kurz, 1874

Moina easu Brehm, 1936 = *Moina micrura* Kurz, 1874

Moina ganapatii Brehm, 1963 = *Moina macrocopa* (Straus, 1820)

Oxyurella lindbergi Brehm, 1953 = *Oxyurella singalensis* (Daday, 1898)

Oxyurella sangramsagari Rane, 1984* = *Oxyurella singalensis* (Daday, 1898)

Pleuroxus aduncus bhigawarensis Rane, 2002 = *Pleuroxus aduncus* (Jurine, 1829)

Simocephalus vidyae Rane, 1983* = *Simocephalus acutirostratus* (King, 1853)

Simocephalus vidyae gajareae Rane, 1986* = *Simocephalus acutirostratus* (King, 1853)

Simocephalus vamani Rane, 1985* = *Simocephalus exspinosus* (De Geer, 1778)

Simocephalus surekhae Rane, 1985* = *Simocephalus serrulatus* (Koch, 1841)

*Synonymized by Sharma and Sharma (1990)

The stated examples reflect poor *state-of-art* of taxonomic standards with rather 'casually diagnosed and sloppily described' new taxa. Ironically all new Indian taxa, except only five species namely: *Alona kotovi* Sinev, *Bosmina tripurae* Korinek et al, *Chydorus angustirostratus* Frey, *Moina hemanti* Padhye & Dumont, *Moina oryzae* Hudec and *Indialona ganapati* Petkovski ex. Kotov, are invalidated. On the contrary, several detailed descriptions of valid new taxa and re-descriptions based on Indian specimens (or including India) were published by Frey (1987b), Hudec (1987, 1991), Sinev (1999), Kotov (2000) and Kotov and Dumont 2000) during the last few decades.

B. 'Species *inquirendae*'

Seven species reported from India are categorized as *species inquirendae* (refer: Kotov, 2011):

Chydorus ciliatus Poggenpol, 1874

Chydorus hermanni Brehm, 1893

Chydorus leonardi King, 1853

Daphnia (Ctenodaphnia) longicephala Hebert, 1977

Daphnia (Ctenodaphnia) projecta Hebert, 1977

Dunhevedia ciliocaudata (Sovinskii, 1891)

Moina elliptica (Arora, 1931)

B. '*Reports inquirendae*' *

The Indian literature is confounded with a notable number of 'dubious reports' or '*reports inquirendae*' indicating 'routine and uncritical' listing of various taxa; lack of 'descriptions and illustrations' as well as 'voucher specimens' warrant their confirmation difficult:

Acantholeberis curvirostris Lilljeborg, 1853	Rajasthan
Alona archeri Sars, 1988	Maharashtra
Alona bukobensis (Weltner, 1898)	Jammu & Kashmir, Rajasthan
Alona cannellata Brehm, 1934	Tamil Nadu- *Species inquirenda*
Alona capensis Ruehe, 1914	Maharashtra
Alona dentifera (Sars, 1901)	Andaman Islands, Assam, Jammu & Kashmir, Rajasthan, West Bengal
Alona glabra Sars, 1901	Rajasthan
Alona harpularia (Sars, 1916)	unspecified location
Alona holdeni (Green, 1962)	Rajasthan- now under *Coronatella*
Alona karelica Stenroos, 1897	Tamil Nadu
Alona protzi Hartwig, 1900	West Bengal, Maharashtra, Tamil Nadu

Alonopsis aureolata Doolitle, 1913	Assam
Alonopsis elongatus (Sars, 1862)	Assam, Kashmir
Anchistropus minor Birge, 1893	Rajasthan
Bosmina (*Eubosmina*) *coregoni* Baird, 1857 s.lat	all Indian records warrant confirmation.
Camptocercus oklahomenis Mackin, 1930	Jammu & Kashmir
Camptocercus rectirostris Schoedler, 1862	Kashmir
Ceriodaphnia acanthina Ross, 1897	Rajasthan
Ceriodaphnia lacustris Birge, 1893	Rajasthan
Ceriodaphnia setosa Matile, 1890	Bihar
Chydorus bicornutus Doolittle, 1909	Rajasthan
Chydorus carolinae Methuen, 1910	Jammu & Kashmir
Chydorus gibbus Sars, 1890	Maharashtra
Chydorus denticulatus Henry, 1919	Rajasthan, Meghalaya
Chydorus herrmanni Brehm, 1933	unspecified location
Chydorus kallipygos Brehm, 1934	Maharashtra, Tamil Nadu
Chydorus ovalis Kurz, 1874	Jammu & Kashmir
Daphnia ambigua Scourfield, 1947	Rajasthan
Daphnia (*Daphnia*) *catawba* Coker, 1926	Jammu & Kashmir
Daphnia (*Ctenodaphnia*) *cephalata* King.1853 s. lat	West Bengal
Daphnia (*Ctenodaphnia*) *similis* Claus, 1876	Jammu & Kashmir
Daphnia dubia Herrick, 1883	Madhya Pradesh, Rajasthan
Daphnia (*Daphnia*) *hyalina* Leydig, 1860	Rajasthan
Daphnia (Daphnia) laevis Birge, 1879	Jammu & Kashmir, Maharashtra
Daphnia (*Daphnia*) *longiremis* Sars, 1862	Jammu & Kashmir
Daphnia (?) *pulicoides* Woltereck, 1932	Jammu & Kashmir
Daphnia (Daphnia) retrocurva Forbes, 1882	Kashmir
Daphnia (Daphnia) rosea Sars, 1862	Jammu & Kashmir, Maharashtra
Diaphanosoma birgei Kořínek, 1981	Gujarat
Diaphanosoma leuctenbergianum Fischer, 1850	West Bengal
Diaphanosoma modigliani Richard, 1894	West Bengal
Disparalona adiyodii Subhash Babu & Thomas, 2007	Kerala
Drepanothrix dentata (Eurén, 1861)	Jammu & Kashmir
Ilyocryptus sordidus (Liévin, 1848) s.lat.	Jammu & Kashmir
Latonopsis occidentalis Birge, 1892	Jammu & Kashmir, Kerala, Rajasthan
Leptodora kindtii (Focke, 1844) s. lat	Andhra Pradesh., Maharashtra, West Bengal
Leydigia (*Neoleydigia*) *laevis* Gurney, 1927	Rajasthan
Leydigia (*Neoleydigia*) *australis* Sars, 1885	Jharkhand, Tamil Nadu, West Bengal
Leydigia (*Neoleydigia*) *macrodonta* Sars, 1916	unspecified location

Megafenestra aurita (Fischer, 1849)	Jammu & Kashmir, Rajasthan
Macrothrix hirsuticornis Norman & Brady, 1867 s.lat.	Jammu & Kashmir, Rajasthan, Tamil Nadu
Macrothrix rosea (Jurine, 1820)	Jammu & Kashmir, Rajasthan, Uttarakhand
Macrothrix tenuicornis Gurney, 1907	Jharkhand
Macrothrix tobaensis Johnson, 1956	location unspecified
Moina affinis Birge, 1893	Kashmir
Moina hutchinsoni Brehm, 1937	Rajasthan
Moina reticulata (Daday, 1905)	location unspecified
Picripleuroxus striatus (Schoedler, 1862)	Delhi, Jammu & Kashmir
Polyphemus pediculus (Linne, 1761) s. lat	West Bengal
Rhynchotalona falcata (Sars, 1862)	location unspecified

*Without illustrations and descriptions, a majority of the invalidated records are dubious reports

C. Misidentifications and Lapsi

In light of changes in levels of Cladocera taxonomy, the following classical misidentifications need attention vis-à-vis earlier Indian reports:

Alona costata Sars, 1862	= *Alona cheni* Sinev, 1999. All Indian reports to be re-checked (Sharma and Sharma, 2013)
Alona quadrangularis (O. F. Muller, 1776)	= *Alona kotovi* Sinev, 2012. All Indian reports to be re-checked (Sharma and Sharma, 2014)
Camptocercus fennicus Stenroos, 1898	Bihar-Sharma and Sharma (2001) is a misidentified *Camptocercus uncinatus* (BKS, Unpublished)
Chydorus faviformis Birge, 1893	= *Chydorus angustirostratus* Frey, 1982. All Indian reports to be re-checked (Sharma and Sharma, 2014)
Pseudosida bidentata Herrick, 1884	= *Pseudosida sazalyi* Daday, 1898. All Indian reports to be re-checked (refer: Chatterjee *et al.,* 2013; Sharma and Sharma, 2013)
Simocephalus vetulus (O. F. Müller, 1776) s.lat.	= *Simocephalus mixtus* Sars, 1903. All Indian reports to be re-checked (Sharma and Sharma, 2013)

We come across of a reasonable number of ‘spelling errors’ (*lapsi*) indicating ’casual’ listing of names of taxa by different Indian workers:

Alona exigua	*Alonella exigua ?*
Alona guitata	*Alona guttata*
Alona intermediate	*Alona intermedia*
Alona quadrata	an obvious *lapsus* and invalid name

Alona rectangular	*Alona rectangula*
Bosmina longistrus	*Bosmina longirostris*
Camptocercus macrorus Baird	a taxon Baird never described.
Ceriodaphnia reticulata	*Ceriodaphnia reticulata*
Ceriodaphnia macrura	No taxon with such a name known
Ceriodaphania quardrugulata	*Ceriodaphnia quadrangula*
Cerioda pheriereticulata	No taxon with such a name known
Chyderinae sp.	No taxon with such a name known
Chydorid species	*Chydorus* sp. ?
Chydorus cornuta	Invalid name and a lapsus.
Chydorus quadrangular	lapsus- *Alona quadrangularis*
Chydorus laticaudata	lapsus- *Ceriodaphnia laticaudata*.
Chydorus macrodonta	no such taxon was described
Chydornus sp.	probably *Chydorus* sp.
Daphnia caritiata	Probably misspelling of *Daphnia carinata*.
Daphnia scholderi	*D. schoedleri* -a dubious record for India.
Macrothrix toiserids	perhaps spelling error of *Macrothrix triserialis*
Moina daphnia	- misunderstanding of the generic names
Moina bachiata	lapsus of *Moina brachiata* (Jurine)
Moina rosea	No taxon with such name known
Oxyurella tenuicornis	A lapsus likely of *Oxyurella tenuicaudis*

TAXONOMIC IMPEDIMENTS VIS-À-VIS INDIAN CLADOCERA

The progress of cladoceran taxonomy is challenged with several limitations impairing its progress and resulting in nomenclatural and taxonomic anomalies. Such impediments are:

A. Levels of taxonomic resolutions

A bulk of the Indian faunal works is far below widely argued internationally acceptable levels. Ironically, a few taxa namely: *Alona kotovi, Bosmina (Bosmina) tripurae*, *Diaphanosoma tropicum*, *Chydorus angustirostratus*, *Moina hemanti*, *Moina oryzae*, *Indialona ganapati*, and *Notoalona globulosa* are described and illustrated from India as per global standards. The reports depicting 'poor illustrations' or many 'without illustrations' pose limitations to enable an objective opinion on the status of the documented taxa. SEM studies, population analysis, trunk-limb morphology and head pore studies are ignored in spite of comments on some aspects by Sharma and Michael (1987).

B. Insufficient literature updates

The current global progress in cladoceran taxonomy largely escaped the attention of many Indian workers. This is particularly true of separation of several new genera in Aloninae or even continued use of old status of several known genera / taxa. The recent nomenclatural changes are, to a certain extent, adopted till date in limited Indian works of Sharma and Sharma (2012, 2014), Sharma and Sharma (2013) and Padhye & Dumont (2014b).

C. Fuzzy species lists

The fuzzy lists and checklists from India 'without critical assessment and authentication' are misleading for their 'uncritical use' by future workers. The checklists of Raghunathan & Suresh Kumar (2002, 2003) are examples of concern while the lists by Fernando and Kanduru (1984), Murugan et al. (1998) and Battish (1992) merit cautious application.

D. Out-dated literature

The Indian works often cite 'obsolete' works of Needham and Needham (1962), Michael (1973) and Tonapi (1980) while Murugan *et al.* (1998) and Battish (1992) fail to facilitate correct species identification. Brooks (1959) is incorrectly cited as 'Ward & Whipple' or 'Edmondson' in several works. Fauna volume on Indian Cladocera (Michael and Sharma, 1988) is rarely accessed in the Indian studies.

E. Lack of 'voucher / type specimens'

It is an important limitation for verification and authentication of various anomalous and dubious taxa reported from India. In some cases (Battish, 1981; Rao et al. 1998a, 1998b) there is no indication of the depository of 'type specimens' while those submitted for Rane's series of new taxa are not 'accessible' (refer: Korovchinsky, 2011).

F. Inadequate taxonomic expertise

With amateurs increasingly creating nomenclatural mess and spurious on-line publications resulting in dubious reports, lack of taxonomic expertise is an alarming reality.

G. Incomplete species inventories

Routinely noticed in the Indian limnological surveys, such inventories are real handicap both for biodiversity and ecological studies.

H. Reservations about national collaborations

Limited Indian workers availed free '*National Identification Advisory Service for Freshwater Zooplankton*' offered by the senior author (BKS) since the last three decades. This coupled with apprehensions on national collaborations is detrimental for promotion of taxonomy in India.

FUTURE OF CLADOCERA SYSTEMATICS IN INDIA

With majority of taxa described at 'L1 level" or below, the Cladocera taxonomy is to be radically improved from a long period of dodgy systematics being practiced in India. Nevertheless, the biodiversity and biogeography of the taxon offers ample future potential as indicated hereunder:

A. New beginning – Revalidation of Indian taxa

The most important task for Indian workers is to consult the specialized global taxonomical literature of the few decades in particular and keep track of current nomenclature changes or revisions. This initiative should be matched with revalidation of known Indian taxa at 'L 3 level' descriptions and illustrations *vide* Van Damme et al. (2010) as well as 'authentic and critical' descriptions of new taxa likely to occur in the country. This stupendous task ushers in an era of 'new beginning' of Cladocera taxonomy in India with potential for its valuable contribution to their diversity in (sub) tropics and the Oriental region.

B. Analysis of cryptic diversity

With reported occurrence of several species-groups, the Indian populations need through analysis of their cryptic diversity with comprehensive 'morpho-taxonomy' based on SEM, functional morphology, embryology, trunk-limb morphology and head-pore studies as well as the male morphology. These efforts need to be supplemented with 'ecosystematics' and molecular systematics.

C. New surveys vis-à-vis Ecosystem diversity

With parts of India in general and the Himalaya region and western Ghats 'hot-spots' in particular yet unexplored / under-explored, attention is desired on intensive surveys vis-à-vis ecosystem diversity rather than on routine Cladocera faunal inventories.

D. National reference collections

A national depository 'voucher' specimens / collections' is essential for 'assessment and authentication' of faunal diversity of the taxon rather than individual domains. A lead role needs to be initiated by Zoological Survey of India to development a mechanism for effective national transfer of all such individual depositories.

E. Authentic identification manual / Hand-book

The need of an 'authentic hand-book' or an 'illustrative manual' to facilitate credible identification of Indian Cladocera is long felt. The authors have initiated steps to bridge this gap.

F. Fauna of Indian volume-a revision

Highly desired revision of fauna volume on Indian Cladocera (Michael and Sharma, 1988), as per current global taxonomic levels, is being initiated by the authors. A suitable support by Zoological Survey of India shall be valuable to facilitate execution of this work.

G. Trained human resources and research initiatives

All Indian Coordinated project on Capacity Building in Taxonomy (AICOPTAX), the Ministry of Environment, Forests and Climate Change (Government of India) can play vital role on the said aspects except for its 'pick & choose' policy of promoting research programs. The short-term 'Training workshops' are useful for human resources development in Cladocera systematics.

CONCLUSION

The taxonomy of Indian Freshwater Cladocera is passing through its transitional phase as species lists from India have been changing with the levels of morphological resolutions and current global knowledge. An estimate of its diversity is still 'ad-hoc' pending revalidation of known Indian taxa, analysis of cryptic diversity, and study of intensive collections from hitherto un-explored or under-explored parts of this country. A holistic biosystematics approach integrating morpho-taxonomy, ecosystematics and molecular systematics is desired to reach a more realistic estimate of true diversity of the taxon in India. With varied ecological heterogeneity, habitat diversity and biodiversity hot-spots, we hypothesize still high diversity of the cladocerans than known now with possibility of local endemism and descriptions of new taxa. The development of adequate taxonomic expertise, a national depositary and collaborative efforts are keys to future biodiversity exploration.

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CRUSTACEA: BRANCHIOPODA (ANOSTRACA, NOTOSTRACA, LAEVICAUDATA, DIPLOSTRACA)

Chapter 15

K. VALARMATHI

ABSTRACT

The Branchiopods are a primitive and diverse class of the Crustacea characterized by flattened and foliaceous thoracic appendages. This reasonably small taxon of primarily freshwater crustaceans encompasses numerous primeval looking members like fairy shrimps (Anostraca), tadpole shrimps (Notostraca), clam shrimps (Diplostraca) and also includes highly modified associates of Cladocerans. Except cladocera the remaining are known as large branchiopod or non cladoceran branchiopods. Presently 40 species of large branchiopods under 14 genera, 11 families and 4 orders are known to occur in India.

Key Words: Anostraca, Branchiopoda, Diplostraca, Notostraca, India.

INTRODUCTION

The Branchiopods are a primordial and diverse class of the Crustacea characterized by having flattened and foliaceous thoracic appendages (thoracopods); these structures have respiratory (as well as other) function and hence the name branchio- (breathing) poda (legs) (Greaves, 2012). It is a reasonably small taxon of primarily freshwater crustaceans with numerous primeval members like fairy shrimps, tadpole shrimps and encompasses highly modified associates of Cladocerans (Martin, 1992, Olesen, 2009). Nearly half of the known branchiopod species are cladocerans. The non-cladocerans (Anostraca=fairy shrimps, Notostraca=tadpole shrimps, Laevicaudata=smooth clam shrimps) are generally named as 'large branchiopods', despite the group being clearly paraphyletic, nevertheless, they share a number of common characteristics like serially similar phyllopodous trunk limbs, their preference for temporary wetlands or salt lakes (Olesen, 2009). In India many of the major groups of non-cladoceran or large branchiopods are well represented in various temporary and semi permanent water bodies, occasionally in some permanent water bodies. The anostracans, inhabiting temporary rain pools and permanent saltwater worldwide, are branchiopods lacking a carapace and with 19-27 postcephalic segments of which 9-19 carry a pair of similar, foliaceous limbs (Weekers *et al.,* 2002). Most of them are about 10-30 mm long (extreme range 5-150 mm), and consist of a long cylindrical body divided into a head, a thorax with many pairs of foliaceous limbs, the genitalia, and an abdomen and interestingly the fairy shrimps swim upside down (Timms, 2015).

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Anostracans are divided into two suborders: the Artemiina containing two genera *Artemia* and *Parartemia* which live in saline waters hence are called brine shrimp and the Anostracina which accommodate the freshwater fairy shrimps (though some live in saline waters) arranged in six extant families (Timms, 2012, 2015). In India the order Anostraca is represented by 5 families. Notostraca is a small and widely distributed order showing an extremely conserved morphology, with fossils from 300 million years back but morphologically identical to extant taxa. They inhabit ephemeral water bodies and produce resistant diapausing cysts that form egg banks in sediments and are also the dispersal stage (Sassaman *et al.,* 1997, Zierold, 2009). The order Notostraca comprises a single Family Triopsidae, and two genera namely *Triops* Schrank, and *Lepidurus* Leach. Among these two genera the genus *Triops* is represented by two species and the latter genus is so far not reported from India. Both the genera have long and complex taxonomic histories about 60 junior synonyms exist for the eleven or so species recognized by Longhurst (1955a) (Sassaman *et al.,* 1997). The single family Lynceidae of the Order Laevicaudata, the Diplostracan suborders Spinicaudata with three families and the only known *Cylestheria hislopi* (Baird) of the suborder Cyclestherida are available in India.

Fossil History

Anostracans have been known, since the Lower Cretaceous period (Fryer, 1987, Peter *et al*., 2002). Notostraca is an ancient order of branchiopod crustaceans dating from the Cambrian and it represents a challenging group from both evolutionary and ecological aspects. Its two genera, *Triops* and *Lepidurus*, constitute a well-known example of 'living fossils', i.e. lineages surviving 'over a long period of time with minimal morphological change' as a result of 'unusual morphological conservatism'(Mantovani *et al.,* 2004). The tadpole shrimps have a fossil record extending back at least 220 million years, mostly disarticulated carapaces or telsons are found but well-preserved entire animals are sometimes uncovered (Greaves, 2012). *Triops* has a long fossil record, specimens assigned to this genus are reported from the Permian of Oklahoma and numerous specimens indistinguishable from modern *Triops cancriformis* have been collected in Triassic formations of Virginia and Germany. Two species described from the Middle Jurassic of China also resemble *T. cancriformis* (Sassaman *et al.,* 1997). Like the Notostraca, clam shrimps have an extensive fossil record, extending at least to the Carboniferous, mostly only carapaces (and not whole animals) are found (Greaves, 2012).

Review of literature

Baird (1860) initiated the awareness of Phyllopod crustaceans of the Indian Empire by describing *Streptocephalus dichotomus* from a single male specimen swimming in a bucket of milk (Bond, 1934). Since then there are many workers who contributed to the knowledge of the non cladoceran branchiopods (Sars, 1887; Alcock, 1898; Gurney, 1906, 1921,1924,1925,1930; Kemp, 1911a,b; Bond, 1934; Mahabate, 1939; Gopinath, 1944; Chako, 1950).

Tiwari (1951, 1958,1962,1965, 1966,1971,1972,1996) made a significant contribution to the large branchipod crustaceans of India. The contribution made by other workers (Raj, 1951; Kulkarni, 1953; Iyengar and Basavaiah, 1956; Mathur and Sidhu, 1957; Baid, 1958,1968,1975; Raji,1951; Karande and Inamdar, 1959, 1961a,b; Nayar, 1965; Shull, 1967; Raj, 1971; Nayar and Nair, 1968, Shanbag and Inamdar, 1968; Issac, 1970; Malhotra and Duda, 1970; Royan *et al*., 1970; Das, 1971; Das and Akhtar, 1971; Royan and Alfred, 1971; Royan and Sumitra, 1973; Radhakrishna and Durga Prasad, 1974,1976; Bhargava and Alam, 1980; Munuswamy, 1982a,b; Battish, 1981, 1983; Joseph *et al.,* 1992; Belk and Esparza, 1995; Ghate and Patil, 1995; Belk and Brendonck, 1997; Ghate and Shetty, 1997; Manca and Mura, 1997) is also noteworthy.

Presently numerous remarkable investigations were carried out by Ghate, *et al*. (2003), Balaraman and Nayar (2004), Durga Prasad and Simhachalam (2004, 2009) Velu, and Munuswamy (2003, 2005,2006,2007), Babu and Nandan, (2010), Padhye *et al*. (2011a,b,c), Simhachalam and Timms (2012), Vikas *et al* (2012) and Padhye *et al*. (2015), Kulkarni *et al*.(2015), Padhye and Dahanukar (2015) and Padhye and Ghate, 2016). Recently Rogers and Padhye (2015) reviewed the large branchiopod crustaceans of Indian subcontinent and Padhye *et al*. (2016) studied the diversity and zoogeography of the fairy shrimps of Indian subcontinent.

Diversity

The large branchiopod crustaceans comprise about 500 species found in aquatic, inland, saline and/or temporary wetland habitats from all continents, including Antarctica (Brendonck *et al*., 2008; Rogers and Padhye, 2015). In general, the Asian large branchiopod fauna has been poorly studied and with many areas not surveyed and much confusion in the taxonomic literature (Rogers, 2013; Rogers and Padhye, 2014, 2015). Rogers and Padhye (2015) made a detailed review of large branchiopod crustaceans of Indian subcontinent (Bangladesh, India, Nepal, Pakistan, and Sri Lanka) based on literature. Out of 86 species of large branchiopods known earlier they have recognized only 42 species: 16 anostracans, 2 notostracans, 3 laevicaudatans, 21 spinicaudatans (with reservations), and a single species of cyclestherid, while the rest are synonymised. Padhye and Ghate (2016) recently described a new species of *Leptestheria* from Western Ghats. Based on the above review work and the recent addition presently 40 species of large branchiopods under 14 genera, 11 families and 4 orders are known to occur in India (Table. 1&3). Brendonck *et al*. (2008) made a comparative analysis of large branchiopod species diversity in different Zoogeographic regions. The maximum species diversity of Anostraca, Notostraca and Spinicaudata is known from Palaearctic region whereas highest species diversity Laevicaudata is observed in the Neotropical region (Table. 2)

Table 1. Global and Indian Distribution of Non Cladoceran Branchiopods

Order/Family	World		India	
	Genra	Species	Genera	Species
Anostraca	26	307	**6**	**13**
Artemiidae	1	9	1	2
Parartemiidae	1	13	0	0

Order/Family	World		India	
	Genra	Species	Genera	Species
Branchinectidae	1	45	0	0
Thamnocephalidae	6	62	2	3
Streptocephalidae	1	56	1	6
Branchipodidae	5	35	1	1
Tanymastigitidae	2	8	0	0
Chirocephalidae	9	81	1	1
Notostraca	2	15	**1**	**2**
Triopsidae	2	15	1	2
Spinicaudata	12	~150	**6**	**22**
Cyzicidae	4	~90	2	7
Leptestheriidae	3	~37	2	7
Limnadiidae	5	~55	1	7
Cyclestheriidae	1	1*	1	1*
Laevicaudata	3	36	**1**	**3**
Lynceidae	3	36	1	3
Total	43	~508	14	40

(Source: Modified and updated after Brendonck *et al.,* 2008; Rogers and Padhye, 2015)

Table 2. Diversity of Anostraca, Notostraca, Spinicaudata and Laevicaudata in different Zoogeographic regions

	PA		NA		NT		AT		OL		AU		PAC		ANT		World	
	G	Sp.	G	Sp.	G	Sp.	G	Sp.	G	Sp.	G	Sp.	G	Sp.	G	Sp.	G	Sp.
Anostraca	**16**	**110**	**11**	**64**	**10**	**33**	**6**	**56**	**6**	**11**	**4**	**48**	**1**	**1**	**1**	**1**	**26**	**307**
Artemiidae	1	6	1	3	1	2	1	1	1	1	1	1	1	1	0	0	1	9
Parartemiidae	0	0	0	0	0	0	0	0	0	0	1	13+	0	0	0	0	1	13
Branchinectidae	1	6	1	24	1	15	0	0	0	0	0	0	0	0	1	1	1	45
Thamnocephalidae	2	5	3	6	3	16	4	4	2	2	1	32	0	0	0	0	6	62
Streptocephalidae	1	16	1	15	1	24	0	0	1	7	1	2	0	0	0	0	1	56
Branchipodidae	2	9	0	0	4	26	0	0	2	2	0	0	0	0	0	0	5	35
Tanymastigitidae	2	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	8
Chirocephalidae	7	61	5	16	1	1	0	0	1	1	0	0	0	0	0	0	9	81
Notostracaa	**2**	**7**	**2**	**7**	**2**	**2**	**1**	**1**	**1**	**2**	**2**	**2**	**0**	**0**	**0**	**0**	**2**	**15**
Triopsidae	2	7	2	7	2	2	1	1	1	2	2	2	0	0	0	0	2	15
Spinicaudata	**9**	**~50**	**5**	~15	5	~13	4	~20	6	~30	5	23	1	1	0	0	**12**	**~150**
Cyzicidae	3	~20	2	6	2	2	1	~7	3	~10	2	10	0	0	0	0	4	~90
Leptestheriidae	3	~15	1	1	1	~5	1	~8	1	~3	0	0	0	0	0	0	3	~37

	PA		NA		NT		AT		OL		AU		PAC		ANT		World	
	G	Sp.	G	Sp.	G	Sp.	G	Sp.	G	Sp.	G	Sp.	G	Sp.	G	Sp.	G	Sp.
Limnadiidae	3	~15	2	~10	2	~10	2	~10	2	~12	3	13	1	1	0	0	5	~55
Cyclestheriidae	0	0	0	0	0	0	0	0	1	1*	0	0	0	0	0	0	1	1*
Laevicaudata	**1**	**8**	**2**	**7**	**2**	**13**	**2**	**4**	**1**	**4**	**1**	**2**	**0**	**0**	**0**	**0**	**3**	**36**
Lynceidae	1	8	2	7	2	13	2	4	1	4	1	2	0	0	0	0	3	36

(Source: Modified after Brendonck *et al.,* 2008)

PA, Palaearctic; NA, Nearctic; NT, Neotropical; AT, Afrotropical; OL, Oriental; AU, Australasian; PAC, Pacific Oceanic Islands; ANT, Antarctic

Distribution: The non-cladoceran branchiopods have a worldwide distribution including the Antarctic peninsula but maximum abundance and species richness is noticed in steppes and deserts which covers numerous temporary water bodies (Brendonck *et al*., 2008). Most of the large branchiopod crustaceans reported were from southern and northwestern parts of India with meager reports from northeast and various regions of the Indian subcontinent remain unexplored (Rogers and Padhye, 2015) (Table 3).

Table 3. List of species reported from India with their distribution in the country

Sl. No.	Order/Family/Species	Distribution in India
	Order ANOSTRACA Sars, 1867 ARTEMIIDAE Grochowski, 1896	
1.	*Artemia franciscana* Kellogg, 1906	introduced to India, where it is spreading (Vikas *et al.,* 2012, Rogers and Padhye, 2015)
2.	*Artemia salina* (Linneaus, 1758)	saline ponds in Maharashtra, Tamil Nadu, the coastal strands of Sourastra and Kutch in Gujarat, Samhar Lake and Didwana Lake in Rajasthan, and West Bengal
	STREPTOCEPHALIDAE Daday, 1910	
3.	*Streptocephalus dichotomus* Baird, 1860	most common and widespread in India
4.	*Streptocephalus echinus* Bond, 1934	Tamil Nadu, Andhra Pradesh
5.	*Streptocephalus longimanus* Bond, 1934	eastern Tamil Nadu
6.	*Streptocephalus sahyadriensis* Rogers and Padhye, 2014	northern region of the Western Ghats
7.	*Streptocephalus simplex* Gurney, 1907	Himachal Pradesh, Rajasthan, Uttar Pradesh, Gujarat and West Bengal
8.	*Streptocephalus spinifer* Gurney, 1907	southern Andhra Pradesh and central Tamil Nadu.

Sl. No.	Order/Family/Species	Distribution in India
	BRANCHIPODIDAE Simon, 1886	
9.	*Branchipodopsis affinis* Sars, 1901	widespread species in various parts of India
	THAMNOCEPHALIDAE Packard, 1883	
10.	*Branchinella hardingi* (Qadri and Baqai, 1956)	Madhya Pradesh
11.	*Branchinella maduraiensis* (Raj, 1951) fide Belk and Brendonck, 1997	It has been widely reported from various parts of India
12.	*Carinophallus ornata* (Daday, 1910)	Sambhar Lake, Naguar District in Rajasthan.
	CHIROCEPHALIDAE Daday, 1910	
13.	*Chirocephalus priscus* (Daday, 1910)	Punjab, Uttarakhand, Rajasthan and Sikkim, as well as adjacent Punjab, Pakistan, across the base of the Himalayas.
	Order NOTOSTRACA, Sars, 1867 TRIOPSIDAE Keilhack, 1909	
14.	*Triops cancriformis* (Bosc, 1801)	Jammu and Kashmir, Gujarat, and Uttar Pradesh.
15.	*Triops granarius* (Lucas, 1864)	Gujarat, Kashmir, Maharashtra, Rajasthan, and Tamil Nadu
	Order LAEVICAUDATA Linder, 1945 LYNCEIDAE Baird, 1845	
16.	*Lynceus brachyurus* Müller, 1776	Tamil Nadu (Nayar and Nair (1968) reported two male *L. brachyurus* from Tamilnadu but Rogers and Padhye doubt the species Identification and they feel it may not be *L.brachyurus*)
17.	*Lynceus denticulatus* (Gurney, 1930) species complex	Tamil Nadu, Kerala, Punjab
18.	*Lynceus indicus* Daday, 1913	Uttarakhand
	Order DIPLOSTRACA Gerstaeker, 1866 Suborder SPINICAUDATA Linder, 1945 CYZICIDAE Stebbing, 1910	
19.	*Cyzicus annandalei* Daday, 1913	Uttar Pradesh, Rajasthan and
20.	*Cyzicus indicus* (Gurney, 1906)	Tamil Nadu
21.	*Cyzicus ludhianatus* (Battish, 1981)	from Punjab
22.	*Eocyzicus bouvieri* Daday, 1913b	Himachal Pradesh and Uttarakhand
23.	*Eocyzicus dhilloni* Battish, 1981	Punjab

Sl. No.	Order/Family/Species	Distribution in India
24.	*Eocyzicus hutchinsoni* Bond, 1934 [species-complex]	Punjab and from Jammu and
25.	*Eocyzicus plumosus* Royan and Sumitra, 1973	Andhra Pradesh, Tamil Nadu
	LEPTESTHERIIDAE Daday, 1923	
26.	*Leptestheria dumonti* Subash Babu and Bijoy Nandan, 2010	Kerala
27.	*Leptestheria gurneyi* Padhye & Ghate, 2016	A small and shallow rock pool (depth of about 30 cm) on Devi Hasol lateritic plateau near Western Coast, Maharshtra
28.	*Leptestheria jaisalmerensis* Tiwari, 1962 (amended Tiwari, 1996)	Maharastra and Rajasthan
29.	*Leptestheria nobilis* Sars, 1900	Andrha Pradesh, Karnataka, Maharashtra Rajasthan and Tamil Nadu.
30.	*Leptestheria sarsi* (Daday, 1923)	Madhya Pradesh, Tamil Nadu
31.	*Leptestheria simhadrii* (Simhachalam and Timms, 2012)	Andhra Pradesh
32.	*Sewellestheria sambharensis* Tiwari, 1966	Endemic to the saline Lake Sambhar, Rajasthan.
	LIMNADIIDAE Baird, 1849	
33.	*Eulimnadia azisi* Subash Babu and Bijoy Nandan, 2010	rock pools in the Western Ghats of Kerala.
34.	*Eulimnadia compressa* (Baird, 1849)	Karnataka, Maharashtra and Tamil Nadu
35.	*Eulimnadia gibba* Sars, 1900	Tamil Nadu
36.	*Eulimnadia gunturensis* Radhakrishna and Durga Prasad, 1976	Andhra Pradesh
37.	*Eulimnadia indocylindrova* Durga Prasad and Simhachalam, 2004	Andhra Pradesh and Maharashtra.
38.	*Eulimnadia micheali* Nayar and Nair, 1968	Kerala, Maharashtra and Tamil Nadu
39.	*Eulimnadia ovata* Nayar, 1965	Rajasthan
	Suborder CYCLESTHERIDA Sars, 1899 CYCLESTHERIIDAE Sars, 1899	
40.	*Cyclestheria hislopi* (Baird, 1859)	Bihar, Maharastra, Punjab, Tamil Nadu and West Bengal. The single pantropical morphospecies *Cyclestheria hislopi* consists of different cryptic 'phylogenetic' species. (Rogers and Padhye, 2015)

See Rogers and Padhye (2015) for details of synonymy and distributional reports etc.

Endemism

Of the nearly 500 described species of large branchiopods, more than one-fourth are known only from their type localities, and several species have only been collected once or twice (Rogers, 2009). In India also many species are known only from their type locality and nearby areas and few species are reported from very limited areas (Table. 3)

Biology

Among the large branchiopod crustaceans, the anostracans have universal distribution in ephemeral ponds, saline inland water bodies, and sporadically in marine lagoons. Some species are known from ultra-pure fresh waters in tundra habitats to extremely turbid and silt-laden puddles (Martin 1992; Martin and Boyce, 2004). Maximum species of anostracans seem to be filter feeders or deposit feeders, but some are rapacious predators on other species of anostracans (Martin and Boyce, 2004). With the exception of Antarctica the Notostracans are reported from all continents and they are mostly restricted to temporary or vernal waters such as freshwater rock pools, paddy fields, puddles and clay pans which are subject to cycles of flooding and drying. *Triops* have been shown to withstand boiling water and still develop normally later and the notostracans feed on detritus or on other organisms, living or dead, they can catch other anostracans and even small fish (Martin and Boyce, 2004). Like notostraca the clam shrimps are also known from all continents except Antarctica, they are mostly available in the temporary water bodies, rarely the members of the family Lynceidae are noticed in praire streams and *Cyclotheria hislopi*, the single known species of the family Cylestheriidae are available in permanent water bodies (Martin and Boyce, 2004). They are known as filter feeders and scavenger species of the aquatic environment.

Habitat

The anostracans inhabit almost exclusively temporary standing freshwaters like clay pans, gnammas on rock outcrops, vegetated pools, newly filled freshwater lakes, salt lakes, ephemeral farm dams, roadside ditches, disconnected creek pools, actually anywhere where water is ponded for more than few days (Timms, 2015). The tadpole shrimp *Triops* occurs in rice fields, rain pools, fishery ponds and other temporary freshwater water bodies (Zierold *et al.,* 2009, Hora *et al.,* 1955, Padhye and Ghate, 2016). The clam shrimps are also noticed in temporary and semi- permanent inland water bodies. We could observe the cyclotheriids even in permanent water bodies like ponds along with cladocerans among the marginal vegetation (Personnel observation).

Life cycle

The branchiopods display a broad range of reproductive modes, including dioecy, hermaphroditism and parthenogenesis (Brantner *et al*., 2013). Within Crustacea, the class Branchiopoda is interesting both because of its phylogenetic importance (Martin and Davis, 2001), and increasingly because of its diversity of reproductive forms (Sassaman, 1995; Dumont and Negrea, 2002; Weeks *et al*., 2009). Anostracans are gonochoric which involves male, female, and sexual reproduction. All fairy shrimps produce drought resistant eggs, which are carried in the brood pouch where they mature, a lot of species discharge these eggs regularly while some retain them even in death (Timms, 2015). The draught resistant eggs contain an embryo in an arrested phase of development which remains viable in the surface sediments for many years (Timms, 2015). At suitable conditions they hatch as nauplii. The nauplius larva is small and oval or pear shaped with three pairs of appendages, the additional appendages are added as somites are added during the growth (Mortin and Boyce, 2004). They have a rapid growth and few species may mature within four days but 2-3 weeks is quite normal (Timms, 2015).

Both self-fertilization and sexual reproduction are observed among the tadpole shrimps, like fairy shrimps they also hatch as nauplii and the notostracan larvae contain much yolk and they do not swim (Fryer, 1988, Mortin and Boyce, 2004).

The Diplostracans (clam shrimp and water fleas) have five modes of reproduction: dioecy (males + females = gonochorism), hermaphroditism (organism possesses a functional ovotestis and is thus capable of self-fertilization), parthenogenesis (reproduction via asexual means), cyclic parthenogenesis (many bouts of parthenogenesis with periodic sexual reproduction) and androdioecy (males + hermaphrodites; Dumont and Negrea, 2002, Brantner *et al.*, 2013). Like other large branchiopods the eggs of the clam shrimps hatch as a pear shaped nauplius larva with three pairs of appendages with more metamorphic stages.

Threats, Conservation and Human Significance

Of the nearly 500 described species of large branchiopods, more than one-fourth are known only from their type localities, and several species have only been collected once or twice (Rogers, 2009). About 31 large branchiopod species are included in the IUCN red list and no Indian species is noticed among them (IUCN, 2016). Many species of fairy shrimps are considered as a live feed in aquaculture industries and they are used effectively as 'living pills' to provide antibiotics, medications, or vitamins to the aquacultural livestock (Amitha *et al.,* 2007; Basil and Pandian, 1991; Rogers, 2009). *Triops cancriformis* has been reported as a rice pest in Kashmir, India (Hora *et al,* 1955, Zaka-ur-Eab, 1984, Padhye and Ghate, 2016). On the contrary the *Triops* species are used in biological control in Japan. In pet industries *Artemia* is frequently sold as 'Sea Monkeys' and the tadpole shrimp *Triops* is sold as a 'living fossil' (Rogers, 2009). Any kind of anthropogenic activities that affects the temporary water bodies will directly or indirectly affect the diversity of large branchiopod crustaceans so if we protect the habitat we can conserve the large branchiopod crustaceans.

Gaps in research

The works on large branchiopod crustaceans are very scattered and except for the recent literature based on the review of Rogers and Padhye (2015) no concrete information is available in this group. Attention should be given to make a detailed taxonomic study based on the materials already collected and available in the museums and fresh faunal surveys to various parts of the country is also essential. The taxonomic ambiguity of various species of the non cladoceran branchiopods should be solved by a detailed study of the already known species and especially by examining more samples from different localities. Apart from that there are many unexplored area of this group and the youngsters should develop expertise in this group to have a better knowledge on these poorly known organisms.

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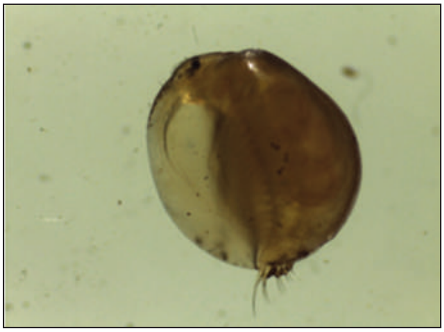
NON CLADOCERAN BRANCHIOPODS

Carinophallus ornata (Daday, 1910)

Streptocephalus echinus Bond, 1934

Triops granarius (Lucas, 1864)



Cyclestheria hislopi (Baird, 1859)

Cyzicus annandalei Daday, 1913

Cyzicus annandalei Daday, 1913

Chapter 16

CRUSTACEA : COPEPODA—A NOTE

YENUMULA RANGA REDDY

Copepods occur in almost all freshwater habitats such as temporary pools and ponds, lakes, slowing-flowing rivers and streams, hot springs, small pools of water within or upon plants (phytotelmata), and even in semi-terrestrial situations such as damp moss and leaf litter in humid forests. They are extremely abundant in freshwater, often constituting a major component of most planktonic, benthic and groundwater communities. Of about 13,000 nominal species so far known in the world, most of them are found in the marine environment, and only about 3, 000 species inhabit freshwaters. Ecologically, the planktonic copepods as primary and secondary consumers constitute a significant trophic link between the algal cells (phytoplankton: primary producers) and the juvenile fish to whales (planktivores) in aquatic food chains. They contribute a major portion of the biomass and secondary production in many aquatic communities. Free-living copepods in general have the potential to be used by mankind in different ways. For example, while some species can be easily cultivated under laboratory conditions and used as live feed for fish and prawn larvae in aquaculture industry, the predatory species, especially certain cyclopoid copepods, are employed as biological agents in mosquito control and also as biological indicators for environmental monitoring purposes, both in the field and laboratory. Some of them are also known to act as intermediate hosts of many of human and animal parasites as well.

Of the nine orders known under the subclass Copepoda, viz. Platycopioida Fosshagen, Calanoida Sars, Misophrioida Gurney, Harpacticoida Sars, Mormonilloida Boxshall, Gelyelloida Huys, Cyclopoida Burmeister, Poecilostomatoida Thorell, Siphonostomatoida Thorell, and Monstrilloida Sars, the free-living freshwater copepods generally belong to three orders: Calanoida, Cyclopoida, and Harpacticoida. All other orders contain predominantly brackish water, marine and/or parasitic forms. The current status of the diversity of the Indian free-living freshwater copepods is summarized below based on the available literature.

Order CALANOIDA Sars

Though the order Calanoida has 40 families, the truly freshwater Indian species are typically planktonic and belong to the family Diaptomidae Baird. The only exceptions are two species of the typically brackish water/marine and demersal family Pseudodiaptomidae Sars: *Pseudodiaptomus lobipes* Gurney, an endemic

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to West Bengal, and *P. binghami* Sewell, a denizen in the River Krishna and its network of canals. The Diaptomidae, which contains about 470 species in 61 genera in the world, has two subfamilies in India: i) Paradiaptominae Kiefer, represented only by *Paradiaptomus greeni* (Gurney), which is widespread in the country in seasonal ponds and pools,; and ii) Diaptominae, comprising **44 nominal species in 12 genera** as listed here (the species number within parentheses): *Acanthodiaptomus* Kiefer (1), *Allodiaptomus* Kiefer (4), *Arctodiaptomus* Kiefer (7), *Eodiaptomus* Kiefer (1), *Heliodiaptomus* Kiefer (6), *Keraladiaptomus* Silva, Kakkassery, Maas & Dumont (1), *Megadiaptomus* Kiefer (2), *Neodiaptomus* Kiefer (7), *Phyllodiaptomus* Kiefer (4), *Sinodiaptomus* Kiefer (2), *Spicodiaptomus* Rajendran (1), and *Tropodiaptomus* Kiefer (8). Of these, *Keraladiaptomus* and *Spicodiaptomus* are extremely endemic whereas the other genera may be said to have either somewhat restricted or widespread distribution. A few species can tolerate estuarine conditions. So far, no obligate groundwater calanoids are known from India.

Order CYCLOPOIDA Burmeister

This order comprises 12 families, but only four of them, viz. Oithonidae Dana, Cyclopinidae Sars, Cyclopettide Martínez Arbizu, and Cyclopidae Rafinesque, are represented in inland waters of India. Of these, the members of Cyclopidae, much like those of Diaptomidae, are most widely and almost exclusively distributed in inland waters, and this family is also highly speciose with over 1,100 world species in about 60 genera. Also, it is an ecologically highly diversified and taxonomically difficult taxon, with species displaying planktonic, benthic, interstitial, and even parasitic adaptations. To date, **86 species in 20 genera** are known in India. The genera together with their respective species number (within parentheses) are as follows: *Afrocyclops* Sars (1), *Anzcyclops* Karanovic, Eberhard & Murdoch (1), *Apocyclops* Lindberg (3), *Brevicyclops* Totakura & Ranga Reddy (3), *Bryocyclops* Kiefer (2), *Cryptocyclops* Sars (2), *Cyclops* O. F. Müller (3), *Diacyclops* Kiefer (1), *Ectocyclops* Brady (3), *Eucyclops* Claus (11), *Halicyclops* Norman (7), *Haplocyclops* Kiefer (3), *Macrocyclops* Claus (3), *Megacyclops* Kiefer (1), *Mesocyclops* Sars (10), *Metacyclops* Kiefer (4), *Microcyclops* Claus (10), *Paracyclops* Claus (3), *Rybocyclops* Dussart (2), *Thermocyclops* Kiefer (8), and *Tropocyclops* Kiefer (5). The species of *Mesocyclops* and *Thermocyclops* are very common in freshwater plankton. In addition, the family Oithonidae has two genera, viz. *Oithona* Baird (2) and *Dioithona* Kiefer (1), the Cyclopinidae and Cyclopettidae have one genus each, viz. *Allocyclopina* Kiefer (1) and *Paracyclopina* (4). The species of the last-mentioned three families generally occur in brackish interstitial conditions of river banks or lakes, but rarely in the plankton community.

Order HARPACTICOIDA Sars

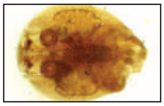
Harpacticoids are principally benthic organisms. Those inhabiting the sediment can be classified as interstitial, burrowing or epibenthic forms. The order Harpacticoida has nearly 50 families, with about 1,200 species occurring in freshwater as well as brackish continental waters in the world.

The Indian freshwater/somewhat brackish water taxa (family followed the genus/genera, with species number within parentheses) are listed here.

Ectinosomatidae Sars: *Ectinosoma* Boeck (1); *Maraenobiotus* (2), *Rangabradya* Karanovic and Pesce (1). Canthocamptidae Sars (most common in freshwater): *Bryocamptus* Chappuis (3); *Elaphoidella* Chappuis (15); *Mesochra* Boeck (3). Parastenocarididae Chappuis is a recently discovered family in India. Its taxa typically exist in the freshwater interstitial/porous aquifers of rivers and streams, and only some in phreatic waters of caves and wells: *Parastenocaris* Kessler (10), *Kinnecaris* Jakobi (1), *Siolicaris* Jakobi (1), *Himalayacaris* Ranga Reddy, Totakura & Corgosinho (1), *Indocaris* Ranga Reddy, Totakura & Shaik (3), *Proserpinicaris* Jakobi (2), and *Dussartstenocaris* Karanovic & Cooper (1). The family Ameiridae Monard is primarily marine/brackish water, benthic as well as interstitial: *Nitocra* Boeck (4) and *Nitocrella* Chappuis (1). The Diosaccidae Sars has representatives distributed in marine/brackish interstitial zones and also phreatic freshwaters: genus *Delavalia* Brady (3); genus *Neomiscegenus* Karanovic and Ranga Reddy (1). Interestingly, two species of *Delavalia*, viz. *D. madrasensis* and *D. longifurca*, described, respectively, from the Madras (now Chennai) coast and the typically brackish Chilka Lake, have established themselves as members of freshwater benthos in Andhra Pradesh. Obviously, they invaded the rivers via the river mouths, and then radiated through a network of canals into village tanks. The Phyllognathopodidae Gurney is primitive and phylogenetically important family, it species occurring in freshwater interstitial/phreatic waters: *Phyllognathopus* (1) and *Neophyllognathopus* (1). The Harpacticidae Sars is a principally a marine family with some of its species inhabiting inland waters, and known in India by genus *Harpacticella* Sars (1) from Chilka Lake. The Laophontidae Scott is principally a marine family, with some of its representatives occasionally found in fresh water/somewhat brackish conditions, e. g. *Folioquinpes* Fiers & Rutledge (1), *Heterolaophonte* Lang (1), *Onychocamptus* Daday (2), and *Paronychocamptus* Lang (1). The Cletodidae Scott is mainly a brackish water/marine family, with its species rarely found in slightly brackish conditions of lakes, etc: *Kollerua* Gee (1), *Cletocamptus* Schmankevitsch (1); and *Limnocletodes* Borutzky (2)– all found in Lake Kolleru. The family Darcythompsoniidae Lang is known by the genus *Leptocaris* Scott (1); *L. brevicornis* is the lone Indian species, rarely found in freshwater and brackish waters. In all, 66 species in 29 genera are presently known from the Indian inland waters.

In conclusion, the free-living inland water Copepoda is so far known only by about 200 species in 60 genera in India. This indeed represents only a minor fraction of the total copepod diversity that is yet to be explored in the country. As for the freshwater calanoids, the northeastern States deserve special attention. Further, the faunistic investigations of the vast freshwater subterranean realm of the country are almost completely neglected excepting the deltaic zone of the Krishna-Godavari basin in southeastern peninsular India. It is now established in the West that the faunal diversity of freshwater subterranean domain is no less than that of the epigean inland waters. This deserves the due attention of the funding agencies, researchers, policy makers and land managers in the country.

Chapter 17



CRUSTACEA : BRANCHIURA : ARGULIDAE (FISHLICE)

K. VALARMATHI

ABSTRACT

Argulids are a group of primarily freshwater parasitic crustaceans commonly known as 'carp-lice' or 'fish lice' and are ectoparasites of fishes primarily but occasionally live on amphibians or invertebrates. The Family Argulidaea comprises four genera namely *Argulus, Dipteropeltis, Chonopeltis, Dolops*. Out of these four genera only the genus *Argulus* is represented by 17 species and one sub species in India of which 14 species and one sub species are freshwater inhabitants. Among the17 species and one sub species of Indian Argulids and 10 species and one subspecies are exclusively available only in India.

Keywords: Argulidae, Argulus, Branchiura, Freshwater, India

INTRODUCTION

The (sub) class Branchiura is a group of primarily freshwater parasitic crustaceans commonly known as 'carp-lice' or 'fish lice' and are primarily ectoparasites of fishes but occasionally live on amphibians or invertebrates, and they can move about freely on their hosts (Poly, 2008, Moller, 2015, Dev Roy, 2015). They are obligate parasites and utilize many different fish hosts from a wide range of families, e.g. carps, sticklebacks, perch, roach, and even predators such as pike (Moller, 2015). They occasionally increase in number and cause fish mortality in aquaculture operations, aquaria of ornamental fishes and rarely in wild populations (Nandi and Das, 1991, Dev Roy, 2015, Saha, 2016). The subclass Branchiura contains a single family, the Argulidae, and four valid genera namely *Argulus* Müller, *Chonopeltis* Thiele, *Dipteropeltis* Calman, and *Dolops*. According to Worms the genus *Argulus* is represented by 127 species, the genus *Chonopeltis* is having 15 species, *Dipteropeltis* is represented by only 2 species and the *Dolops* with 13 species at global level. Among the four genera of Branchiura only the genus *Argulus* was reported from India with 18 species of which 15 species were from freshwater fishes.

Review of literature

The first report of Indian Branchiura of was made by Southwell (1915) who reported *Argulus foliaceous* from the skin of *Labio rohita* in Bengal Fisheries. Later Hora (1943) also reported this species from the then Bengal. Ramakrishna (1951) described *A. bengalensis* from West Bengal, *A. giganteus* from Andhra Pradesh

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and a variety of *A. siamensis* namely *A. siamensis peninsularis*. From Madhya Pradesh, Malaviya (1955, 1958) reported *A. siamensis peninsularis*. *A.indicus.* Again Ramakrishna (1959) added *A. puthanvaliensis* from Kerala. From Bangalore Sundari Bai (1973) reported *A. siamensis,* where as Sreenivasan (1976) reported *A. japonicas* from Tamilnadu. *A. boli* and *A.parsi* were described by Tripathi (1975) from river Son at Dehri-on-son and river Hoogly near Kolkata. Simultaneously Thomas and Devaraj (1975) described *A. cauveriensis* from River Cauvery. From Tamilnadu, Devaraj and Hamsa (1977) described *A. quadristriatus* as new species. Natarajan (1982) added a new species *A. mangalorensis* from Karnataka. Omprakasam and Manohar (1992) described *A. krishnangiriensis* from Indian major carps the exact locality is not known but the species name is not available in the World Register of Marine species. For the first time from Punjab, Brar and Battish (1993) reported the occurrence of *A. bengalensis, A. indicus, A. monadi, A. schoutedeni and A. siamensis*. Mallick *et al.* (2010) noticed the occurrence of *Argulus* sp. on Indian Snow Trouts in a subtropical Himalayan Lake of Bhimtal, Uttarakhand. Dev Roy (2015) provided a synaptic list of Indian Argulids. Saha and Bandyopadhyay (2015) observed the infection of three species of *Argulus* namely *A. coregoni, A. japonicas*, and *A. foliaceus* infecting Oranda gold fish (*Carassius auratus auratus*) in West Bengal and affecting their marketing value.

Diversity, Distribution and Endemism

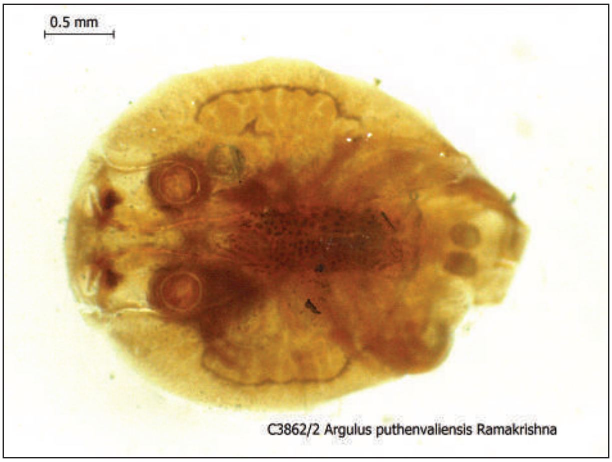
The Branchiurans contain four genera. The genus *Dipteropeltis* contains two valid species and occurs in South America; *Chonopeltis* has 15 valid species and is found only in Africa; and *Dolops,* with 14 valid species, has a Gondwanan distribution (South America, Africa, and Tasmania; Fryer 1969; Poly, 2009; Worms, 2017). The genus *Argulus* contains about 129 valid species and occurs on or around all continents, except Antarctica, in marine, estuarine, and freshwater habitats and nearly 85 species are reported from freshwater (Poly, 2009). Out of the four genera of Branchiurans only the genus *Argulus* is represented by 17 species and one sub species in India of which 14 species and one sub species are freshwater inhabitants. Among the17 species and one sub species of Indian Argulids and 10 species and one subspecies are exclusively available only in India (Dev Roy, 2015).

LIST OF SPECIES AVAILABLE IN INDIA

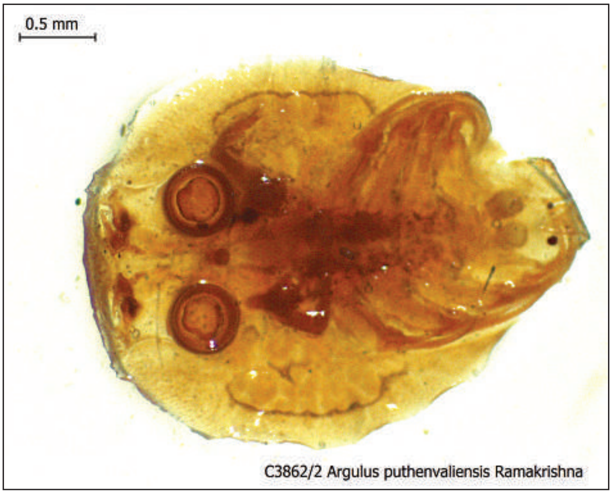
1. *Argulus bengalensis* Ramakrishna, 1951*
2. *Argulus boli* Tripathi, 1975*
3. *Argulus cauveriensis* Thomas and Devaraj, 1975*
4. *Argulus coregoni* Thorell, 1865
5. *Argulus fluviatilis* Thomas & Devaraj, 1975*
6. *Argulus foliaceus* (Linnaeus, 1758)
7. *Argulus indicus* Weber, 1892
8. *Argulus japonicas* Thiele, 1900
9. *Argulus krishnagiriensis* Omprakasam and Manohar, 1992*
10. *Argulus mangalorensis* Natarajan, 1982 (Back Water)*

11. *Argulus monodi* Fryer, 1959
12. *Argulus parsi* Tripathi*
13. *Argulus puthenveliensis* Ramakrishna, 1959*
14. *Argulus quadristriatus* Devaraj & Ameer Hamsa, 1977 (Marine)*
15. *Argulus schoutedeni* Monod, 1928
16. *Argulus siamensis* Wilson C.B., 1926
17. *Argulus siamensis peninsularis* Ramakrishna, 1951*
18. *Argulus vittatus* (Rafinesque-Schmaltz, 1814) (Marine)*

(Source: Modified and updated after Dev Roy, 2015; *species available only in India)



Dorsal



Vental

Argulus puthenveliensis Ramakrishna, 1959 (Dorsal and Ventral view)

Significance

Argulids are obligate ectoparasites of fishes, unlike other aquatic parasites, they retain the ability to swim freely throughout the whole of their life and quickly increase in number, their uncontrolled proliferation leads to a disease called argulosis. The *Argulus*-infected fish have reduced feeding, reduced growth rate and behavioral changes, a significantly reduced growth rate, and loss of physical condition makes them susceptible to stress and secondary infection (Mikheev *et al.*, 2015; Saha *et al.*, 2015, De Zoysa, 2017). As these ectoparasites repeatedly change their hosts and inflict skin damage, they can act as vectors for fish pathogens (Mikheev *et al.*, 2015). They are known to affect both wild and cultured fishes and cause fish mortality which leads to the economic loss in fishery industries. Hora, (1943) noticed the infection of fish louse *Argulus foliaceous* causing the heavy mortality among carp fisheries of Bengal. Prabavathy and Sreenivasan (1976) reported the occurrence of *Argulus japonicus* in brood fish ponds in Tamil Nadu. Nandi and Das (1991) observed the juvenile mortality in some fishes at Kakdwip, West Bengal due to argulosis. Both modern and indigenous techniques are used to control these fish pathogens.

ACKNOWLEDGMENTS

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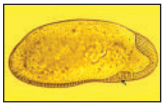
Chapter 18



CRUSTACEA: OSTRACODA (SEED SHRIMPS)

KARUTHAPANDI, M. AND RAO, D.V.

ABSTRACT

So far about 154 species of freshwater ostracods belonging to 05 families, 40 genera have been documented from India. The family Cyprididae representing 78%, Notodromadidae 9%, Candonidae 8%, Ilyocyprididae 4% and Darwinulidae 1% of species. The oriental zoogeographic region has 200 species, of which 58% of species are endemic to India. There are several new species described in the past few decades from the Indian subcontinent by various workers, but the descriptions of most of the species seem to be insufficient to give the status of new species. Hence, the recent studies emphasizes that there is a need for further extensive exploration and revision on Indian freshwater ostracods as many species have not been described completely and no much information on uncertain species.

Keywords: Freshwater Ostracods, Diversity and Distribution in India.

INTRODUCTION

Ostracods are commonly known as "seed shrimps". They are microscopic and one of the most diverse organisms in Crustacean and exist in all aquatic ecosystems, *viz*. marine, brackish and freshwater including subterranean waters. Their most important feature is presence of a bivalve carapace that can completely enclose a laterally compressed and weakly segmented body. Globally, 2103 species of freshwater ostracods were documented (Martens and Savatenalinton, 2011). They play a vital role in food chain and energy flow in the aquatic ecosystem (Altmsach *et al.,* 2014). Ostracod taxonomy has been of great interest because of their possible use as indicators in climate and environmental change, due to their specific ecological preference and tolerance (Kulkoyluoglu, 2003). Their diversity, abundance and seasonal fluctuations have a direct link with water quality (Tiwari and Mishra, 1985; Padmanabha and Belagali, 2008).

The taxonomic study on Indian Ostracods was first initiated by Baird (1859). Later Victor and Fernando (1979) listed about 56 freshwater ostracod species from India. Subsequently, Venkataraman and Krishnamoorthy (1998) reported 120 species of ostracods from freshwater and marine habitats, which include four families and 24 genera. The literature analysis reveals that there are several new species described in the past few decades from the Indian subcontinent by various workers like Baird (1859), Gurney (1907), Klie (1927), Arora (1931), Brehm (1950), Hartmann (1964), Deb (1972, 1973a,b,c, 1983), Victor and Michael (1975), Victor and Fernando (1979, 1981), Battish (1978, 1998, 2000), Harshey

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and Victor (1983), Harshey and Shrivastava (1983), Gupta (1984, 1988 and 1991), Harshey and Srinivasan (1984), Harshey *et al.,* (1987), Harshey and Patil (1988), Harshey (1996, 2008), George *et al.* (1993), Jayasree *et al.* (1994) Venkataraman and Krishnamoorthy (1998), Patil (2002), George and Martens (2002, 2003, 2004), Patil and Talmale (2005a,b, 2012), Karanovic and Reddy (2008) and Harshey and Thilak (2011). The current status of the species nomenclature and their validity was reviewed by Kauthapandi *et al.,* 2014. The present communication provided a compiled valid list, diversity and distribution of Indian freshwater Ostracods.

Methodology

There are different techniques and equipment available for their collection and studies. Generally, Ostracods are collected from the littoral regions of the water bodies by using zooplankton net (64µm mesh size). The collections must be stored in 100ml plastic containers, preserved with 4% formalin solution and properly labeled with all collection details for laboratory studies. A single individual of each species has to be picked up from sample and keep on a clean slide containing water and glycerin (1:1 ratio) or propylene glycol for dissection under the stereo zoom binocular microscope. The carapace of the Ostracod should be separated out and preserved in a cavity slide or a vial and the soft internal organs need to be mounted on the slides for further studies under a compound light microscope and the taxonomical characteristic features need to be drawn by using camera lucida. The identification of the species should be made following standard literatures. The collections need to be preserved in 75% ethyl alcohol or in 96% ethyl alcohol in case the material is needed for the DNA studies.

Habit and Habitat

Ostracods live in all aquatic environments like rivers, lakes, ponds, rice fields, small pools and puddles, ground waters, springs, and wet leaf litter. They are mainly colonized benthic and periphytic habitats and feed on both living and detrital particles including organic detritus, algae, plant material, dead animals and sometimes live animals such as young snails, worms and larvae of other crustaceans. More rarely, they can be predators or parasites (Rossettil *et al.,* 2006). Stagnant water especially, lakes, reservoirs, temporary water and small pools hold more diversity. Ostracods use their antennae, mandibles, maxillulae and in some groups, the fifth limbs to feed. They are bisexual, even through parthenogenesis is a very common way of reproduction. Growth is characterized by a number of molts. Podocopids have nine instars (Karanovic, 2012).

Morphology

They are usually around 0.3 to 5 mm in length, body is covered by bivalved calcified carapace that covers and protects the non-mineralised body parts and appendages. The surface of the carapace ornamented with pits, striations, spines, ridges, flanges etc. Inside the carapace have a complex body consisting of typically eight pairs of appendages (Fig. 3,4,6). The carapaces originate from the head region, and are hinged along the dorsal margin. The valves are closed by the adductor muscles, which are attached directly to each valve usually just anterior of the mid-length of the animal. These attachment points are called the adductor muscle scars, often seen through external side of the carapace. Antennula, antenna, and eyes are situated on the forehead. Mandibula and maxillula are connected to the upper margin of the lower lip with chitinous supports. Other appendages in the body are also connected to the body and with each other by a network of chitinous rods. Attachment of the uropodal ramus is by far the most apparent of all other attachments in the body, and is often used in the taxonomy of freshwater ostracods (Karanovic, 2012).

Classification

Ostracods are considered as a separate class under Crustacea and it has been divided into the subclasses Myodocopa (only marine representatives) and Podocopa (Martin and Davis 2001; Horne *et al.,* 2002). The subclass Podocopa has the following three orders: Platycopida, which includes marine and a very few brackish water forms; Podocopida which is present in both freshwater and the marine environment; and Palaeocopida known only from fossils records (Karanovic 2012). All the freshwater ostracod belongs to Podocopida are very common in most of the inland waters (Meisch, 2000).

Kingdom ANIMALIA
Phylum ARTHROPODA
Subphylum CRUSTACEA
Class OSTRACODA

<table>
<tr><th>Subclass</th><th>Order</th><th>Suborder</th><th>Superfamily</th><th></th></tr>
<tr><td rowspan="10">Podocopa</td><td rowspan="8">Podocopida</td><td rowspan="2">Cytherocopina</td><td>Cytheroidea (27 families)</td><td rowspan="8">Both freshwater and marine</td></tr>
<tr><td>Terrestricytheroidea (1 family)</td></tr>
<tr><td rowspan="3">Cypridocopina</td><td>Macrocypridoidea (1 family)</td></tr>
<tr><td>Pontocypridoidea (1 family)</td></tr>
<tr><td>Cypridoidea (4 families)</td></tr>
<tr><td>Darwinulocopina</td><td>Darwinuloidea (1 family)</td></tr>
<tr><td>Bairdiocopina</td><td>Bairdioidea (3 families)</td></tr>
<tr><td>Sigilliocopina</td><td>Sigillioidea (1 family)</td></tr>
<tr><td>Platycopida</td><td>Platycopina</td><td>Cytherelloidea (1 family)</td><td>Marine and a very few brackish water forms</td></tr>
<tr><td>Palaeocopida</td><td>Kirkbyocopina</td><td>Puncioidea (1 genus)</td><td>Fossil Records</td></tr>
<tr><td rowspan="6">Myodocopa</td><td rowspan="3">Myodocopida</td><td rowspan="3">Myodocopina</td><td>Cypridinoidea (1 family)</td><td rowspan="6">Only marine representatives</td></tr>
<tr><td>Cylindroleberidoidea (1 family)</td></tr>
<tr><td>Sarsielloidea (3 families)</td></tr>
<tr><td rowspan="3">Halocyprida</td><td rowspan="2">Halocypridina</td><td>Thaumatocypridoidea (1 family)</td></tr>
<tr><td>Halocypridoidea (1 family)</td></tr>
<tr><td>Cladocopina</td><td>Cladocopoidea (1 family)</td></tr>
</table>

Classification of Podocopid (Freshwater Ostracods)

Class OSTRACODA Latreille 1802

Subclass MYODOCOPA Sars 1866 m

Order MYODOCOPIDA Sars 1866

Suborder MYODOCOPINA Sars 1866

Order HALOCYPRIDA Dana 1852

Suborder HALOCYPRIDINA Dana 1852

Suborder CLADOCOPINA Sars 1866

Subclass PODOCOPA Sars 1866 m/f

Order PLATYCOPIDA Sars 1866 m

Order PODOCOPIDA Sars 1866 m/f

Suborder BAIRDIOCOPINA Sars 1866 m

Superfamily Bairdioidea Sars 1866

Family Bairdiidae Sars 1866

Family Bythocyprididae Maddocks 1969

Suborder Cytherocopina Baird 1850 m/f

Superfamily Cytheroidea Baird 1850 m/f

Family Bythocytheridae Sars 1866 m

Family Cobanocytheridae Schornikov 1975 m

Family Cuneocytheridae Mandelstam 1959 m

Family Cushmanideidae Puri 1974 m

Family Cytherettidae Triebel 1952 m

Family Cytheridae Baird 1850 m

Family Cytherideidae Sars 1925 m/f

Family Cytheromatidae Elofson 1938 m

Family Cytheruridae Muller 1894 m/f

Family Entocytheridae Hoff 1942 f

Family Eucytheridae Puri 1954 m

Family Hemicytheridae Puri 1953 m/f

Family Kliellidae Schafer 1945 f

Family Krithidae Mandelstam 1960 m

Family Leptocytheridae Hanai 1957 m/f

Family Limnocytheridae Klie 1938a f

Family Loxoconchidae Sars 1925 m/f

Family Microcytheridae Klie 1938a m

Family Neocytheridae Puri 1957 m

Family Paracytherideidae Puri 1957 m

Family Paradoxostomatidae Brady and Norman 1889 m

Family Parvocytheridae Hartmann 1959 m

Family Pectocytheridae Hanai 1957 m

Family Psammocytheridae Klie 1938a m

Family Schizocytheridae Howe 1961 m

Family Trachyleberididae Sylvester-Bradley 1948 m

Family Xestoleberididae Sars 1928 f/m

Superfamily Terrestricytheroidea Schornikov 1969 m

Family Terrestricytheridae Schornikov 1969

Suborder Darwinulocopina Sohn 1987 f

Superfamily Darwinuloidea Brady and Norman 1889

Family Darwinulidae Brady and Norman 1889

Suborder Cypridocopina Jones 1901 m/f

Superfamily Cypridoidea Baird 1845 m/f

Family Candonidae Kaufmann 1900a m/f

Family Cyprididae Baird 1845 f

Family Ilyocyprididae Kaufmann 1900 f

Family Notodromadidae Kaufmann 1900 f

Superfamily Macrocypridoidea Muller 1912 m

Family Macrocyprididae Muller 1912

Superfamily Pontocypridoidea Muller 1894 m

Family Pontocyprididae Muller 1894

Suborder Sigilliocopina Martens 1992 m

Superfamily Sigillioidea Mandelstam 1960

Family Sigilliidae Mandelstam 1960

f- Freshwater, m- Marine, f/m- Both freshwater and maine

Classification provided by Horne, D.J., Cohen, A. and Martens, K. 2002; Martens and Savatenalinton, 2011; Karanovic, 2012

Systematic List of Ostracod fauna of India

Class OSTRACODA Latreille 1802

Subclass PRODOCOPA G.W. Müller, 1894

Order PODOCOPIDA Sars 1866

Suborder CYPRIDOCOPINA Jones 1901

Super family CYPRIDOIDEA Baird 1845

Family CYPRIDIDAE

Subfamily CYPRETTINAE

1. *Cypretta alagarkoilensis* Victor & Michael, 1975
2. *Cypretta fontinalis* Hartman, 1964

3. *Cypretta foveata* Hartmann, 1964
4. *Cypretta gargi* Deb, 1983
5. *Cypretta globosa* (Brady, 1886)
6. *Cypretta globula* (Sars, 1889)
7. *Cypretta patialaensis* Battish, 1982
8. *Cypretta raciborskii* (Grochmalicki, 1915)
9. *Cypretta ramai* Deb, 1984
10. *Cypretta seurati* Gauthier, 1929
11. *Cypretta turgida* Sars, 1896
12. *Pseudocypretta maculata* Klie, 1932

Subfamily CYPRICERCINAE

13. *Astenocypris papyracea* (Sars, 1903)
14. *Bradleycypris vittata* (Sars, 1903)
15. *Bradleystrandesia dani* (George & Martens,1993)
16. *Bradleystrandesia mollis*(Furtos, 1936)
17. *Bradleystrandesia parva* (Hartmann, 1964)
18. *Bradleystrandesia reticulata* (Zaddach, 1844)
19. *Bradleystrandesia trichurensis* (Victor et al.,1980)
20. *Bradleystrandesia weberi* (Moniez, 1892)
21. *Bradleytriebella tuberculata* (Hartmann, 1964)
22. *Cypricercus indrani* Deb, 1983 #
23. *Cypricercus munshii* Deb and Nasar, 1977 #
24. *Cypricercus steosus* Farkas, 1857
25. *Cypricercus vietsi* Farkas, 1957
26. *Strandesia antetuberculata* Hartmann & Petersen, 1985
27. *Strandesia bicornuta* Hartmann, 1964
28. *Strandesia flavescens* Klie, 1932
29. Str*andesia calapanensis* Tressler, 1937
30. *Strandesia gopinathani* George & Martens, 1993
31. *Strandesia hartmanni* Victor et al., 1980
32. *Strandesia labiata* Hartmann, 1964
33. *Strandesia madhuriae* Harshey & Srinivasan 1984
34. *Strandesia odiosa* (Moniez, 1892)
35. *Strandesia perakensis* Victor & Fernando, 1981
36. *Strandesia bornemiszai* Klie, 1935
37. *Strandesia pupurascens* (Brady, 1886)
38. *Strandesia quasirotunda* Hartmann & Petersen, 1985

39. *Strandesia vinciguerrae* (Masi, 1905)
40. *Strandesia saetosa* Hartmann, 1964
41. *Strandesia victori* Harshey & Srinivasan, 1984
42. *Tanycypris pellucida pellucida* (Klie, 1932)

Subfamily CYPRIDINAE

43. *Cypris debi* Deb, 1983 #
44. *Cypris decaryi* Gauthier, 1933
45. *Cypris dravidensis* Victor & Michael, 1975 #
46. *Cypris elongata* Deb, 1983 #
47. *Cypris globosa* Deb, 1983 #
48. *Cypris kumari* (Arora, 1931) #
49. *Cypris protubera* Victor & Fernando, 1978 #
50. *Cypris subglobosa* Soweby, 1840
51. *Pseudocypris patialaensis* Battish, 1977

Subfamily CYPRIDOPSINAE

52. *Cypridopsis maduraiensis* Victor & Michael, 1975
53. *Klieopsis horai* (Klie, 1927)
54. *Plesiocypridopsis angularis* (Victor & Michael, 1975)
55. *Plesiocypridopsis dispar* (Hartmann, 1964)
56. *Plesiocypridopsis newtoni* (Brady & Robertson, 1870)
57. *Potamocypris dubia* (Masi, 1905)
58. *Potamocypris narayanani* George & Martens, 2002
59. *Sarscypridopsis ochracea* (Sars, 1924)

Subfamily CYPRINOTINAE

60. *Cyprinotus cingalensis* Brady, 1886
61. *Hemicypris anomala* (Klie, 1938)
62. *Hemicypris arorai* (Battish, 1981)
63. *Hemicypris bairdi* Martens & Wouters 1985
64. *Hemicypris bhatiai* Battish, 1981
65. *Hemicypris dentatomarginatua* (Baird, 1859)
66. *Hemicypris derweshensis* Battish, 1981
67. *Hemicypris dissonus* Victor & Fernando, 1976
68. *Hemicypris falcatus* Victor & Fernando 1976
69. *Hemicypris gillensis* (Battish, 1981)
70. *Hemicypris malerkotlaensis* Battish, 1981
71. *Hemicypris megalops* Sars, 1903
72. *Hemicypris ovata* Sars, 1903

73. *Hemicypris pailensis* Battish, 1981
74. *Hemicypris pyxidata* (Moniez, 1892)
75. *Heterocypris anitae* Battish, 1981
76. *Heterocypris aurea* Sars, 1895
77. *Heterocypris chandrai* (Arora, 1931)
78. *Heterocypris fluviatilis* (Furtos, 1933)
79. *Heterocypris giesbrechti* (G.W. Müller, 1898)
80. *Heterocypris incongruens* (Ramdohr, 1808)
81. *Heterocypris indica* (Battish, 1981)
82. *Heterocypris makua* (Tressler, 1937)
83. *Heterocypris malini* Deb, 1983
84. *Heterocypris nuda* (Victor & Michael, 1975)
85. *Heterocypris salina* (Brady, 1868)

Subfamily: **Dolerocypridinae**

86. *Dolerocypris sinensis* Sars, 1903

Subfamily: **Eucypridinae**

87. *Eucypris biharensis* Deb, 1984
88. *Eucypris bispinosa* (Victor & Michael, 1975)
89. *Eucypris compressa* Deb, 1983
90. *Eucypris ellipticalis* Deb, 1983
91. *Eucypris gomti* Deb, 1983
92. *Eucypris himani* Deb, 1983
93. *Eucypris indica* Deb, 1983
94. *Eucypris inaequalis* Deb, 1983
95. *Eucypris munia* Deb, 1983
96. *Eucypris sonia* Deb, 1983

Subfamily: **Herpetocypridinae**

97. *Chrissia achandii* (George & Martens, 1993)
98. *Chrissia biswasi* (Deb, 1972)
99. *Chrissia canaliculata* (Hartmann, 1964)
100. *Chrissia dyalpurensis* Battish, 1998
101. *Chrissia fasciculata* (Daday, 1910)
102. *Chrissia formosa* (Klie, 1938)
103. *Chrissia fuelleborni* (Daday, 1910)
104. *Chrissia goddeerisi* (George et al., 1993)
105. *Chrissia halyi* (Ferguson, 1969)
106. *Chrissia hislopi* (Ferguson, 1969)

107. *Chrissia humilis* (Klie, 1932)
108. *Chrissia humilis indica* Hartmann, 1964
109. *Chrissia khopoliensis* (Deb, 1983)
110. *Chrissia krishnakantai* (Deb, 1972)
111. *Chrissia spinosa* (Tressler, 1937)
112. *Herpetocypris ludhianensis* Battish, 1982
113. *Humphcypris sewelli* (Klie, 1927)
114. *Stenocypris derupta* Vavra, 1906
115. *Stenocypris distincta* Victor & Fernando, 1978
116. *Stenocypris jabalpurensis* Harshey & Patil, 1988
117. *Stenocypris major* (Baird, 1859)
118. *Stenocypris sohni* Deb, 1983
119. *Stenocypris simulans* Rome 1965

Subfamily MEGALOCYPRIDINAE

120. *Sclerocypris rajasthaniensis* (Deb, 1973)

Family CANDONIDAE

Subfamily CANDONINAE

121. *Candonopsis* (*Candonopsis*) *putealis* Klie, 1932
122. *Candonopsis* (*Candonopsis*) *urmilae* Gupta, 1988
123. *Fabaeformiscandona subacuta* (Yang, 1982)
124. *Indocandona krishnakanti* Gupta, 1984
125. *Indocandona nagarjuna* Karanovic & Ranga Reddy, 2008

Subfamily Cyclocypridinae

126. *Cypria brevisetigera* Cole, 1965
127. *Cypria devai* (Arora, 1931)
128. *Cypria javana javana* G.W. Müller, 1906
129. *Cypria minutua* (Victor & Michael, 1975)
130. *Cypria sharmai* Battish, 1985
131. *Physocypria armata* (G.W. Muller, 1897)
132. *Physocypria crenulata* (Sars, 1903)
133. *Physocypria furfuracea* (Brady, 1886)

Family ILYOCYPRIDIDAE

Subfamily ILYOCYPRIDINAE

134. *Ilyocypris australiensis* Sars, 1889
135. *Ilyocypris bradyi* Sars, 1890
136. *Ilyocypris dentifera* Sars, 1903
137. Ilyocyipris *gibba* (Ramdohr, 1808)

138. *Ilyocypris mckenziei* Bhatia & Mannikeri, 1975

139. *Ilyocypris nagamalaiensis* Victor & Michael, 1975

Family NOTODROMADIDAE

Subfamily INDIACYPRIDINAE

140. *Indiacypris chalakkudensis* George & Martens, 2004

141. *Indiacypris dispar* Hartman, 1964

Subfamily Notodromadinae

142. *Centrocypris bhagirathiae* Battish, 1981

143. *Centrocypris horrida* (Vavra, 1895)

144. *Centrocypris indica* Gupta, 1991

145. *Centrocypris madani* Battish, 1981

146. *Centrocypris matthaii* (Arora, 1931)

147. *Gurayacypris kangraensis* Battish, 1987

148. *Newnhamia dumonti* George & Martens, 2004

149. *Newnhamia fenestrata* King, 1855

150. *Notodromas serrata* Deb, 1984

Subfamily ONCOCYPRIDINAE

151. *Oncocypris bhatiai* Battish, 1982

152. *Oncocypris voeltzkowi* G.W. Muller, 1898

153. *Sataracypris gibbosa* (Baird, 1837) #

Super family DARWINULOIDEA

Family DARWINULIDAE

154. *Darwinula stevensoni* (Brady & Robertson, 1885)

Uncertain species

Diversity of Ostracods

Globally, freshwater ostracods were documented and classified under the order Podocopida, which contains three superfamilies, 15 families, 209 genera and 2103 species (Martens *et al.,* 2008; Martens and Savatenalinton, 2011; Karanovic, 2012). In India, about 154 species of ostracods belonging to five families, two super families and 40 genera were documented from freshwater habitat (Tables 1, 2). It constitute 78% Cyprididae, 9% Notodromadidae, 8% Candonidae, 4% Ilyocyprididae and 1% Darwinulidae. Among the global species, 87 species (4.13%) were originally described from India (Fig.1, 2). There are many species status consisted to be uncertain which is marked with hash sign (#) in the systematic list. About 50 species earlier reported from India have been synonymised (Martens and Savatenalinton 2011; Karanovic 2012) and their current valid nomenclature was provided by Karuthapandi *et al.,* 2014. In a recent study we have collected and documented two more species *Fabaeformiscandona subacuta* and *Stenocypris simulans* which are new to India.

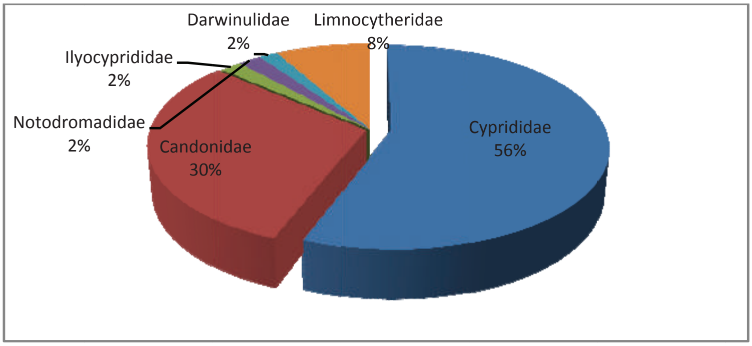

Fig. 1. Global Ostracoda Family percentage

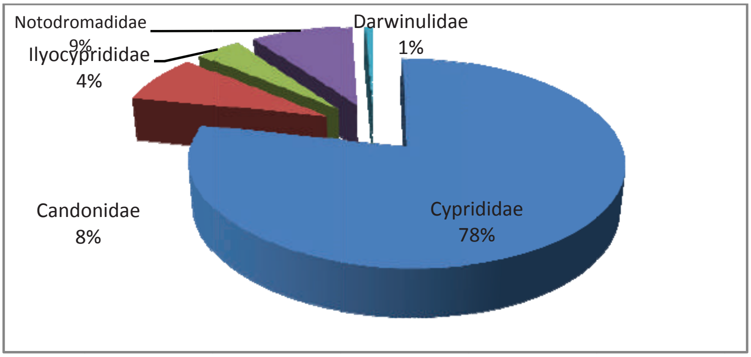

Fig. 2. Family-wise ostracoda species percentage from India

Table 1. Current Status of the Freshwater Ostracoda of the world and India

Sl. No		World	Oriental region	India
1	Superfamilies	04	1	2
2	Families	15	06	5
3	Subfamilies	34	16	15
4	Genus	209	46	40
5	Species	2103	200	154

Table 2. Family wise ostracoda species account from India

Sl. No	Families	World	Oriental region	India
1	Cyprididae	998	154	120
2	Candonidae	545	17	13
3	Ilyocyprididae	33	08	6
4	Notodromadidae	36	15	14
5	Darwinulidae	29	04	1
6	Limnocytheridae	144	01	-
7	Laxoconchidae	04	01	-

(World and Oriental region data source from Martens *et al.*, 2008)

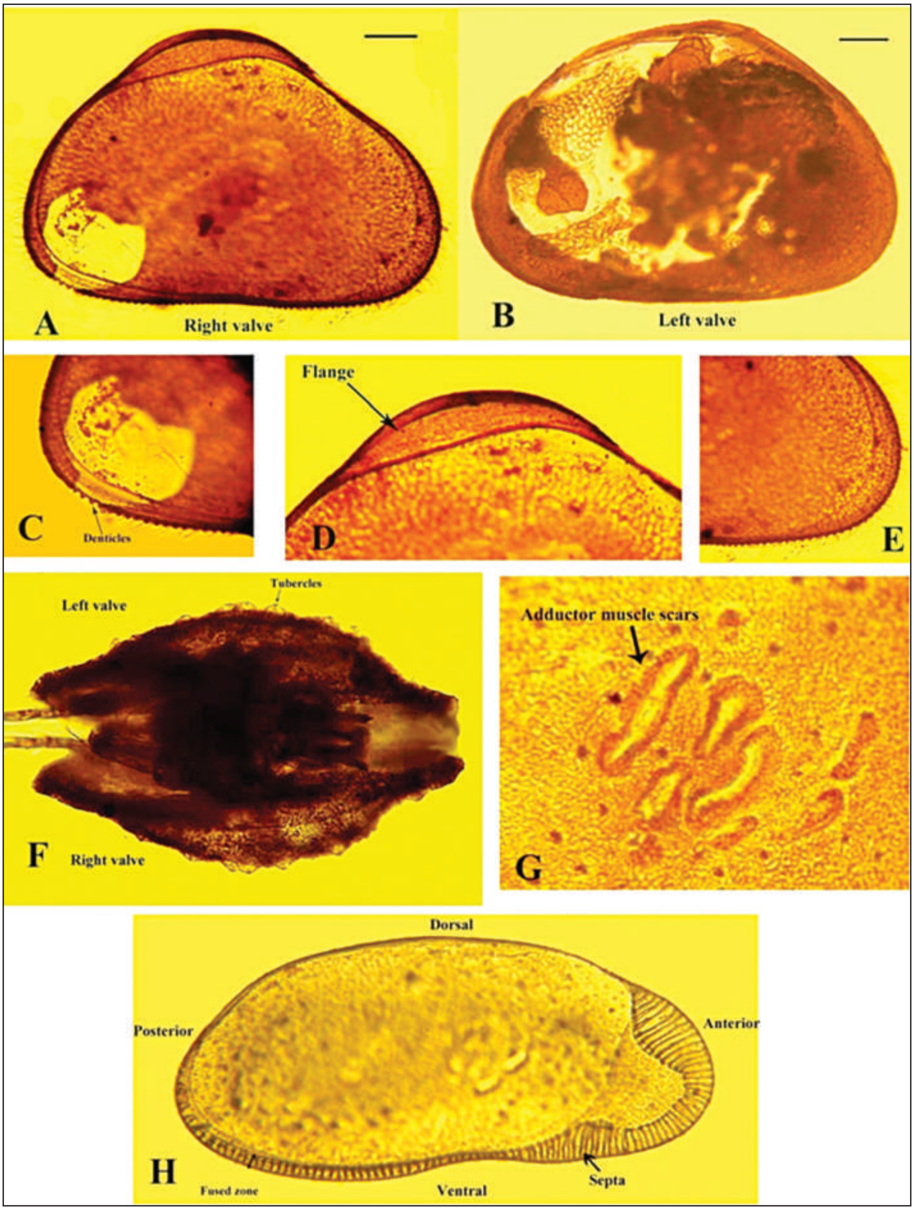

Fig. 3. Carapace morphology

There are several new species described in the past few decades from the Indian subcontinent by various workers, but the descriptions of most of the species seem to be insufficient to give the status of new species. Although most Indian taxonomists emphasized carapace morphology in ostracod identification, recent taxonomi8c studies highlighting the morphology of soft parts also which is crucial for their proper systematic placement. It is also observed that most of the species reported from India lack voucher and type locality information, which additionally contributes to the instability of the current Ostracoda nomenclature and validity of the species Karanovic (2012).

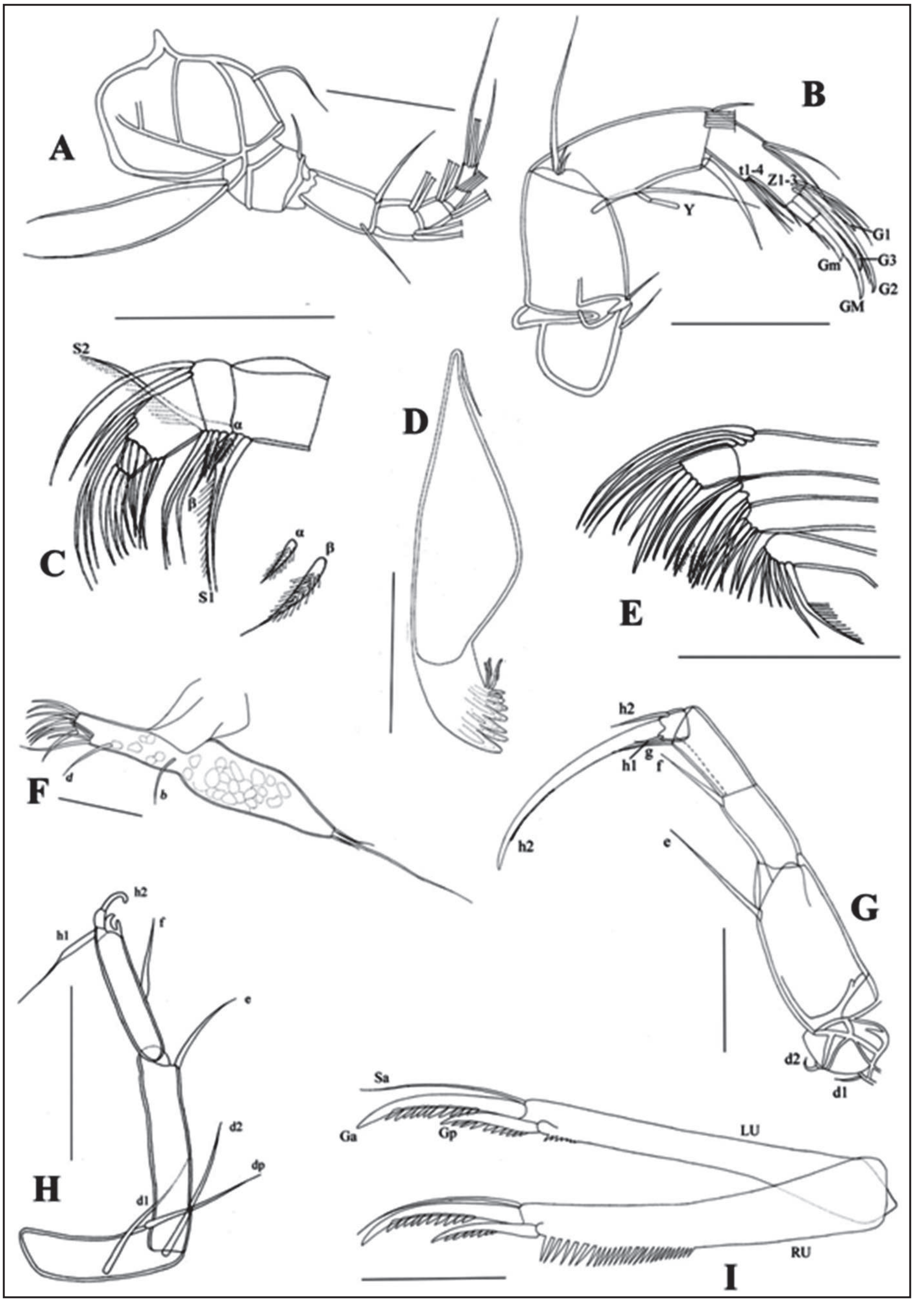

Fig. 4. Typical ostracod body parts: A- Antennula; B- Antenna; C- Mandibula (Palp); D- Mandibula (Coxa); E-Maxillula;F- First Thoracopod; G- Second Thoracopod; H- Third thoracopod; I- Uropodal

Distribution and Endemism

India is one of the biodiversity rich countries in the world. However, Freshwater faunal studies of Indian Ostracoda are limited and scattered compared to the global studies. The distribution of Indian freshwater ostracods was given in Fig. 5. In fact, the studies in this country are confined to a few states like Andhra Pradesh, Chhattisgarh, Kerala, Maharashtra, Madhya Pradesh, Punjab, Rajasthan and Tamil Nadu. There are no much studies from the freshwater ecosystems of Himalaya, Western Ghats and sub terrain regions. The oriental region is the hotspot of ostracoda diversity with 200 species, of which 83% are endemic (Martens *et al.*, 2008) and nearly 58% of the species are endemic to India within the oriental region. Freshwater habitat exhibits high ostracoda diversity even though witnessing a rapid decline in freshwater biodiversity in recent times (Dudgeon *et al.*, 2006, Martens and Savatenalinton 2011).

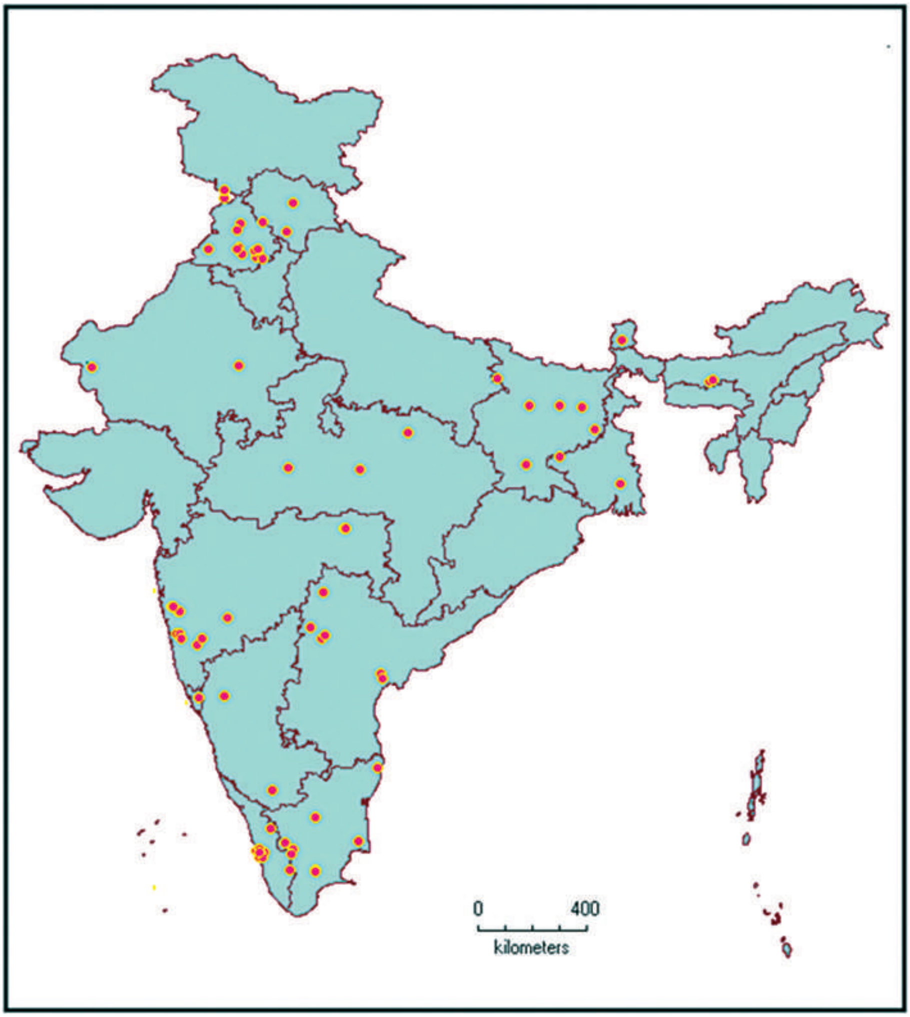

Fig. 5. Distribution of Freshwater Ostracord species in India

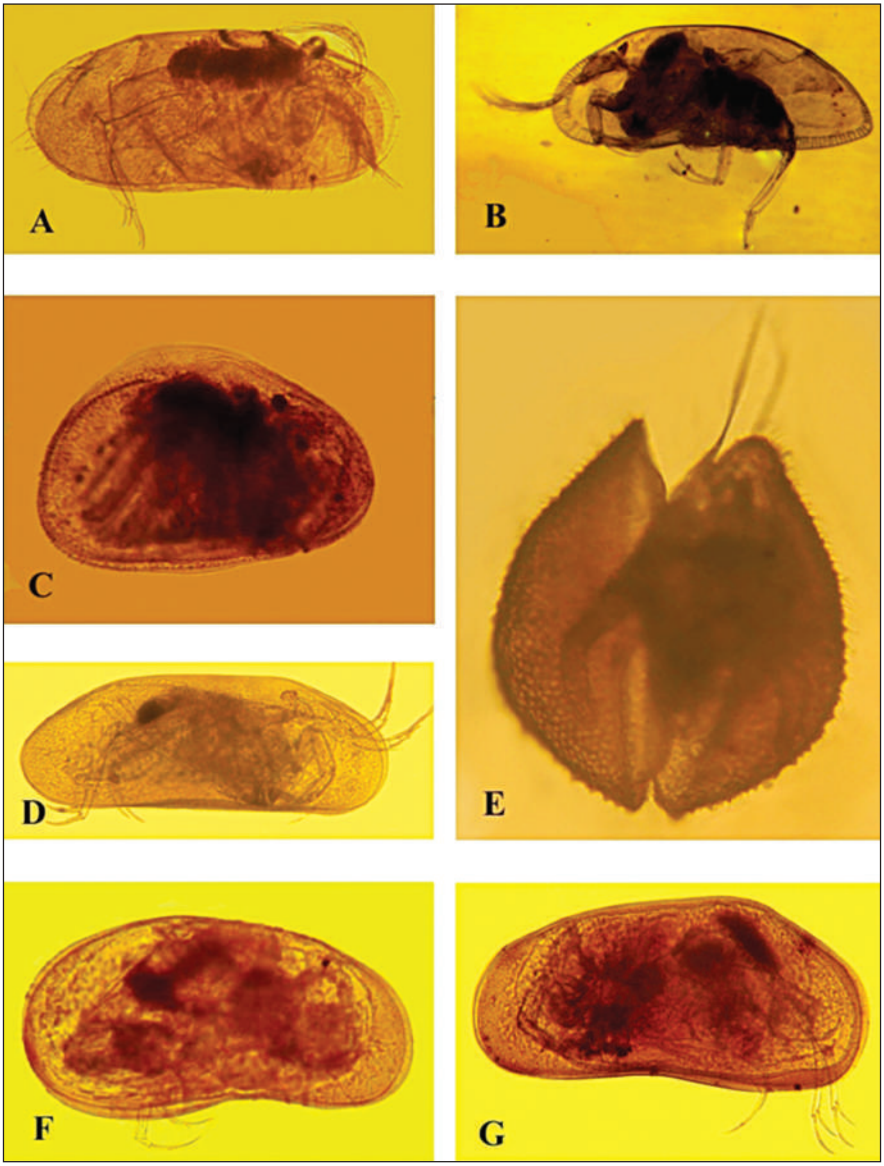

Fig. 6. A- Chrissia spinosa; B- Stenocypris derupta; C- Cyprinotus cingalensis; D- Chrissia halyi; E- Cypris subglobosa; F- Fabaeformiscandona subacuta (Male); G- F. subacuta (Female)

At this stage, intensive exploration and detailed revisionary investigations are needed for confirming the validity and status of the Indian freshwater ostracods.

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CRUSTACEA : EUMALACOSTRACA : BATHYNELLACEA

Chapter 19

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ABSTRACT

Bathynellaceans are minute, vermiform, primitive eumalacostracan crustaceans, which are a typical component of the groundwater fauna worldwide. The faunistic investigations undertaken on this group since 2002, especially in the deltaic plain of the Krishna-Godavari basin of the southeastern peninsular India, have yielded nearly nominal 30 species in five genera. Nothing is known about this group from the rest of the country. This essay is primarily meant to provide the reader with the basic morpho-taxonomic details of the bathynellacean body and its various appendages. It will also serve as a basis for further study, and as an introduction to the literature. Besides the identification keys to the Indian genera and their species, the various sampling methods adopted are described and illustrated. Notes are also given on the biogeography and the anthropogenic threats to, and conservation of, the Indian bathynellaceans.

Key words: Bathynellacea, morpho-taxonomy, identification keys, biogeography, conservation.

INTRODUCTION

The Order Bathynellacea is a compact group of Eumalacostraca crustaceans, typically occurring in the interstitial spaces of sandy shore sediments of lakes, sandy and gravelly banks of rivers, streams and phreatic systems like caves and borewells, and springs. There are, of course, a few exceptions. For example, *Baicalobathynella magna* (Bazikalova, 1954) lives in Lake Baikal on soft bottoms at depths ranging from 0.2 m to1440 m (Bazikalova, 1954) besides in gravel and pebble of the rivers discharging into Lake Bakal (Drewes & Schminke, 2011). The Australian *Hexabathynella halophila* Schmike, 1972, is known from a marine beach, having a water salinity of 27‰ and such like Australian examples include *Brevisomabathynella clayi* Cho & Humphreys, 2010 and *B. uramurdahensis* Cho & Humphreys, 2010, and a few species can live in oligohaline and polyhaline waters as well. The African *Thermobathynella adami* Capart, 1951, was found in a hot spring, at temperatures ranging up to 55°C.

Bathynellaceans have no fossil record (Schram, 2008) and are found almost throughout the world, with the exception of the Antarctica and certain parts of Northern Hemisphere that had been covered by ice during the last glacial period. Also, they are not known from Central America, volcanic islands and several

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islands of continental origin such as New Caledonia, Fiji, Caribbean islands (Schminke & Cho, 2013). They apparently feed on detritus, bacteria and fungi, and also on protozoans and other animals, and could even be cannibalistic (Schminke & Cho, 2013). Sexes are separate, and no resting stages exist. Eggs are shed freely and pass through a nauplius and parazoeal (larval) phases (the latter comprising three or four instars) before the appearance of a juvenile bathynellacean.

Historically, the discovery of Bathynellacea dates back to 1882 when Vejdovsky described *Bathynella natans* Vejdovsky, 1882 from a well in Prague, Czech Republic, but he could not fix it in the taxonomic hierarchy. It was Calman (1899) who reexamined Vejdovsky's preparations and placed the species in the then Order Syncarida (now Superorder Syncarida Packard, 1885). Bathynellaceans are phylogenetically close to, but more primitive than, the extinct and fossilized syncarid Order Palaeocaridacea, and represent one of the oldest groups of freshwater fauna, whose ancestors inhabited the sea during the Carboniferous, or even earlier (Schminke, 1974). According to Schminke's (2014) review of the origin of Bathynellacea, there are two opposing and as yet unresolved hypotheses, i. e. marine vs. freshwater. The marine hypothesis maintains that Bathynellacea invaded continental groundwater from the sea via marine interstitial beaches ("two-step model"), whereas the freshwater hypothesis supports the view that this group reached the groundwater from the sea via epigean freshwaters and the interstitial of gravelly banks of rivers and streams.

Following the increasing number of species discovered, especially in Europe (see Chappuis, 1929), preliminary systems of classification were proposed for Syncarida (Siewing, 1959; Brooks, 1962). Noodt (1965) introduced the first classification of the Bathynellacea Chappuis, 1915, and it was adopted by Brooks (1969) and reinforced by Schminke (1973, 1975, 1978). Coineau (1996, 1998) provided a synthesis of all of the hypotheses and classifications of the Superorder Syncarida as a whole. Among the chief contributors to the bathynellacean taxonomy, mention must be made of Delamare Deboutteville (1953-1973), Coineau (1964-2013), Noodt (1965-1974), Serban (1972-2000), Schminke (1972-2013), Camacho (1986-2016), and Cho (1995-2015) (see Coineau & Camacho, 2013, for the list of complete references).

It cannot be overemphasized that vast tracts of the globe still remain *terra incognito* for bathynellaceans (Ranga Reddy, 2002a). As for the Indian subcontinent, or even South Asia as a whole, regular faunistic investigations on this group have started only recently and mostly in the coastal deltaic belt of the Krishna-Godavari Basin in the southeastern peninsular India (see Ranga Reddy, 2002a, b, 2004a, b, 2006, 2011, 2014; Ranga Reddy & Schminke, 2005a, b, 2009a, b; Ranga Reddy & Totakura, 2010; Ranga Reddy *et al.*, 2008, 2011; Totakura & Ranga Reddy 2014; Elia *et al.*, 2016). Mention must also be made here of the contributions made to the bathynellacean group by Elia (2009), Shabuddin (2016), and Totakura (2013), in their doctoral theses. No molecular tools have yet been used to study the India bathynellacean taxonomy. However, Camacho *et al.* (2013) recommend the integrative approach of combining morphological and molecular data to discern the subtle differences between the species, especially in the family the Bathynellidae.

This essay gives the basic morpho-taxonomic details of the bathynellacean body and its various appendages, sampling methods, the identification keys to the hitherto known Indian genera and their species. Notes are also given on the biogeography and the threats and conservation of the Indian Bathynellacea.

SAMPLING METHODS

The various methods of sampling of the subterranean fauna have been dealt with *in extenso* in a sampling manual brought out by the European Project PASCALIS (Protocols for the Assessment and Conservation of Aquatic Life In the Subsurface) (see Malard *et al.,* 2002; http//www.pascalis-project.com). The following are the common methods employed for collecting the bathynellaceans and other stygobiotic animals.

A. Collection of samples from the field

1. Karaman & Chappuis method (Chappuis 1942) (Fig. 1A). This method consists in digging a few holes of varying depths (10-30 cm), a few meters apart from one another, in the alluvial deposits next to a stream or river, and sampling the subsurface water that seeps into the pits. Coring is also done in the dug-out pits, as detailed in the Coring and filtration method (see below). Each time the sample is filtered through bolting-silk plankton net (mesh size 70 µm), and the filtrate fixed in 5% formaldehyde in plastic vials.

2. Coring and filtration method (Fig. 1B-C). A rigid PVC tube (length c. 70 cm, diameter c. 10 cm) is used to extract cores directly from the sediment surface to a depth of 10-50 cm from both exposed and submerged parts of stream/river banks. At each sampling site, the core samples are pooled in a bucket, filled with the water from the sampling spot and stirred vigorously. The supernatant is filtered, and the filtrate fixed as mentioned above.

3. Direct filtration of water from residential and farm bores (Fig. 1D-F). When sampling a borewell in any residential area, plankton net (mesh size 70 µm) is tied to the inlet delivery tube of overhead tank and left over there for a day or two for filtering the incoming water. For sampling an agricultural bore, plankton net is either tied securely to the outlet delivery tube or manually held against the water current for at least 30 minutes when bore water is being pumped out of the bores. The filtrate is then fixed as mentioned already.

4. Sampling of open boreholes (Fig. 1F). Generally these boreholes (or borewells) of varying depths (30 m-140 m or more) are drilled by various agencies for harnessing groundwater for drinking or agriculture purpose. Before the pump-set is fitted to the open boreholes, the groundwater samples are collected from near the bottom by using haul nets. Haul nets are simple plankton nets of different sizes suitable for the wells, having a diameter of 4-10 cm. The weighted plankton haul net (mesh size 70 µm) is sent down, the bottom sediments of the borehole are then disturbed by moving the net a little up and down, and then hauling up the net. The filtrate is fixed as before.

Any of the samples collected must always be labeled right at the respective sampling sites themselves. The label should invariably contain the following information: name of the habitat and the nearby place/town and its coordinates (always carry GPS device to the field), the method and date of collection, collector's name, and if possible, some water parameters such as temperature, pH, etc., are also measured and entered in the Field Notebook

Laboratory methods

Sorting of the samples and dissecting of specimens (Fig. 2A-F): samples are scanned under a binocular stereomicroscope and the bathynellacean specimens together with those of the other interstitial animal groups are sorted out into small vials in

Fig. 1. Different types of sampling methods. (A) River bank, Karman-Chappuis method; (B) R. Godavari, direct coring method; (C) Filtering supernatant of core sample; (D) Direct filtration of water pumped out of an agricultural borewell; (E) Water from a hand-operated suction pump filtered through plankton net; (F) Sampling a newly dug-out borehole; and (G) Direct filtration of drippings from cave ceilings (here, stalactites).

Fig. 2. Laboratory methods. (A) A view of the chemicals, reagents, needles, etc. used for slide preparation; (B) Making dissection; (C-F), Different stages in preparing permanent mounts; and (G) Making line drawings by using the Leica trinocular microscope.

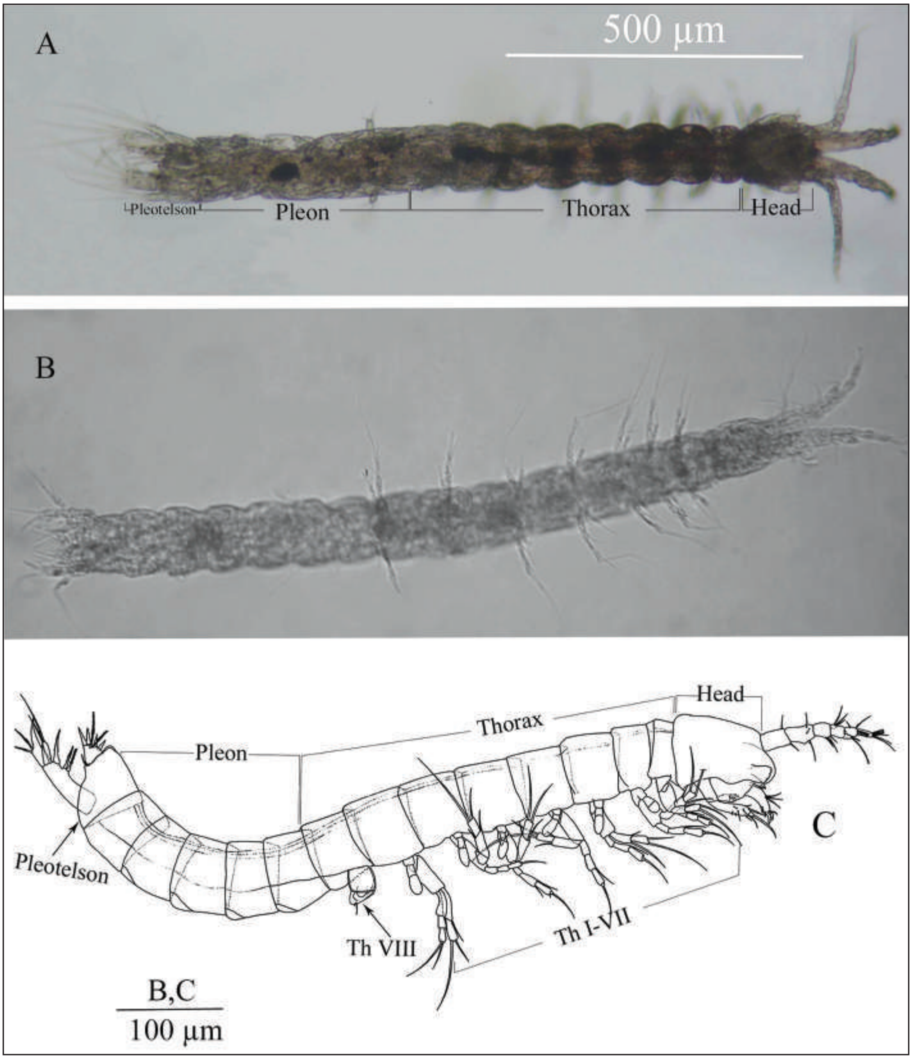

Fig. 3. Habitus: (A) *Camachobathynella meghalayaensis* (female, dorsal); (B) *Serbanibathynella secunda* (female, ventral); and (C) *Habrobathynella savitri* (male, lateral).

70% alcohol. Two sharp tungsten needles (c. 0.2 mm in diameter) mounted on glass or metal or plastic holders are used for dissecting the various appendages. The tip of the needle has to be sharpened by electrolysis in the medium of saturated solution of KOH, using 6-volt power supply. Alternatively, the tip the tungsten needle is cautiously dipped into $NaNO_2$ crystals melted in a metal spoon held over Bunsen burner. If tungsten wire is not available, micro-dissecting needles or fine insect pins mounted on a metal or plastic holder can be used. Dissection of the various appendages is also done under binocular stereomicroscope at a magnification of about 90× and in the medium of glycerol. For permanent preparations, the habitus and/or appendages are mounted in glycerol, and sealed with paraffin and Araldite.

Preparation of illustrations (Fig. 2G): drawings are made with the aid of a drawing tube mounted on high-resolution compound microscope equipped with Universal Condenser for Adaptation (UCA), Interference Contrast objective prism and 1-2× magnification changer. The black-and-white contrast of the line drawings can be enhanced with 0.3 mm HB Staedtler leads and then thickened and composed into the components of figures, using Adobe Photoshop CS3 Extended software. Ocular and Stage Micrometers need to be used for collecting the morphometric data.

Morphological characterization of species: detailed and accurate line drawings with pencil have to be made of the habitus in dorsal, lateral and ventral views, and of the appendages starting from the antennules to the last abdominal appendages. Making line drawings of given species is a conventional way collecting its morphological data. Hence accurate drawings constitute the heart of any taxonomic paper. Wherever necessary and possible, digital images of taxonomically important body parts body and/or appendages are also taken, using a good Digital Camera, or still better, Scanning Electron Microscope.

For establishing a definitive new species, the types (holotype, allotype, and some paratypes, etc.) must perforce be designated and deposited in the national and international repositories, and their registration numbers duly mentioned in the manuscripts. A good acquaintance with the provisions of the International Code of Zoological Nomenclature (ICZN, 1999) is a must.

Here, the bathynellacean description of the external morphology is based chiefly on the following accounts: Schminke (1973), Ranga Reddy & Totakura (2010), and Coineau & Camacho (2013). Schminke's (2011) monographic compilation of the Parabathynellidae is also made use of.

Abbreviations. A I = antennule; A II = antenna; enp = endopod (enp-1 to enp-4 = endopodal segments 1 to 4); exp = exopod (exp-1 and exp-2 = exopodal segments 1and 2); Lb = labrum; Md = mandible; MX I = maxillule; Mx II = maxilla; Prg = paragnath; Th I-VIII = thoracopods I-VIII; Urp = uropod.

EXTERNAL MORPHOLOGY

Bathynellaceans are small (generally 0.5-3.0 mm in length), blind and vermiform animals (Fig. 3A-C). Body comprises head, thorax and pleon (abdomen); head is without rostrum and with 5 pairs of appendages: antennules (A I), antennae (A II), mandible (Md), maxillule (Mx I) and maxilla II. In addition, a flap-like structure called labrum (Lb) lies immediately in front of mouth, and 1 tiny paired but fused lobe-like structure, termed paragnath (Prg), is located immediately posterior to and often overlapping Md (see The appendages). Thorax consists of 8 somites/segments (thoracomeres), each of which has 1 pair of legs or thoracopods, i. e. thoracopods I-VII (Th I-VIII), which are typically biramous and almost similar in structure in both sexes; Th VIII in male is transformed into penile organ but reduced to a variable degree in female (see below). Pleon has 6 somites (pleomeres), of which the last one called pleotelson, bears 1 pair of caudal furcae (furca, singular) posteriorly and 1 pair of dorsal or dorso-lateral setae near base of caudal furcae. Each caudal furca with 1 terminal and generally 2-4 inner spines of varying lengths and 2 unequal dorsal setae, sometimes none; each furca with a small or large modified projection, called "furcal organ" at inner distal corner.

First pleomere (abdominal somite) with or without paired uniramous appendages or pleopods. Sixth pleomere, called pleotelson, with 1 pair of biramous Urp (tail feet) (see below).

Drewes & Schminke (2011) recognized only two families under Bathynellacea, viz. Bathynellidae Grobben, 1905 and Parabathynellidae Noodt, 1964, treating the third family Leptobathynellidae Noodt, 1965, as a synonym of Parabathynellidae. However, according to Serban (1972, 1980), Coineau & Serban (1973, 1978), Ranga Reddy *et al.*, 2011; and Coineau & Camacho (2013), Leptobathynellidae is a valid taxon. Pending detailed morphological as well as molecular phylogenetic studies, it seems appropriate to uphold the view expressed by Drewes & Schminke (2011). Currently, while Bathynellidae has more than 100 species in 28 genera, and is mainly distributed in temperate regions, Parabathynellidae contains about 180 species in 48 genera and has much wider distribution in both tropical and temperate zones.

THE APPENDAGES

The principal morphological differences between the two families, viz. Bathynellidae and Parabathynellidae are as detailed in Table 1 and depicted as in Figs. 3-16.

Table 1. Principal morphological differences between Bathynellidae and Parabathynellidae*

	Bathynellidae	Parabathynellidae
Pleotelson setae	dorsal, stout	lateral, slender
A I	7-segmented	6-segmented (exception: 7-segmented in *Chilibathynella*)
A II	1-to 5-segmented; generally directed anteriorly, with 1-segmented exp bearing sensory seta	7-segmented; bent backwards and without exopod
Lb free margin	smooth	serrulate, fringed with setules or rarely smooth
Md palp	prehensile, 3-segmented, with 2 stout apical seta	non-prehensile, 1-segmented with 1-3 apical setae, or, rarely, palp completely absent.
Mx I: setae on outer margin of distal endite	plumose	smooth
Th I coxa	generally with 1 long feathered seta	invariably without any seta
Th I-VII exp	1-segmented	2-segmented (exception: 1-segmented in *Atopobathynella* and *Chilibathynella*)
Th I-VII enp-3	always without seta at outer distal corner	the said seta generally present, but rarely absent

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	Bathynellidae	Parabathynellidae
Th VIII male	strongly built; exp large with 4 or 5 seta	small, with basal segment of protopod bulging into more or less spherical structure; exopod greatly reduced and without setae.
Th VIII female	epipod present	epipod absent
Pleopod I	always present, uniramous and 2-segmented	generally absent(exception: 1-segmented in *Chilibathynella*)
Urp sympod	rather short, with oblique row of spines at end	distinctly elongate, with longitudinal row of spines
Urp exp vs. enp	always shorter	either shorter or longer

*based on the hitherto known Indian taxa.

The taxonomically important morphological details of each of the appendages, based on the hitherto known Indian taxa of the family Parabathynellidae alone, are summarized below, but figures are given for certain species of both families.

A I (Fig. 4): uniramous, with 6 or 7 segments, and without any sexual dimorphism except in *Atopobathynella* and *Chilibathynella* species in which second segment in male has characteristic 'antennal organ' at inner distal corner. Proximal 3 segments (praecoxa, coxa and basis) constituting peduncle, has 2 flagella: primary or outer flagellum either 3- or 4-segmented and accessory or inner flagellum small, lobe-like, bearing 3 unequal setae (inner flagellum completely fused to third segment in the 2 nominal Indian *Atopobathynella* spp.). Fourth segment (counted from base) produced at outer distal corner into apophysis of variable length. Fifth and sixth segments with 2 or 3 aesthetascs each. Length of apophysis, number and relative lengths of aesthetascs on last 2 segments and setal armature of different segments are taxonomically important.

A II (Fig. 5): uniramous, bent backwards and shorter than AI; 1-segmented in *Atopobathynella* (Fig. 5E), 2-segmented in *Habrobathynella* (Fig. 5D), 5-segmented in *Parvulobathynella*, (Fig. 5G) and 6-segmented in *Chilibathynella* (Fig. 5F); if more than 1-segmented, basal segment devoid of armature.

Lb (Fig. 6): free margin of this unpaired, arched structure either straight, concave or bilobed and usually beset with varying numbers of denticles or spinules or setules; ventral surface is variously ornamented among different taxa.

Md (Fig. 7): 3 parts can be recognized: i) the distal part, called *pars incisiva*, has 3 or 4 teeth; ii) *pars molaris* ("Borstenlobus") has 6 claws on a distinct rectangular lobe in *Chilibathynella* (Fig. 7G), 5 or 6 unequal teeth on a characteristic pyriform structure in *Habrobathynella* (Fig. 7E), 5 teeth/spines on short protuberance in *Atopobathynella* (Fig. 7H) and 3 unequal teeth are directly fused to the Md body (*corpus mandibularis*) in *Parvulobathynella* (Fig. 7F); and iii) the tooth of ventral edge lying between *pars incisiva* and *pars molaris*, the size and orientation of which varies in different taxa. Palp 1-segmented, carrying non-prehensile apical seta; palp completely absent in *Habrobathynella* (Fig. 7D, E).

Prg (Fig. 8): with lateral projections/arms and a median projection, called coupler. Prg is not described in most world species of Parabathynellidae. And yet, the size and orientation of the lateral arms and the shape and size of the coupler are found to be species-specific at least in *Habrobathynella* (see Ranga Reddy *et al*., 2014; Elia *et al.*, 2016).

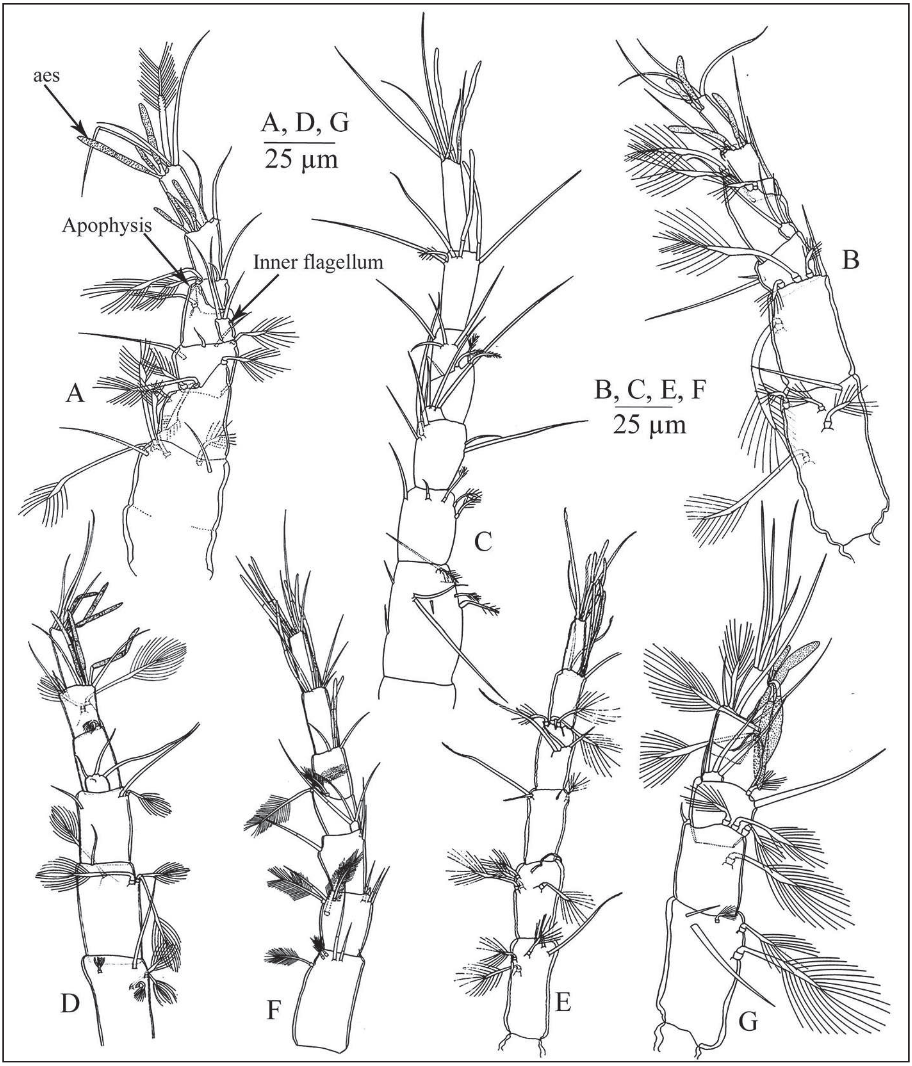

Fig. 4. A I: (A) *Serbanibathynella secunda*; (B) *Indobathynella prehensilis*; (C) *Camachobathynella meghalayaensis*; (D) *Habrobathynella vaitarini*; (E) *Atopobathynella paraoperculata*; (F) *Chilibathynella kotumsarensis*; and (G) *Parvulobathynella macrodentata.*

Mx I (Fig. 9): with 2 endites; proximal endite small, carrying 4 unequal armature elements on inner distal margin; distal endite elongate and armed with 5-7 claw-like setae, and 2 or 3 simple setae on outer distal corner.

Mx II (Fig. 10): 2- to 4-segmented and armed with setae; apical segment with

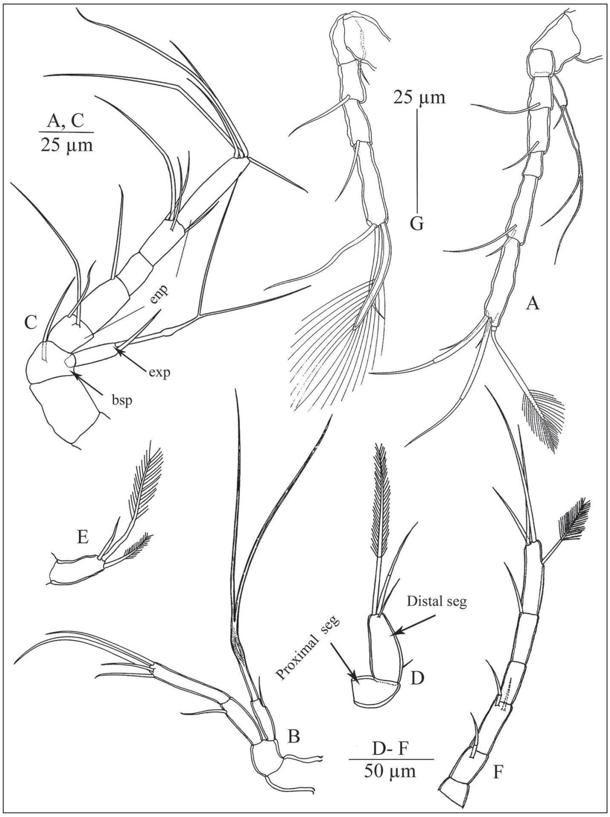

Fig. 5. A II: (A) *Serbanibathynella secunda*; (B) *Indobathynella prehensilis*; (C) *Camachobathynella meghalayaensis*; (D) *Habrobathynella vaitarini*; (E) *Atopobathynella paraoperculata*; (F) *Chilibathynella kotumsarensis*; and (G) *Parvulobathynella macrodentata.*

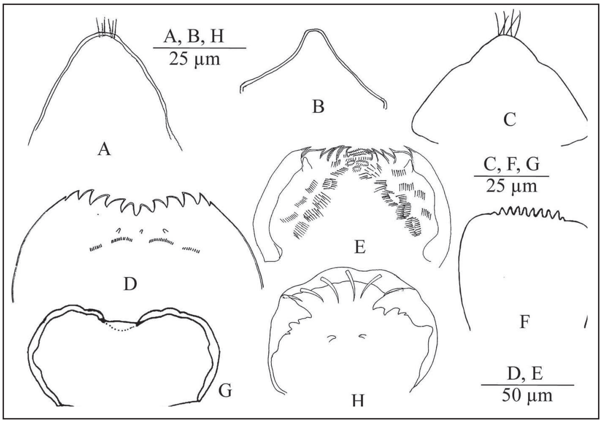

Fig. 6. Lb: (A) *Serbanibathynella secunda*; (B) *Indobathynella prehensilis*; (C) *Camachobathynella meghalayaensis*; (D) *Habrobathynella vaitarini*; (E) *Atopobathynella paraoperculata*; (F) *Chilibathynella kotumsarensis*; (G) *Parvulobathynella projectura;* and (H) *Parvulobathynella macrodentata*

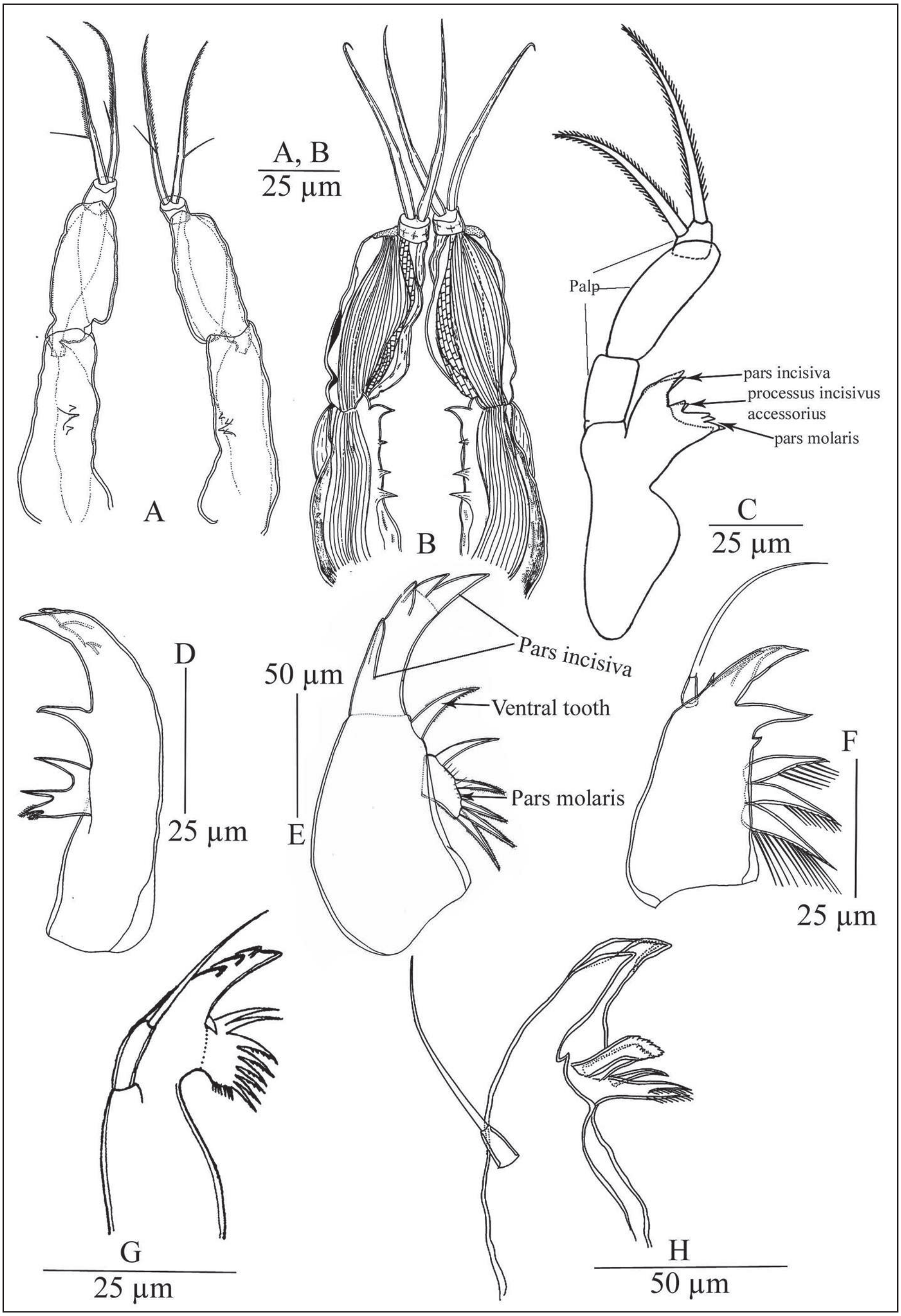

Fig. 7. Md: (A) *Serbanibathynella secunda*; (B) *Indobathynella prehensilis*; (C) *Camachobathynella meghalayaensis*; (D) *Habrobathynella ajraoi*; (E) *Habrobathynella vaitarini;* (F) *Parvulobathynella macrodentata*; (G) *Chilibathynella kotumsarensis;* and (H) *Atopobathynella paraoperculata.*

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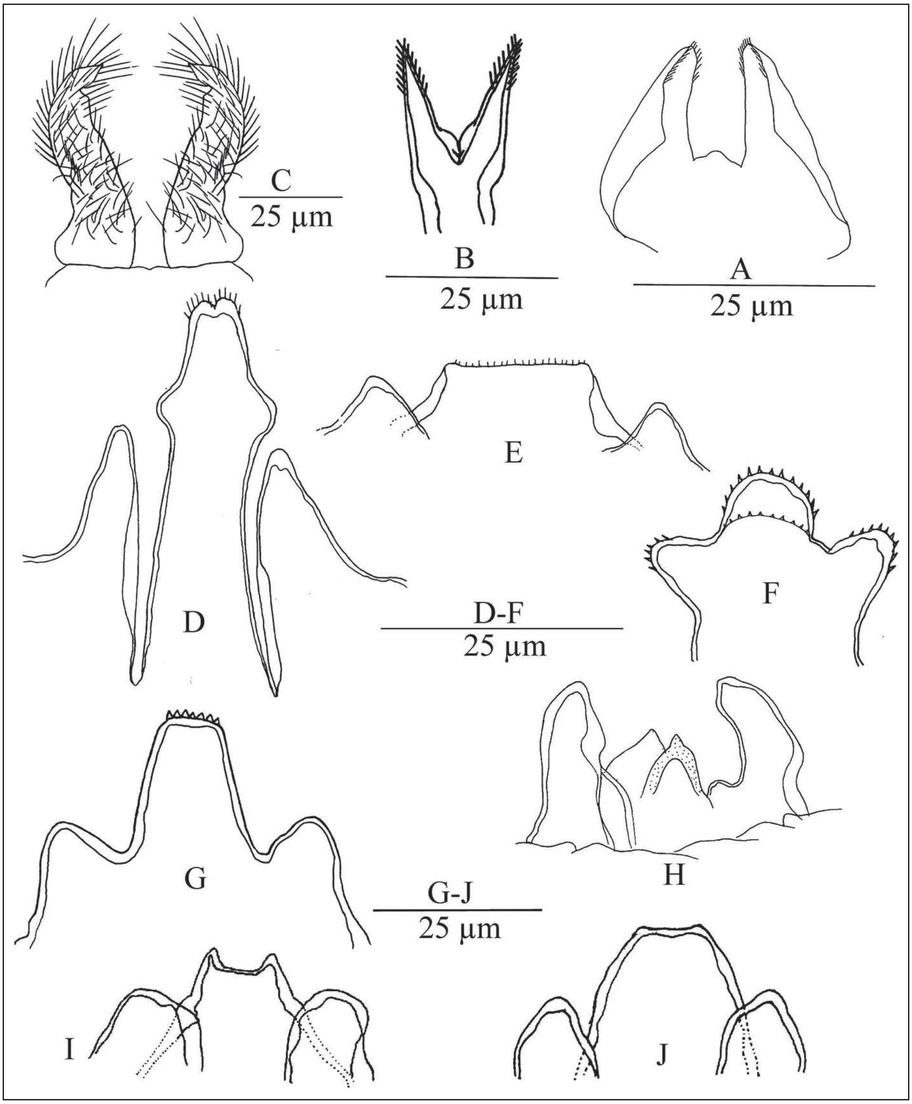

Fig. 8. Prg: (A) *Serbanibathynella secunda*; (B) *Indobathynella prehensilis*; (C) *Camachobathynella meghalayaensis*; (D) *Habrobathynella indica*; (E) *H. vaitarini*; (F) *H. borraensis*; (G) *Atopobathynella paraoperculata;* (H) *Parvulobathynella macrodentata;* (I) *P. distincta;* and (J) *P. projectura.*

or without prehensile claw-like seta(e); number of armature elements on inner distal corner of the first segment varies from 0 to 4 among different taxa, and this is an important taxonomic criterion.

Th I-VII (Figs. 11-13): typically biramous, with outer ramus/branch (exp) and inner ramus/branch (enp). Basal or first portion of thoracopod, referred to as the protopod, consists of 2 segments, coxa/coxopodite and basis/basipodite. Coxa is unarmed but generally bears a club-shaped structure called epipod at outer distal

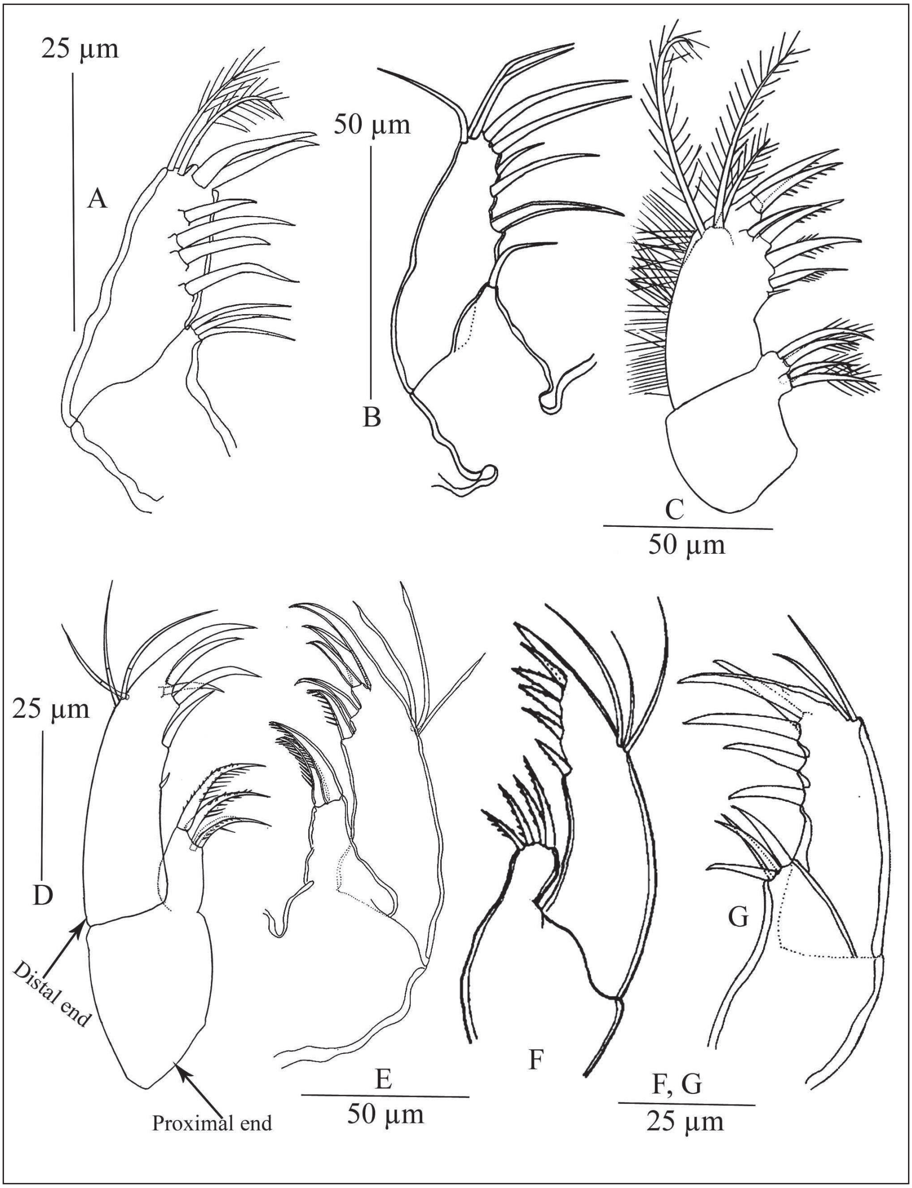

Fig. 9. Mx I: (A) *Serbanibathynella secunda*; (B) *Indobathynella prehensilis*; (C) *Camachobathynella meghalayaensis*; (D) *Habrobathynella borraensis;* (E) *Atopobathynella paraoperculata*; (F) *Chilibathynella kotumsarensis*; and (G) *Parvulobathynella distincta.*

corner. Exp is either 2-segmented as in *Habrobathynella* and *Parvulobathynella* (Fig. 11D, G) or 1-segmented as in *Atopobathynella*, *Chilibathynella*.(Fig. 11E-F). Enp invariably 4-segmented. Setal pattern of basis and rami varying in different taxa and also between Th I-VII, and generally expressed as setal formula. Ornamentation, if any, of exp and enp segments need to be described.

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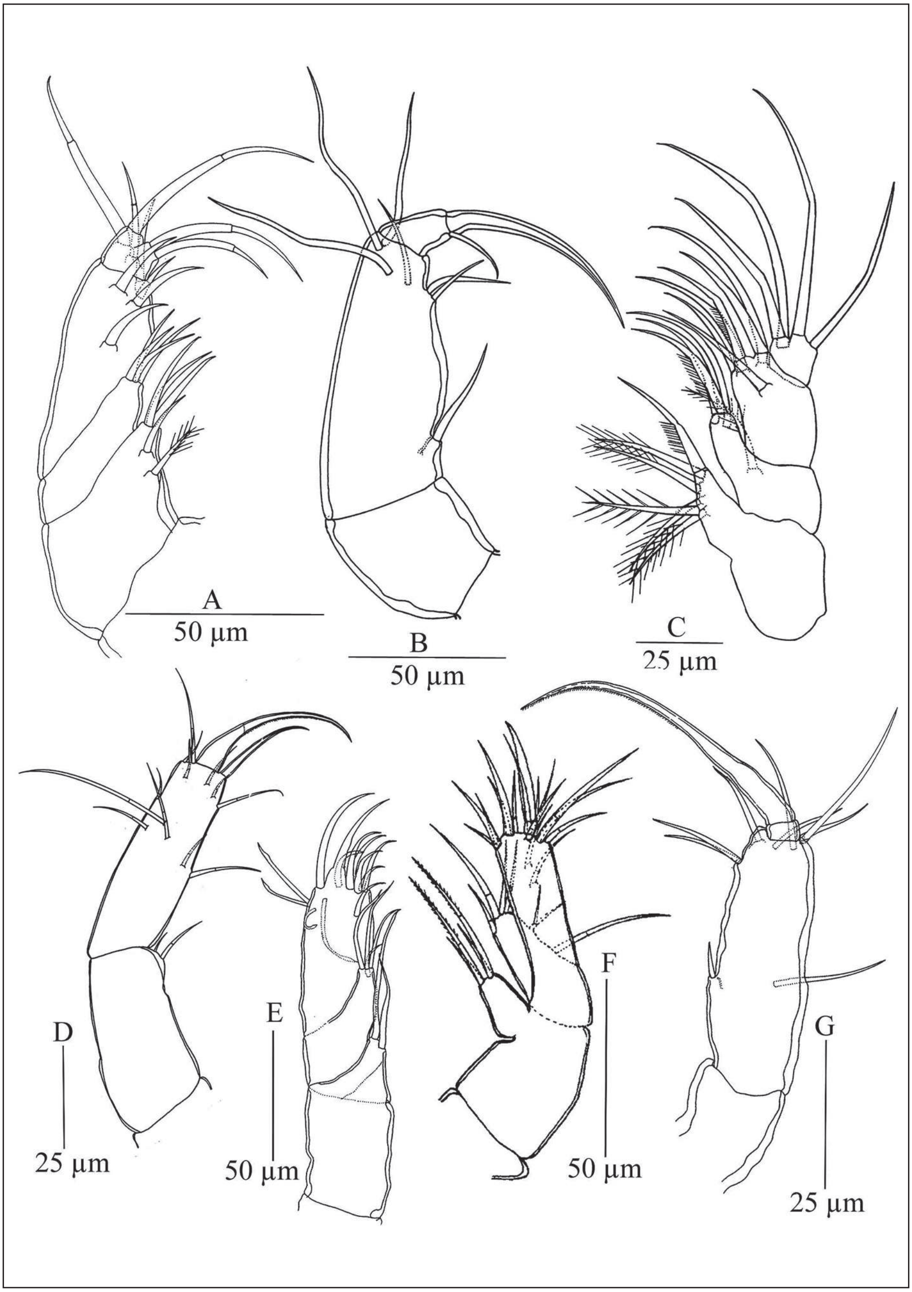

Fig. 10. Mx II: (A) *Serbanibathynella secunda*; (B) *Indobathynella prehensilis*; (C) *Camachobathynella meghalayaensis*; (D) *Habrobathynella krishna;* (E) *Atopobathynella paraoperculata*; (F) *Chilibathynella kotumsarensis*; and (G) *Parvulobathynella macrodentata.*

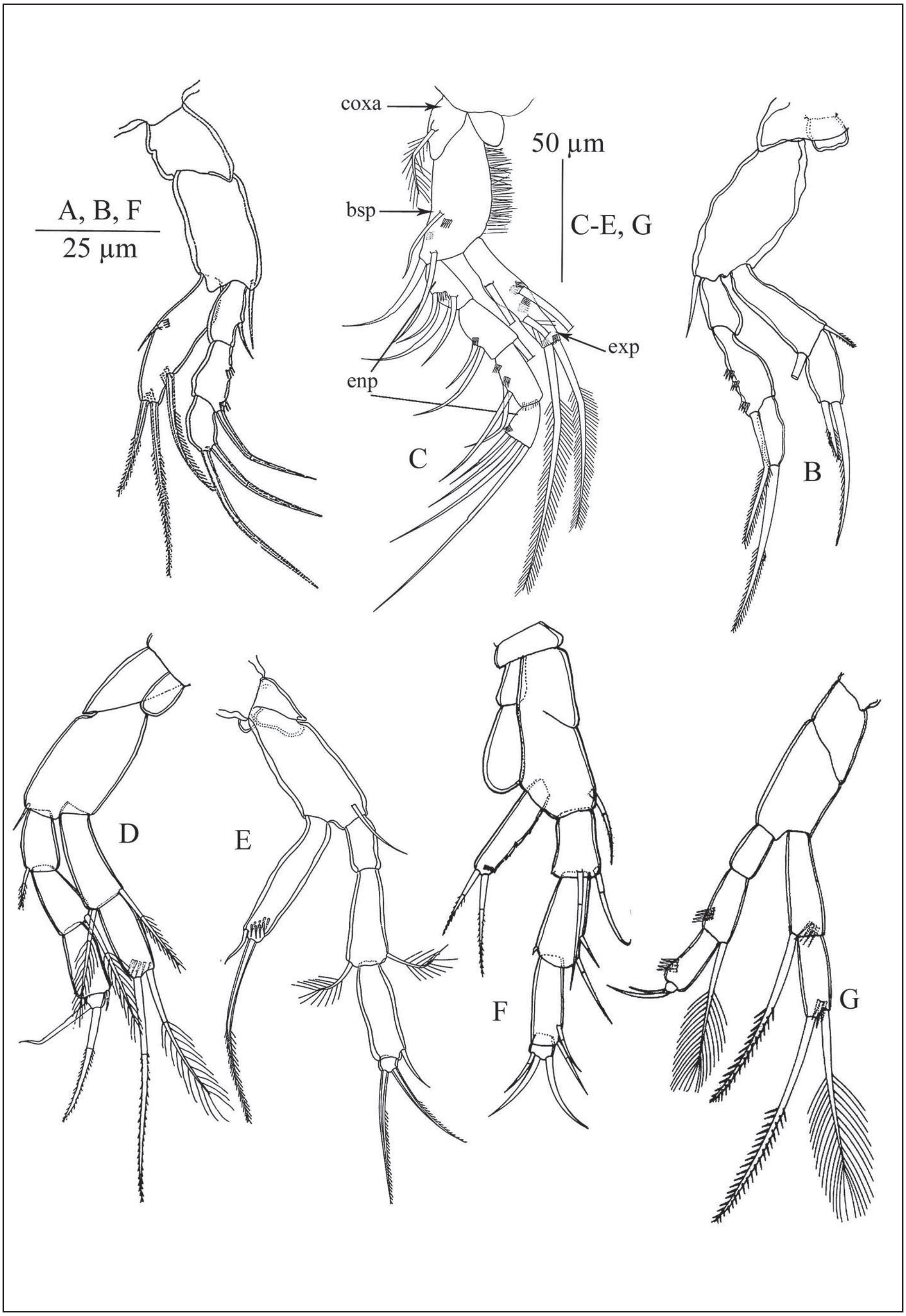

Fig. 11. Th I: (A) *Serbanibathynella secunda*; (B) *Indobathynella prehensilis*; (C) *Camachobathynella meghalayaensis*; (D) *Habrobathynella savitri;* (E) *Atopobathynella paraoperculata*; (F) *Chilibathynella kotumsarensis*; and (G) *Parvulobathynella distincta.*

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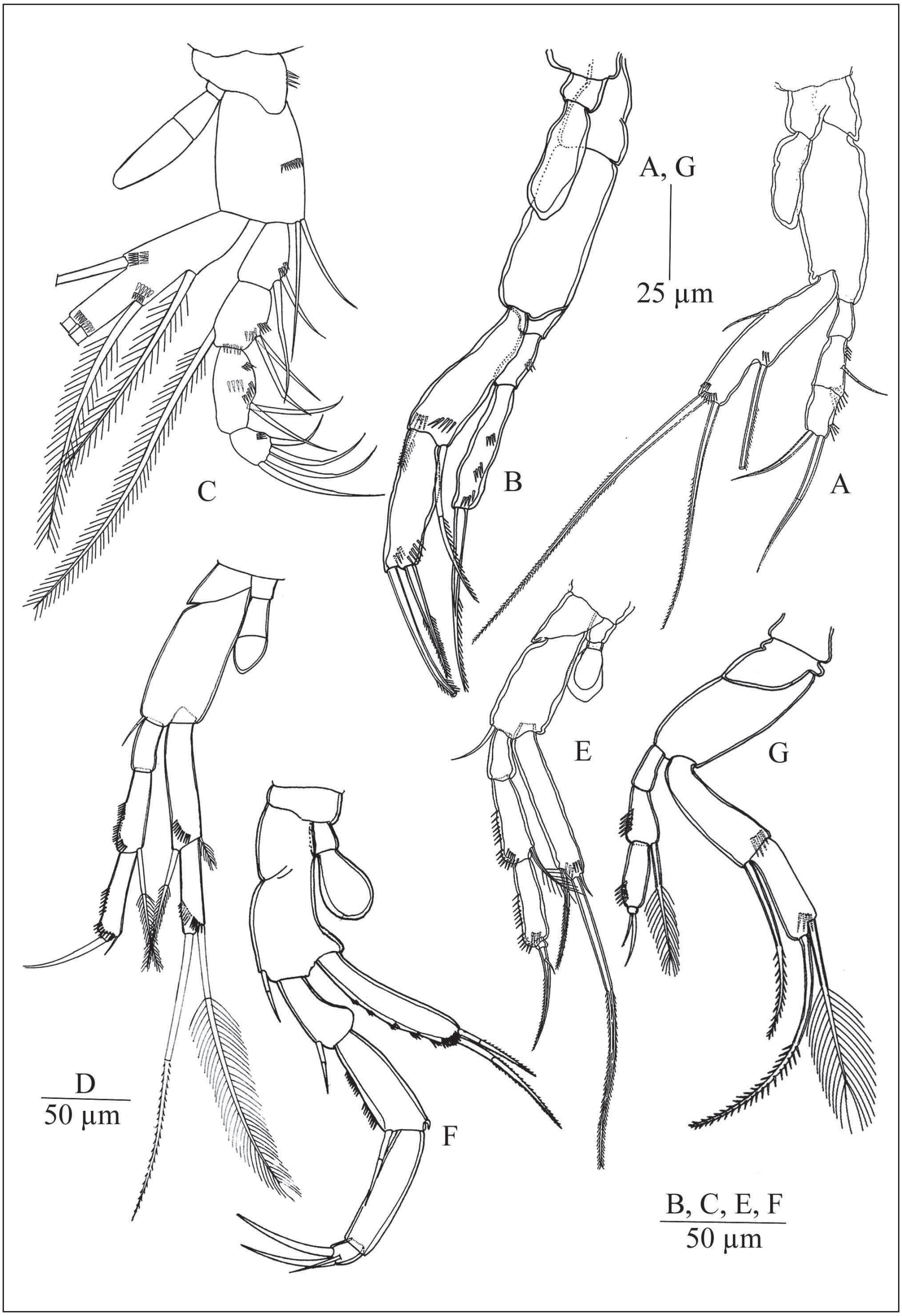

Fig. 12. Th IV: (A) *Serbanibathynella secunda*; (B) *Indobathynella prehensilis*; (C) *Camachobathynella meghalayaensis*; (D) *Habrobathynella vaitarini;* (E) *Atopobathynella paraoperculata*; (F) *Chilibathynella kotumsarensis*; and (G) *Parvulobathynella distincta.*

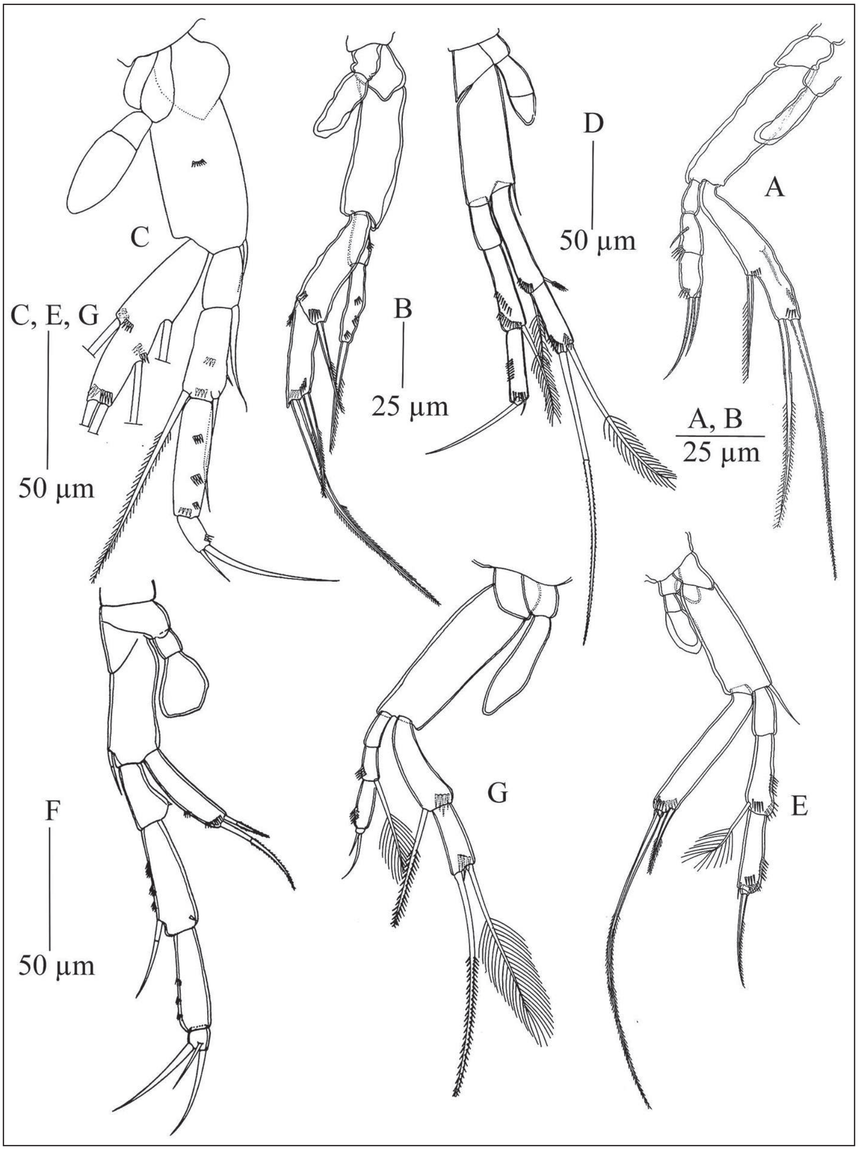

Fig. 13. Th VII: (A) *Serbanibathynella secunda*; (B) *Indobathynella prehensilis*; (C) *Camachobathynella meghalayaensis*; (D) *Habrobathynella vaitarini;* (E) *Atopobathynella paraoperculata*; (F) *Chilibathynella kotumsarensis*; and (G) *Parvulobathynella distincta*

Th VIII (Figs. 14): very short and reduced to mere triangular/crescentic/globular lobe in female (Fig. 15D-F), but transformed into a complex penile organ of different shapes and much taxonomic significance. Generally, protopod prominently developed, oval or narrow and elongate in *Habrobathynella* spp. (Fig. 14D) or laterally expanded (hemispherical) in *Atopobathynella* spp. (Fig. 14G); basal segment of protopod characteristically large and balloon-shaped in *Chilibathynella* (Fig. 14F). Basis usually distinct from basal protopod (coxa) as in *Habrobathynella*

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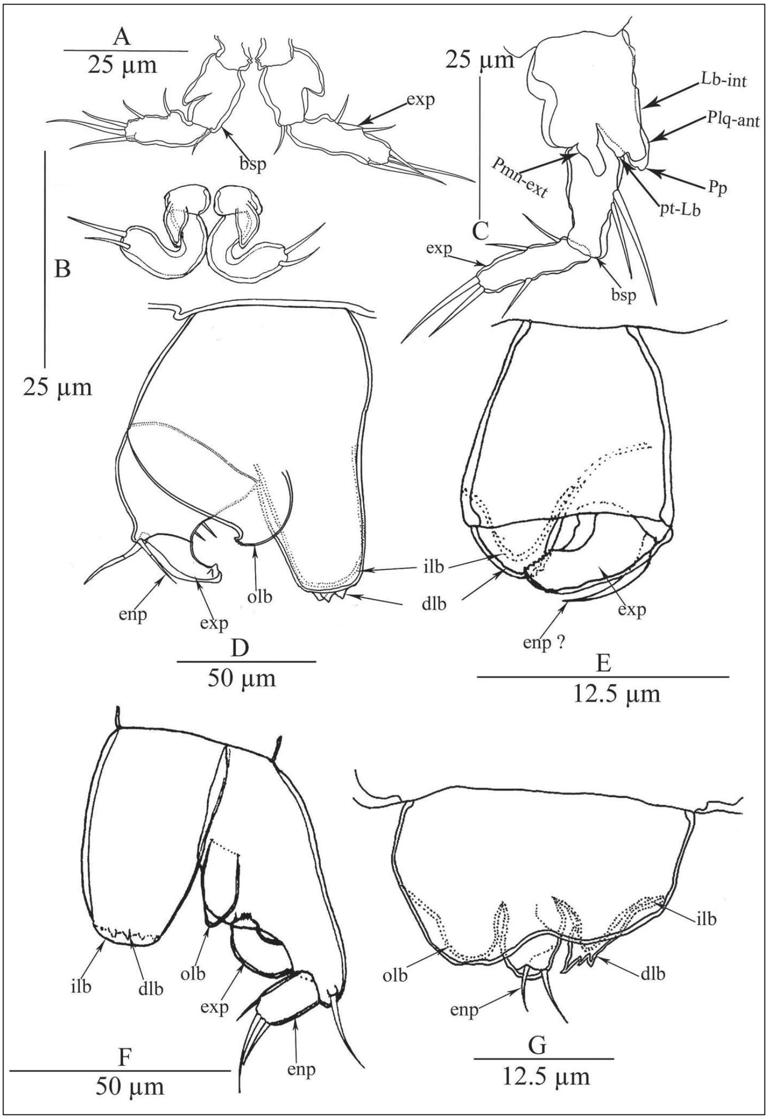

Fig. 14. Th VIII male: (A) *Serbanibathynella secunda*; (B) *Indobathynella prehensilis*; (C) *Camachobathynella meghalayaensis*; (D) *Habrobathynella krishna;* (E) *Parvulobathynella macrodentata*; (F) *Chilibathynella kotumsarensis*; and (G) *Atopobathynella paraoperculata.*

spp., but fused to coxa in *Parvulobathynella* spp., and somewhat triangular or conical and beset with 1 seta at outer distal angle. Protopod extended distally into dentate and inner lobes, constituting penile region; dentate lobe ornamented with varying number of denticles in transverse/oblique rows; inner lobe always smooth and shorter than dentate lobe in *Habrobathynella* and *Parvulobathynella* spp., but slightly longer in *Chilibathynella kotumsarensis*. In *Habrobathynella indica*, penile region is drawn out into unusually large, double-horn-like structure—a unique feature in Parabathynellidae (not figured). Outer lobe (epipod) small,

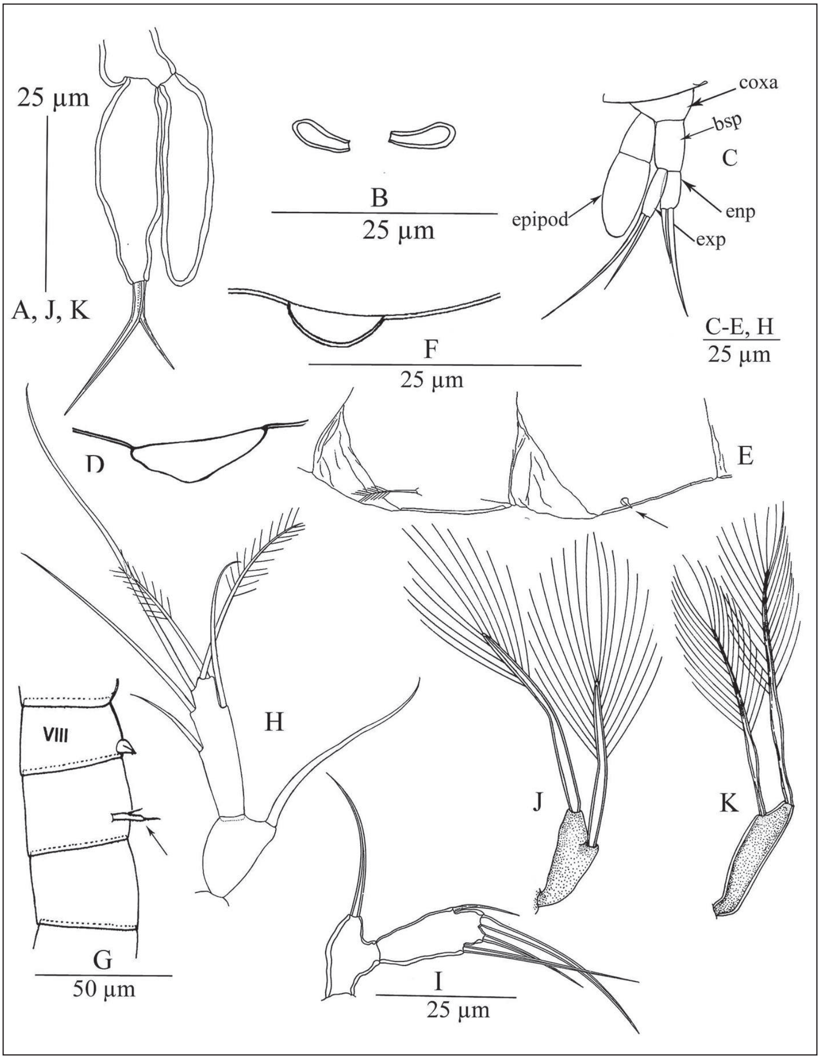

Fig. 15. Th VIII (A-F) and Pleopod I (G-K) : (A) *Serbanibathynella secunda*; (B) *Indobathynella prehensilis*; (C) *Camachobathynella meghalayaensis*; (D) *Habrobathynella krishna;* (E) *Atopobathynella paraoperculata;* (F) *Parvulobathynella projectura;* (G) *Chilibathynella kotumsarensis*; (H) *Camachobathynella meghalayaensis;* (I) *Serbanibathynella secunda;* (J) *Indobathynella prehensilis* (male); and (K) *Indobathynella prehensilis* (female).

conical, generally smooth and fused to basal protopod in *Habrobathynella*, but indiscernible in *Parvulobathynella* spp. In certain species of *Habrobathynella*, it is denticulate, suggesting its 'dynamic role in copulation as an element of the male genital complex' (Ranga Reddy & Totakura, 2010: 42; Coineau & Camacho, 2013: 373). Exp and enp small but distinct, showing great variation in size, shape, orientation and ornamentation, as in *Habrobathynella*. Exp is fused to basis (baexopod) in *Atopobathynella*; enp is apparently absent in *Parvulobathynella* (Fig. 14E).

Pleopod I (Fig. 15): present only in *Chilibathynella kotumsarensis* among the hitherto_species of Parabathynellidae; 1-segmented and armed with 1 apical and 1 subapical setae.

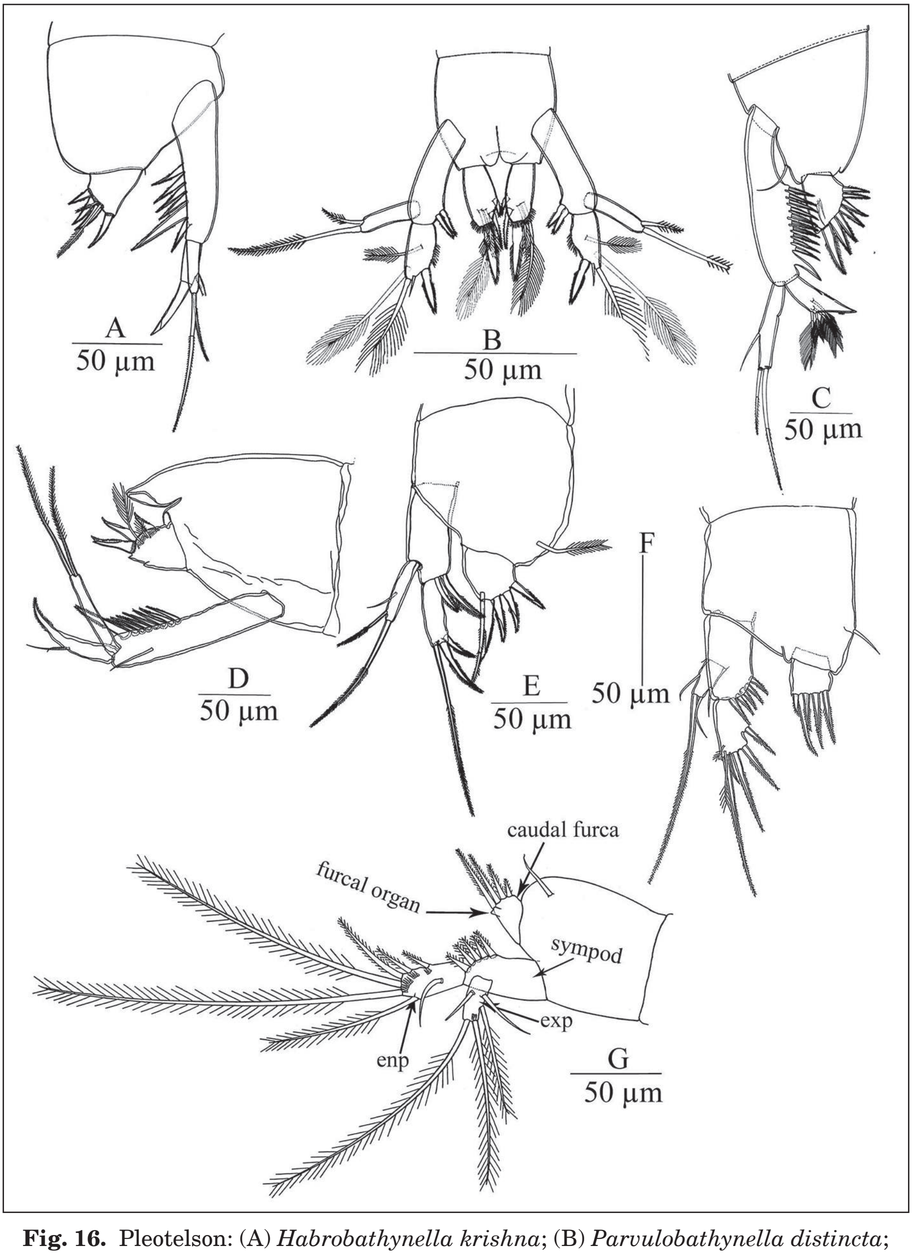

Fig. 16. Pleotelson: (A) *Habrobathynella krishna*; (B) *Parvulobathynella distincta*; (C) *Chilibathynella kotumsarensis*; (D) *Atopobathynella paraoperculata;* (E) *Indobathynella prehensilis;* (F) *Serbanibathynella secunda*; and (G) *Camachobathynella meghalayaensis*.

Urp (Fig. 16): basal segment, called sympod, has a row of similar (homonomous) or dissimilar (heteronomous) spines on inner distal margin or corner, and rarely 1 seta on outer distal margin, as in the Indian *Atopobathynella* spp. (Fig. 16D). Exp and enp of Urp vary in their relative size, shape and armature among taxa; enp generally sickle-shaped.

SYSTEMATIC ACCOUNT

Subphylum CRUSTACEA Brünnich, 1772

Class MALACOSTRACA Latreille, 1802

Subclass EUMALACOSTRACA Grobben, 1892

Superorder SYNCARIDA Packard, 1885

Order BATHYNELLACEA Chappuis, 1915

Family BATHYNELLIDAE Chappuis, 1915

Genus *Serbanibathynella* Ranga Reddy & Schminke, 2005

S. primaindica Ranga Reddy & Schminke, 2005

S. secunda Totakura & Ranga Reddy, 2014

Genus *Indobathynella* Ranga Reddy & Totakura, 2012

I. prehensilis Ranga Reddy & Totakura, 2012

Genus *Camachobathynella* Ranga Reddy, Shaik & Totakura, 2015

C. meghalayaensis Ranga Reddy, Shaik & Totakura, 2015

Family PARABATHYNELLIDAE Noodt, 1965

Genus *Chilibathynella* Noodt, 1964

C. kotumsarensis Ranga Reddy, 2006

Genus *Atopobathynella* Schminke, 1973

A. operculata Ranga Reddy, Drewes & Schminke, 2008

A. paraoperculata Ranga Reddy & Totakura, 2015

Genus *Habrobathynella* Schminke, 1973

H. nagarjunai Ranga Reddy, 2002

H. schminkei Ranga Reddy, 2004

H. indica Ranga Reddy & Schminke, 2005

H. plenituda Ranga Reddy & Schminke, 2009

H. krishna Ranga Reddy & Totakura, 2010

H. savitri Ranga Reddy & Totakura, 2010

H. vaitarini Ranga Reddy & Totakura, 2010

H. vidua Ranga Reddy & Totakura, 2010

H. ajraoi Totakura & Ranga Reddy, 2014

H. parakrishna Totakura & Ranga Reddy, 2014

H. pseudoindica Totakura & Ranga Reddy, 2014

H. borraensis Ranga Reddy, Shaik & Totakura, 2014

H. adishankara Elia, Shaik & Ranga Reddy, 2016

H. muvattupuzha Elia, Shaik & Ranga Reddy, 2016

Genus *Parvulobathynella* Schminke, 1973

P. distincta Ranga Reddy, Elia & Totakura, 2011

P. projectura Ranga Reddy, Elia & Totakura, 2011

P. macrodentata Ranga Reddy & Totakura, 2012

N.B. About a dozen new bathynellacean taxa in our samples await formal description.

Family BATHYNELLIDAE Chappuis, 1915

Genus ***Serbanibathynella*** Ranga Reddy & Schminke, 2005

Diagnosis: A I 7-segmented, second segment with apophysis at distal inner corner; A II 7-segmented; Md without gnathobase, 3 teeth on proximal segment of palp; palp 3-segmented, first and second segments subequal in length and with massive musculature and a joint between them; 2 long and sturdy setae on short distal segment; Mx II 4-segmented; enp of Th I–VII 3-segmented, second segment without feathered seta at outer distal corner; Urp with similar spines on sympod; furca with 5 spines, second one from inner margin longest.

Type species: *Serbanibathynella primaindica* Ranga Reddy & Schminke, 2005.

Other species: *S. secunda* Totakura & Ranga Reddy, 2014

Remark: Both species occur only in borewells (see Ranga Reddy & Schminke, 2005; Totakura & Ranga Reddy, 2014).

Table 2. Chief morphological differences between *Serbanibathynella primaindica* and *S. secunda*.

Characters	*primaindica*	*secunda*
A I: seta on basis	present	absent
Lb: shape of medial free margin	concave	convex
Md: teeth on proximal segment	3	4
Mx I: claws on proximal endite	4	3
Mx II: claws on segment 1 claws on segment 3	7 5	5 7
Th I-VII: build of enp	slender	strong
Th VIII male: setae on exp	4	5
Th VIII female: exp and enp armature elements	distinct 3	fused completely 2
Pleotelson: sympod spine row	homonomous	inhomonomous

Genus *Indobathynella* Ranga Reddy & Totakura, 2012

Diagnosis: Mx II 3-segmented and strongly prehensile; first segment unarmed; second segment large, bearing 7 setae; third segment with 1 apical claw and 1 seta.

Male Th VIII uncinate, with only 1 lobe (outer lobe) on coxa; Exp fused to basis and with 2 setae; enp totally absent. Female Th VIII reduced to 1 simple lobe. Th I-VII with 2-segmented exp and enp except for 3-segmented enp on Th I. Pleopod I 1-segmented, with 2 plumose setae; sexually dimorphic. A II with 4-segmented endopod, exp shorter than enp-1, and basis unarmed. Md with 3-segmented palp, similar in both sexes, and prehensile; gnathobase fused to basal segment of palp and represented by 5 teeth. Prg cuneiform and basally fused. Mx I with 1 slender claw on proximal endite; distal endite with 8 armature elements including 3 smooth subterminal outer setae. A I 7-segmented. Enp of Urp with 2 claws and 1 seta; exp with 3 setae including 1 ventro-medial seta. Caudal furca with 4 unequal spines and 1 seta. Pleotelson with 2 dorsal setae.

Type species: *Indobathynella prehensilis* Ranga Reddy & Totakura, 2012

Other species: Currently none.

Remarks: *I. prehensilis* is a highly aberrant bathynellacean species, showing an intriguing mix of plesiomorphic and apomorphic morphological features, and it is confined to phreatic waters of borewells (Ranga Reddy & Totakura, 2012).

Genus *Camachobathynella* Ranga Reddy, Shaik & Totakura, 2015

Diagnosis: Animals slightly exceeding 1 mm in length. A I 7- segmented, with 5 setae on segment 7. Enp of A II 5- segmented and perpendicular to A I, and exp without medial seta. Md palp 3-segmented and gnathobase moderate in size. Prg defined at base, densely covered with spinules and ending in dentate projection. Lb somewhat triangular with apical spinules. Max II 4- segmented; setal formula 6-4-6-4. Male Th VIII penile region consisting of moderately developed anterior plate, internal lobe and small lobe; basis slightly tapering distally and armed with 2 unequal setae at about mid-inner margin; exp about 4 times as long as wide and armed with 5 setae; and enp absent. Female Th VIII with large epipod, unarmed coxa and basis; exp and enp 1- segmented, with 2 setae each; enp slightly shorter than exp. Pleopod I 2- segmented, second segment with 6 setae. Urp sympod with 5 equal spines in oblique row; exp with 5 setae; enp 1.5 times longer than exp and with 3 claws and 4 setae. Caudal furca with 4 spines, increasing in length from inner to outer margin. Furcal organ large and dorso-lateral. Pleotelson with 2 dorsal moderately strong setae.

Type species: *Camachobathynella meghalayaensis* Ranga Reddy, Shaik & Totakura, 2015.

Other species: currently none.

Remarks: C. *meghalayaensis* an interesting Palearctic species on the Indian subcontinent (Ranga Reddy *et al.,* 2015). Morphologically, it is decisively primitive as compared with the hitherto known four tropical Gondwanan species in two genera of Bathynellidae, viz. *Nannobathynella marcusi* Noodt, 1969, from São Paulo (Noodt, 1969), *Nannobathynella africana* Schminke and Wells, 1974, from Zimbabwe (Schminke & Wells, 1974), and *Nannobathynella eburnea* Schminke, 1979, from Ivory Coast (Schminke, 1979), and *Agnathobathynella ecclesia* Schminke, 1980, from Malawi (Schminke, 1980). All the current records show that C. *meghalayaensis* is apparently endemic to the Meghalaya State.

Family PARABATHYNELLIDAE Noodt, 1965

Genus ***Chilibathynella*** Noodt, 1964

Diagnosis: A I 7- segmented, with sexual dimorphism, with 'antennal organ' at inner distal corner of second segment in male. Antenna 4- to 6- segmented. Md p*ars molaris* with 8 claws. Mx II 4-segmented with profuse setation. Exp of Th I-VII 1-segmented; outer plumose seta of enp-2 of Th V-VII rudimentary or absent. Th VIII male with large subglobular protopod and large bulbous posteriorly directed basis; small enp with 2 or 3 setae; exp with tooth-like structures. Th VIII female 1-segmented. Pleopod I I-segmented, with terminal seta(e). Urp sympod with row of several spines. Both dorsal setae on caudal furca smooth and subequal in length, short, not reaching beyond tip of terminal spines.

Type species: *Chilibathynella clandestina* Noodt, 1963 (Central Chile)

Other species: *C. australiensis* Schminke, 1973 (Southern Australia) and *C. kotumsarensis* Ranga Reddy, 2006 (India).

Remarks: For dichotomous key for the above-mentioned species, the reader is referred to Schminke (2011). Two more species have recently been added to this genus by Camacho & Hancock (2012) from New South Wales, Australia: *C. joshuai* Camacho & Hancock, 2012, and *digitus* Camacho & Hancock, 2012.

Genus *Atopobathynella* Schminke, 1973

Diagnosis: A I 6-segmented, with 'antennal organ' in male. A II 1-segmented, with 2 smooth and 1 plumose apical setae, and 1 inner proximal seta. Lb heterodont with numerous teeth, of which middle ones smaller. Md with *pars incisiva* with generally 3 and rarely 2 teeth; *pars molaris* with 1 row of 5 or 6 claws; palp very short. Distal endite of Mx I with 6 or 5 claws. Mx II generally 4-segmented, with setal formula: 2-4-n-7. Exp of Th I-VII 1-segmented, of Th II-VII with 2 apical setae and 1 ventral subapical seta; enp of Th I-VII 4-segmented, fourth segment tiny, of Th II-VII with 1, rarely 2 very long claws; setal formula of segments 1-3: 0+0/0+1/0+1. Th VIII rather small, semicircular in lateral view; protopod massive, anteriorly with dentate lobe; external lobe drawn out into anteriorly-directed conical projection; basis triangular, as large as external lobe, with 2 setae of unknown homology. Pleopod I represented by 1 seta. Urp sympod generally with homonomous row of sever spines; enp with dagger-like extension and with 2 setae at base.

Type species: *Atopobathynella valdiviana* Noodt, 1965 (Chile)

Other species: *A. chelifera* Schminke, 1973 (Australia), *A. compagana* Schminke, 1973 (Australia), *A. hospitalis* Schminke, 1973 (Australia), *A. gascoyneensis* Cho, Humphreys, & Lee, 2006 (Australia), *A. glenayleensis* Cho, Humphreys, & Lee, 2006 (Australia), *A. hinzeae* Cho, Humphreys, & Lee, 2006 (Australia), *A. readi* Cho, Humphreys, & Lee, 2006 (Australia), *A. schminkei* Cho, Humphreys, & Lee, 2006 (Australia), *A. wattsi* Cho, Humphreys, & Lee, 2006 (Australia), *A. operculata* Ranga Reddy, Drewes & Schminke, 2008 (India), and *A. paraoperculata* Ranga Reddy & Totakura, 2015 (India).

Remarks: According to Ranga Reddy & Totakura (2015), the hitherto known two Indian species (some more Indian new species in our samples await formal description), viz. *A. operculata* and *A. paraoperculata* stand out in the genus by the following characters: (i) the inner flagellum of the antennule is fused to the fourth segment or the first segment of the outer flagellum; (ii) the 'antennal organ' consists exclusively of two massive lobes; (iii) the antenna has three-instead of four armature elements; (iv) the proximal segment of the maxillule has two instead of four distinct claws; (v) the uropodal sympod has an outer seta in its distal third; (vi) the uropodal sympod also has an inhomonomous row of spines, with strongly developed distalmost spine; and (vii) the anal operculum is massive, reaching as far back as caudal furca. While the first, fourth and fifth characters are unique in the family Parabathynellidae (Ranga Reddy *et al.,* 2008), the other three characters render both species quite distinct from all their known congeners. *A. operculata and A. paraoperculata* can be easily separated from each other mainly by the following principal criteria: the second A I segment in the female has one seta vs. two setae seta at inner distal corner; A II is distinct vs. fused; the labrum is with vs. without tubular pores; the tooth/ spine that is next-to-the proximalmost one (see below) of the mandibular *pars molaris* is normal vs. modified; enp2 of Th I has one vs. two setae; the sympod of Urp has eight vs. four spines; the uropodal enp has one normal seta vs. two weak setae; Urp exp is shorter than vs. as long as endopod; and pleotelson is armed vs. unarmed.

Both *A. operculata* and *A. paraoperculata* have so far been known only from the interstitial hyporheic habitats in the costal deltaic region.

Key to *Atopobathynella* Schminke, 1973

1. Caudal furca with 3 or 4 spines...2

   Caudal furca with more spines...4

2. Urp sympod with inhomonomous spine row and with 1 lateral seta; A II with 3 armature elements; Mx I proximal segment with 2 distinct claws 3

   Urp sympod with homonomous spine row and without lateral seta; A II with 4 armature elements; Mx I proximal segment with 4 distinct claws 8

3. Urp sympod with 4 spines; Urp enp with 1 normal seta; massive anal operculum rounded distally; Lb with tubular pores; enp of Urp with 1 seta ....*A. operculata*

   Urp sympod with 8 spines; enp of Urp with 2 weak setae; massive anal operculum triangular and pointed distally; Lb without tubular pores; enp of Urp with 2 setae ....*A. paraoperculata*

4. A I segment 1 with dorsal simple seta; labrum with 16 teeth; Urp sympod greatly dilated; Urp exp and enp of much reduced in size............*A. schminkei*

   A I segment 1 with 2 dorsal simple setae; Lb with more than16 teeth; Urp sympod not dilated; Urp exp and enp normal size 5

5. Exp of Th II–VI with 4 setae (2 terminal, 2 ventral), both terminal setae long but subequal in length; Th II–VII enp-4 with 2 claws ....*A. readi*

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Exp of Th II–VI with 3 setae (2 terminal, 1 ventral), dorsal terminal seta shorter than ventral one; Th II–VII enp-4 with 1 claw......................................6

6. Exp of Th I with 2 terminal and 1 ventral setae; setae of enp of Urp unequal in length (proximal seta 25% shorter)...*A. hospitalis*

   Exp of Th I with 2 terminal setae only; setae of enp of Urp subequal in length 7

7. Th I without epipod; exp of Th VII with 2 setae; male A I with antennal organ ....*A. hinzeae*

   Th I with epipod; exp Th VII with 3 setae; male A I without antennal organ ....*A. gascoyneensis*

8. Enp of Urp with 2 long setae, reaching beyond tip of enp; Th I with epipod....9

   Enp of Urp with 2 short setae, not reaching beyond tip of enp; Th I without epipod...11

9. Caudal furca with 5 spines; spine row of Urp sympod with 4 homonomous spines ....*A.valdiviana*

   Caudal furca with more spines; spine row of Urp sympod with more 10 homonomous spines 10

10. Dorsal terminal seta of exp of Th II–VII short (only 1/3 as long as ventral seta); caudal furca stretched (3 times longer than wide); exp of Urp long (over half as long as enp)...*A. wattsi*

    Dorsal terminal seta of exp of Th II–VII long (as long as ventral seta); caudal furca normal (1.5 times longer than wide); exp of Urp short (less than half as long as enp)..*A. glenayleensis*

11. Exp Th I–VII with tiny dorsal seta; caudal furca twice as long as wide; male A I with antennal organ as long protrusion with 2 setae at inner distal corner of second segment...*A. chelifera*

    Exp Th I–VII with long dorsal seta; caudal furca slightly longer than wide; male A I with antennal organ as rod-like seta as long as next segment *A. compagana*

Genus ***Habrobathynella*** Schminke, 1973

Diagnosis: Md palpless, *pars molaris* somewhat pyriform, bearing 5-6 teeth. Male Th VIII globular to oval in outline, basis bearing 1 seta, and exp highly chitinised, generally distinct from basis and as incurved claw or hook (appearing as rectangular or conical denticulate structure in ventral view) and enp represented by 1 seta. Caudal furca armed with 4 spines. Lb generally vaulted or sometimes nearly straight, with 8-12 main teeth. A II 2-segmented, distal segment with 4 setae. A I 6-segmented, apophysis on segment 4 digitiform and penultimate segment with 2–3 aesthetascs. Mx II 2- or 3-segmented; segment 2 with 1 modified, somewhat prehensile seta; segment 3 either distinct or fused to massive prehensile terminal claw. Th I–VII with 2-segmented exp. Urp sympod spine row inhomonomous (exception: homonomous in *H. nagarjunai*).

Type species: *Habrobathynella milloti* (Delamare Deboutteville & Paulian 1954) (Madagascar)

Other species: *H. jeanneli* (Delamare Deboutteville & Paulian 1954) (Madagascar), *H. nagarjunai* Ranga Reddy, 2002 (India), *H. schminkei* Ranga Reddy, 2004 (India), *H. indica* Ranga Reddy & Schminke, 2005 (India), *H. plenituda* Ranga Reddy & Schminke, 2009 (India), *H. krishna* Ranga Reddy & Totakura, 2010 (India), *H. savitri* Ranga Reddy & Totakura, 2010 (India), *H. vaitarini* Ranga Reddy & Totakura, 2010 (India), *H. vidua* Ranga Reddy & Totakura, 2010 (India), *H. ajraoi* Totakura & Ranga Reddy, 2014 (India), *H. parakrishna* Totakura & Ranga Reddy, 2014 (India), *H. pseudoindica* Totakura & Ranga Reddy, 2014 (India), *H. borraensis* Ranga Reddy, Shaik & Totakura, 2014 (India), *H. adishankara* Elia, Shaik & Ranga Reddy, 2016 (India), and *H. muvattupuzha* Elia, Shaik & Ranga Reddy, 2016 (India).

Key to the species of *Habrobathynella* Schminke, 1973

1. All spines of Urp sympod equal in size ....*H. nagarjunai*

   Either or both of ultimate and penultimate spines of Urp sympod longer than others 2

2. Both ultimate and penultimate spines of Urp sympod longer than others; setae on pleotelson absent ....*H. vidua*

   Either ultimate or penultimate spine of Urp sympod longer than others; setae on pleotelson present 3

3. Penultimate spine of Urp sympod longer than others 4

   Ultimate spine of Urp sympod longer than others 9

4. Ultimate spine of Urp sympod unmodified and of the size of others; setae on Urp enp as long as or shorter than exopod 5

   Ultimate spine of Urp sympod modified into a typical seta; at least one seta of Urp enp as long as or longer than exopod 8

5. Setae on Urp enp shorter than exopod; pleotelson setae extremely reduced..*H. krishna*

   Setae on uropodal endopod as long as or larger than exopod; pleotelson setae normal..6

6. Male Th VIII rectangular, protopod being not expanded distally ....*H. parakrishna*

   Male Th VIII subglobular, protopod being expanded distally 7

7. Mx II segment 1 with 2 setae; fifth AI segment with 2 aesthetascs; A II segment 1 short ....*H. muvattupuzha*

   Mx II segment 1 with 1 seta; fifth A I segment with 3 aesthetascs; first II segment long..*H. adishankara*

8. Mx II segment 1 with 2 unequal setae; Mx II segment 3 unfused to terminal claw; spine-row margin of Urp sympod undilated; Prg with large and bilobed coupler and large lateral lobes ....*H. schminkei*

   Mx II segment 1 with 1 greatly reduced seta; Mx II segment 3 fused to terminal claw; spine-row margin of Urp sympod dilated; Prg with unilobed coupler and small lateral lobes ....*H. savitri*

9. Md *pars molaris* ("lobe") fork-like with 4 teeth; male Th VIII with extraordinary long basipodal seta .... *H. ajraoi*

   Mdr *pars molaris* ("lobe") nearly pyriform with 5 or 6 teeth; male Th VIII with short basipodal seta 10

10. Urp sympod with 3 proximal spines 11

   Urp sympod with either 4 or 6 proximal spines 14

11. Male Th VIII with penile region (inner and dentate lobes) produced into unusually long penis-like organ extending forward up to Th VII .... *H. indica*

   Male Th VIII with unproduced penile region .... *H. jeanneli*

12. Mx II segment 1 with 2 setae; Th I without seta on enp-1 .... *H. pseudoindica*

   Mx II segment 1 with 1 setae; Th I with1 seta on e1 13

13. Urp exp produced into short spinous process at inner distal angle; A I segment 5 with 2 aesthetascs; female Th VIII absent .... *H. milloti*

   Urp exp without any such process at inner distal angle; A I segment 5 with 3 aesthetascs; female Th VIII present .... *H. borraensis*

14. Urp sympod with 4 proximal spines; Mx II segment 3 not fused to terminal claw; pleotelson setae longer than caudal furca .... *H. plenituda*

   Urp sympod with 6 proximal spines; Mx II segment 3 fused to terminal claw; pleotelson setae shorter than caudal furca .... *H. vaitarini*

Genus *Parvulobathynella* Schminke, 1973

Diagnosis: A I 6-segmented. A II 5-segmented; seta; formula: 0+0/0+1(0)/1+0/1+0/3(1). Lb lobes with spinules. Md with proximal-most tooth of *pars incisiva* lying perpendicular to other teeth; cutting edge with 4-5 small teeth. Mx I with proximal endite protruding only slightly, with 4 setae; distal endite with 5 claws, distal 3 claws grouped together, other 2 claws spaced apart on inner margin; 2 setae on distal outer margin. Mx II 3- or 2-segmented, prehensile; proximal endite without setae; terminal segment tiny, fused to or distinct from sturdy curved claw. Th I-VII with 2-segmented exp; enp 4-segmented; setal formula 0+0/0+1/0+0/2(1). Pleotelson without lateral setae. Caudal furca rounded terminally, with 1 terminal spine and 2 inner spines or setae (rearranged from Schminke, 2011).

Type species: *Parvulobathynella ypacaraiensis* (Noodt, 1963) (Paraguay)

Other species: *P. composicola* (Jakobi, 1961) (Brazil), *P. duodecima* Cho & Schminke, 2001 (South Africa), *P. octacantha* Cho & Schminke, 2001(South Africa), *P. pentodonta* (Serban & Coineau, 1982) (Ivory Coast), *P. riegelorum* (Noodt, 1965) (Chile), *P. distincta* Ranga Reddy, Elia & Totakura, 2011 (India), *P. projectura* Ranga Reddy, Elia & Totakura, 2011 (India), and *P. macrodentata* Ranga Reddy & Totakura, 2012 (India).

Remark: Of the three Indian species, while *P. distinct* and *P. projectura* inhabit the alluvial sediments of rivers (Ranga Reddy *et al.,* 2011), *P. macrodentata* is confined to borewells (Ranga Reddy & Totakura, 2012).

Key to Species of *Parvulobathynella* Schminke, 1973

1. Body with rounded protuberance at postero-lateral angle of each of thoracic and abdominal segments; Lb smooth .... *P. projectura*

   Body without such protuberances; Lb spinulose 2

2. Th I alone without epipod; Urp enp with 2 separate spines ...... *P. camposicola*

   Either Th I-II or Th I-III without epipod; Urp enp with 1 separate or fused spine 3

3. Th I-II without epipod 4

   Th I-III without epipod 7

4. Md with large, contiguous molar teeth; ventral edge tooth large and with proximal denticle. .... *P. macrodentata*

   Md with small, closely-spaced molar teeth; ventral edge tooth small and without denticle 5

5. Urp enp with fused spine; inner spines on caudal furca only slightly smaller than terminal spine .... *P. pentodonta*

   Urp enp with separate spine; inner spines of caudal furca distinctly smaller than terminal spine 6

6. Urp enp with small, bare, spiniform inner terminal seta; maxillule with rudimentary distal–most armature element on proximal endite. *P. duodecima*

   Urp enp with tiny inner terminal spinous process; the said armature element on maxillule strong .... *P. riegelorum*

7. Terminal furcal spine as long as furca; epipod Th IV-VII unsegmented .... *P. distincta*

   Terminal spine distinctly shorter than furca; epipod on Th IV-VII bisegmented 8

8. Urp enp with small, naked, terminal spiniform seta; labrum with 8 spinules .... *P. octacantha*

   Urp enp with tiny terminal spine; labrum with 28 spinules .... *P. ypacaraiensis*

BIOGEOGRAPHY

To understand the biogeography of the Indian Bathynellacea, it would only be appropriate to refer to the milestones in its biogeographical evolution of India. India was initially nestled in the supercontinent Pangaea at high southerly latitudes between Late Paleozoic and Early Permian *ca.* 255 Ma. The Pangaea was intact during the Late Triassic and Early Jurassic periods, but the first stage of its rifting took place in the Middle Jurassic period *ca.* 180 Ma. Before its journey into northern latitudes, the Indian plate rifted from other Gondwana landmasses at different times in the geological past—from Africa along with Madagascar *ca*. 180-170 Ma, from Antarctica-Australia *ca*. 130 Ma, and from Madagascar *ca*. 90 Ma. Eventually, the docking against Asia began *ca.* 55-65 Ma. During its tectonic evolution from the Pangaean times to the present day, the Indian plate acted both as a biotic "ferry" and a biotic sink (Rust *et al.,* 2010), and experienced, *inter alia*, extensive exchange between the peninsular autochthonous and the Asian Tertiary biota (Mani, 1974; Chatterjee & Scotese, 1999; Briggs, 2003; Ali & Aitchison, 2008). As a result, the modern terrestrial and freshwater biota of India are overwhelmingly "Oriental" despite the fact that a few living relicts, both invertebrates and vertebrates that might date back to the pre-drift period, do exist here. According to Mani (1974), "The Peninsula *per se* is biogeographically *India vera*, the largest and the oldest region of differentiation of the original floras and faunas of India."

Generally, all the obligate subterranean fauna (stygobionts) may be good candidates for historical biogeography. However, the crustaceans as a group are better suited for this purpose because they are dominant and widespread in the ecosystems of both of karstic and alluvial aquifers. And amongst crustaceans, the members of the order Bathynellacea, in particular, have long been recognized as suitable objects for understanding the history of the earth crust as well as biological speciation. This is because they belong to vey an ancient lineage, live as unobtrusive ecological generalists, occupy relatively inaccessible, cryptic habitats, i.e. interstitial spaces of sandy river banks, caves, etc.; and are endowed with very limited powers of dispersal, lacking resting stages. Further, the biogeographical studies based on stygobionts assume special importance at this juncture when the globalization of world's economy has brought about increasing effects of homogenization of the world's biota. As a result, the study of biogeography, which was once "a pillar of evolution science", has now come to be greatly distorted by the presence of alien invasive organisms. For example, the biogeographical catastrophe that has befallen the San Francisco Bay, USA, which reportedly has some 234 invasive species, constituting about 90% of its aquatic population is worthy of note (Schram, 2008).

All the four genera of the Parabathynellidae show typical Gondwanan heritage (Ranga Reddy 2011), but, not surprisingly, all their 20 species (see Systematic Account) are endemic to peninsular India. On the other hand, all the three known Indian genera of Bathynellidae are endemic to India. Whereas *Serbanibathynella* and *Indobathynella are* confined to the peninsular zone, the monotypic *Camachobathynella* occurs in the northeastern Meghalaya state of the Extra-Peninsular area of the ancient Indian Peninsula, and it is "in all probability a younger Palaearctic intrusive ..." (Ranga Reddy et al. 2015: 712). *Serbanibathynella* and *Indobathynella* might have evolved as Briggs' (1989) "peculiar fauna on the Indian plate, which existed far out in the Tethys Sea as an isolated continent for about 100 ma." All in all, the present-day geographic distribution of Bathynellacea can more plausibly be explained by the vicariance model rather than by the classic dispersal model (see Schram 1977; Schminke 1981).

The biogeographical affinities of the four Indian parabathynellid genera and their implications are outlined below.

Genus *Chilibathynella*. When it was known only by two species, viz. the Chiliean *C. clandestina* and the Australian *C. australiensis,* this genus was presumed to be "an entirely austral group", displaying transantarctic relationships (Schminke 1974). Also, in terms of panbiogeography, this genus was believed to belong to the southern temperate track, which connects the southern South America, Australia, Tasmania, and New Zealand, with Pacific basin baseline (Lopretto & Morrone 1998). However, the discovery of the Indian cavernicolous *C. kotumsarensis* has extended the biogeographical range of the genus far north into the tropical belt of Northern Hemisphere (Ranga Reddy 2006). Till date, this species is endemic to the Kotumsar Cave in Chhattisgarh state and further Indian species, if any, of this genus have yet to be discovered.

Genus *Habrobathynella*. Originally established for two Madagascan species (*H. milloti* and *H. jeanneali*), this genus is most speciose in India, with 14 species having already been known from the peninsular region. Most of these species inhabit alluvial sediment of rivers and streams of the Krishna-Godavari basin, but are yet to be discovered in far inland phreatic ecosystems (Ranga Reddy *et al.,* 2014). The speciation process of within this genus vis-à-vis other genera, in the interstitial hyporheic habitats of the Krishna-Godavari basin is remarkable. Among the known species, *H. schminkei*, given its recent find in a far-flung cave in Meghalaya state (unpubl.), has such a remarkably wide range of distribution that runs counter to the generally accepted concept of short-range endemism of Harvey (2002), Schram (2008), Eberhard et al. (2009), Karanovic & Cooper (2011a, b), and several other stygobiologists. Harvey's (2002) stipulated distribution range is only <10,000 km^2. Hence this species, *inter alia*, prompts much deeper morphological as well as molecular studies to determine if it is a cryptic species (see Totakura & Ranga Reddy, 2015: 4).

Genus *Atopobathynella*. Of the 12 species so far known under this genus, one species is from Chile, nine from Australia and two from India. This genus is also known from an undescribed Madagascan species (Schminke, 1981). The geographical range of this genus thus extends to both East and West Gondwana continents. Prior to its Indian records, Lopretto & Morrone (1998) assigned this genus as well as *Chilibathynella* to the southern temperate track (see above), which is no longer tenable.

Genus *Parvulobathynella*. This is a most derived genus, presently containing nine species in the world, all from the Gondwana landmasses. This is yet another iconic case of Gondwanan lineage.

Not surprisingly, the Indian bathynellaceans show no close phylogenetic affinity with their Asian counterparts. In fact, the latter taxa are clearly plesiomorphic, which prompted Schminke (1974) to presume that East Asia was the centre of evolution of Bathynellacea.

THREATS AND CONSERVATION MEASURES

As already mentioned under Introduction, bathynellaceans inhabit mainly the hyporehic zone of rivers and streams and the phreatic systems like caves and borewells. How these habitats have been threatened by various anthropogenic activities, and the measures to be initiated to protect and conserve the bathynellaceans are summarized below.

1. Loss and pollution of hyporheic habitats

The hyporheic zone present within the sandy banks of rivers and streams and sandwiched between the surface water and groundwater ecosystems as a dynamic ecotone is well known to harbor a heterotrophic assemblage of both interstitial and benthic community (hyporheos) of diverse groups of organisms including some ancient and relictual taxa (see Hakenkamp & Palmer, 1999). Indeed, our stygofaunistic investigations have revealed that the bathynellacean species richness is higher in the hyporheic system than in the phreatic ecosystems (Ranga Reddy, 2014). However, scant attention, if any, has been paid to the study of biodiversity and functioning of hyporheic ecosystems in India. It is disconcerting to note that these unique and as-yet unexplored ecosystems have already come under the devastating impact of excessive sand extraction, fuelled by the construction boom in the wake of rapid urbanization. In Andhra Pradesh state where regular stygofaunistic investigations have just begun for the first time in the country, the Government has legalized the sand mining and auctioning as a social welfare measure, thus further exacerbating the loss of hyporheic habitats and their irreplaceable biodiversity.

In this context, it is also noteworthy that bathynellaceans are apparently more sensitive than other stygobionts to chemical pollutants. A case in point is the local extinction of *Habrobathynella indica* at its type locality, i.e. the River Krishna at Vijayawada city. Not even a single specimen of this species has been found at its type locality despite periodic samplings after it was first collected on 31 August 1998 (two males and two females turned up in a sample collected on 7 December 2008 in the same river, but 47 km downstream of the type locality). One possible reason for the local extinction of *H. indica* is that the untreated domestic sewage is being continuously released into the river. Furthermore, the deleterious effects of increased industrial pollution in the vicinity of the type locality cannot be underestimated (Ranga Reddy & Totakura, 2010). Some of the measures/ recommendations to protect and conserve hyporheic biodiversity include:

At least certain tracts of each of our river banks must be given legal protection against the sand mafia so that such protected corridors could ensure the regeneration and preservation of the hyporheic biota. Dry-pit mining is preferable to other mining methods.

Large rivers and streams should be used for selective sand mining instead of small rivers and streams.

Immediate steps need be taken to encourage research activities leading to the finding of suitable, low-cost and easily available alternatives to river sand for construction industry.

To enforce strict antipollution measures and to monitor point sources pollution.

2. Overexploitation and contamination of groundwater

Groundwater was once thought to be an inexhaustible natural resource. There are no legal curbs whatsoever on the extraction of groundwater for drinking, agricultural or industrial purpose. As a result, people are exploiting it so much that water tables are falling at dangerously low levels on every continent. Hence, incalculable damage is being done to the phreatic fauna including bathynellaceans. Many valuable species must have already gone extinct by the relentless overexploitation of groundwater alone. Furthermore, the State Governments in India have aggravated the problem by offering the farmers either free or subsidized electricity supply to operate the agricultural pump sets. Overexploitation of groundwater is compounded by the fact that groundwater recharging has been reduced by changes in land use. Besides being depleted, groundwater is becoming increasingly polluted by fertilizers, pesticides, sewage, fuel from leaking storage tanks, and other contaminants.

Some measures to enhance the groundwater supply and ameliorate its quality include water-saving technologies such as root-zone irrigation, educating the general public and impressing upon them its dwindling supply, economy of its use, and reducing subsidies for fertilizers and pesticides. According to Danielopol et al. (2003), "Groundwater ecosystems should be included in the plans for the establishment of protected areas and natural resources."

3. Threats to cave ecosystems

What with its vast territory, ancient and varied geomorphology, hydrology, and climate, the Indian subterranean domain has given rise to numerous natural caves and cavities of varied shapes and sizes. So far, no regular faunistic studies of the Indian caves have begun. Our recent survey of certain caves has revealed not only several interesting bathynellaceans and other ancient crustaceans as well (see Ranga Reddy, 2006; Wilson & Ranga Reddy, 2011; Totakura *et al.,* 2014; Wilson *et al.,* 2015). Unfortunately, cave ecosystems in India have already been threatened by a host of anthropogenic activities such as mining/quarrying, agriculture, religious rituals and the consequent pollution, land clearance, etc. (Harries et al., 2008; Biswas, 2009, 2010). There are no legal curbs whatsoever on such ongoing pernicious myopic activities, which are indeed threatening the very existence of not only the cave organisms but the caves themselves. The State Governments have indeed added to the problem by converting the caves into tourist spots. Certain caves are even illumined and artificially aerated as part of tourism industry (e. g. Belum Caves and Borra Caves in Andhra Pradesh). In safeguarding the caves, NGOs can play a vital role in creating awareness among the general public about the cave organisms and their importance. More importantly, the Central and State Government need to enact suitable, stringent legislation to protect the caves in the country. The funding agencies will do well to play proactive role in liberally funding and encouraging biospeleological research in India.

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Chapter 20

CRUSTACEA : DECAPODA (SHRIMPS AND CRABS)

K. VALARMATHI

ABSTRACT

The order Decapoda which comprises the familiar crustaceans like shrimps and crabs are an important group of the class Malacostraca. A global estimate accounts 655 species of caridean shrimps and 1,476 species of brachyuran crabs are available in freshwater. In India two families of the Caridean shrimps namely Atyidae and Palaemonidae are well represented by 118 species and 14 genera. Among the brachyuran crabs106 species belonging to 40 genera and 5 families are known from freshwater. This includes 100 species of primary freshwater crabs placed under the families Gecarcinucidae and Potamidae; and 6 species of secondary freshwater crabs belonging to the families Hymenosomatidae, Sesarmidae and Varunidae.

Key words: Crustacea, Decapoda, Caridea, Brachyura, Freshwater, India.

INTRODUCTION

The order Decapoda is a remarkably diverse group of the class Malacostracans both morphologically and ecologically and is a group of great economic and environmental importance (Dixon, 2003). The decapod crustaceans possess ten pairs of thoracic legs. The first one to 3 pairs of legs are modified in different groups to carryout some specialized functions and they are often considered as important taxonomic characters to differentiate allied taxa. Out of 15,000 described species of decapod crustaceans about 3000 species (ca. 20%) are considered as freshwater species, which includes caridean shrimps, freshwater crayfish, brachyuran and anomuran freshwater crabs (De Grave *et al*., 2008; Yeo *et al*., 2008; Vogt, 2014). The freshwater carideans are dominated by the nearly exclusively freshwater Atyidae and the Palaemonidae but these families also include many brackish water and marine representatives (De Grave *et al*., 2008; Vogt, 2014). At present 45 genera are recognized under the family Ayidae and the genus *Caridina* is numerically dominated. The species rich genus *Macrobrachium* of the family Palaemonidae is well represented in many freshwater ecosystems.

An estimate of 6800 species of brachyuran crabs are known globally of which most of them are marine but one fifth of them are strictly freshwater forming the largest assemblage within Brachyura which in turn forms a species rich group of freshwater Decapod crustaceans (Cumberlidge *et al.* 2009). The freshwater crabs can be divided into primary freshwater crabs that belong to the families Gecarcinucidae, Potamidae, Potamonautidae, Pseudothelphusidae and

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Trichodactylidae, and the secondary freshwater crabs that have representatives in Gecarcinucidae, Goneplacidae, Hymenosomautidae, Ocypodidae, Sesarmidae, Portunidae, Xanthidae and Varunidae (*Yeo et al.,* 2008; Vogt, 2014). Among the 5 families primary freshwater crabs of the families Gecarcinucidae and Potamidae are well established in India and a few species of secondary freshwater crabs belonging to the families Hymenosomautidae, Sesarmidae, and Varunidae are reported in freshwater zones.

Fossil Record

The fossil record of freshwater decapod crustaceans is generally very sparse and from India *Potamon sivalense* was described by Glaessner (1933) from the Siwalik beds (Middle Miocene to Pliocene) in the northern part of the Indian Subcontinent, but there is no information on the exact location and age (Klaus *et al.,* 2011).

Historical Resume

Caridea: As for as the Caridean shrimps are concerned Fabricius (1798) described three new species of *Palaemon* (=*Macrobrachium*) from Southern India. Much later Henderson and Matthai (1910) reported the distribution of 9 species of *Palaemon* (=*Macrobrachium*) including three new species from Southern India. Kemp (1913, 1917, 1918, 1924 and 1925) made a significant contribution to the Indian decapod taxonomy and described many new species. Chopra and Tiwari (1947) reported the distribution of 3 species of *Caridina* including a new species and 3 species of *Macrobrachium* from then Patna State. Subsequently, Tiwari (1947) provided preliminary description of major characters of the two new species of *Palaemon* (=*Macrobrachium*) collected from Bengal. The contribution made by Tiwari (1949a,b, 1952,1955a,b and 1963) is highly commendable which resulted in addition of many new species of freshwater shrimps from India and adjoining countries. Pillai (1964) reported four species of Atyid shrimps from Kerala and later a new species *Caridina natarajani* was described by Tiwari and Pillai (1968). From Dharwar area of Karnataka Jalihal *et al*. (1984) erected five new species of the genus *Caridina*. Jayachandran and Joseph (1985a,b, 1988a,b,c, 1989), Jayachandran (1984, 1987,1991,1992,2001 and 2002) made a noteworthy contribution to the taxonomy, distribution and bioecology of palaemonids shrimps of Kerala and they have also described many new species from there. While studying the freshwater prawns of Dharwar area of Karnataka Jalihal *et al.* (1988) recorded 10 species of *Macrobrachium* of which three species were new to science. While investigating the faunal resources of West Bengal (North & South 24 Parganas districts) Nandi *et al*. (1993 & 1999) reported some Atyid and Palaemonid shrimps from West Bengal. Richard and Chandran (1994) studied the freshwater prawns of the family Atyidae from Chennai (=Madras) and reported the occurrence of four species of *Caridina*. The faunal inventory of Meghalayan Palaemonid prawns by Ghosh and Ghattak, (1999) revealed the distribution of 9 species of *Macrobrachium.*

Maya Deb (2000) and Ghosh and Roy (2000) reported 8 species of *Macrobrachium* from Tripura. While studying the distribution of prawns in Assam, Dutta (2001) noticed the presence of *Caridina weberi* de Man, and 8 species of *Macrobrachium.* Mariappan *et al*. (2002a) reported the distribution of 7 species of

Macrobrachium in River Cauvery, Tamilnadu. Roy *et al*. (2003) studied the decapod fauna of Sikkim and reported *Macrobrachium hendersoni* (de Man) along with six species of crabs. From Manipur Roy *et al.* (2004) reported 10 species Decapods comprising 8 species of *Macrobrachium*. Jayachandran and Raji (2004) described a new beautifully colored *M. ornatus* from the Muvattupuzha River at Pothanikkad, Kerala. Ghosh *et al.* (2005) while investigating the freshwater prawns of Andhra Pradesh reported the occurrence of five species of *Macrobrachium.* Jayachandran and Raji (2005) during the exploration of Western Ghats described three new species of *Macrobrachium* from Kerala. Almelkar and Sankolli (2006) described two new species of *Macrobrachium* from Mahrashtra. From Kanchipuram and Thiruvallur district of Tamilnadu Mariappan and Richard (2006) recorded 6 species of *Caridina* including a new species and 3 species of *Macrobrachium*. Raghunathan and Valarmathi (2007a,b) reported 4 species of *Caridina* and 4 species of *Macrobrachium* from a paddy field located in Singaperumal Koil near Chennai and 3 species of *Caridina* and 5 species of *Macrobrachium* from Bannerghatta National Park, Karnataka. Jayachandran *et al.* (2007) described a new species of freshwater prawn namely *M. kulsiense* from the Kulsi River, one of the tributaries of River Bramaputra (India). Tessa Thomas and Jayachandran (2007) reported the occurrence of *C. jalihali* for the first time outside its type locality from paddy fields and adjoining channels at Anchal, Kollam District and recommended it as a candidate species for aquarium. Patil *et al.* (2007) while exploring the freshwater Decapods of Narth Sagar wetland noticed the presence of *M. lamarrei* (H. M. Edwards) and *M. kistnense* (Tiwari). Klotz (2008) described a new species namely *M. agwi* from Alipurduar District, West Bengal. Valarmathi (2009) made an investigation of the Atyid and Palaemonid Shrimps of Southern India. Silas and Jayachandran (2010) described *C. mathiassi* from Southern Western Ghats. From Vamanpuram River, Kerala Jayachandran and Thomas (2012) described a new species namely *C. vithuraensis*. Thomas, (2011) described *C. chalakkudiensis*, *C. keralensis* from Kerala and this information is available in her thesis but there were no further published information about this species and moreover the validity of the species is doubtful. Unnikrishnan et al. (2011) described *M. madhusoodani* from Ithikara River Kerala. Subsequently Pillai and Unnikrishnan (2013) found a new species *M. snpurii* from Kerala. Valarmathi and Raghunathan (2013) studied the freshwater shrimps of Karnataka and reported 6 species of *Caridina* and 14 species *Macrobrachium* from the state. Pillai *et al*. (2015) described *M. indianum* from Pamba River in Kerala.

Brachyura: The Indian freshwater crabs are poorly investigated (Cumberlidge *et al.* 2009, Pati and Sharma, 2014) and the earlier contributions were made by Wood-Mason (1871), Henderson (1893, 1912 and 1913), Doflein (1900) etc. Alcock (1909a,b, 1910) made a significant contribution to the Indian carcinology. The contribution made by other workers like Chhapkar (1956) Ramakrishna (1950), Bott (1970), Ramakrishna (1977), Dutta (1983), Pretzman (1984), Krishnamurthy (1995), Ghosh and Ghatak (2000) and Srivastava (2005) is worth mentioning. Bahir and Yeo (2005) revised the genus *Oziotelphusa* and added 8 new species to this genus. Again Bahir and Yeo (2007) made a detailed revision of the gecarcinucid crabs of southern India and they have reported 23 species belonging to 9 genera which includes the description of 10 new species and 6 new genera. At present the taxonomy, phylogeny and status of freshwater crabs of Western ghats is progressing well (Ghatak & Ghosh, 2008; Pati & Sharma 2011,2013, 2014a,b; Klause *et al.,* 2014; Pati and Sudha Devi, 2015a,b; Pati *et al.*, 2016). Recently Pati and Singh (2017) added a new species of *Himalayapotamon* from Uttarakand. Valarmathi and Mitra (In Press) studied the decapods crustaceans of Himachal Pradesh and Mitra (In press) investigated the availability of freshwater crabs in Mizoram.

Diversity

A global estimation of freshwater shrimps reveals that 655 species caridean shrimps are available in freshwaters (De Grave *et al.,* 2008) and the present investigation shows that in India 118 species of shrimps belonging to 14 genera and 2 families are available in freshwater. It is numerically dominated by the genus *Macrobrachium* of the family Palaemonidae and *Caridina* of the family Atyidae. Out of 6,800 globally known species of brachyuran crabs, a total of 1,476 species under 238 genera are considered as freshwater crabs (Yeo *et al.,* 2008) and in India (Table.1) at present 106 species of brachyuran crabs belonging to 40 genera and 5 families are reported from freshwater. This includes 100 species of primary freshwater crabs placed under the families Gecarcinucidae and Potamidae, and 6 species of secondary freshwater crabs belonging to the families Hymenosomatidae, Sesarmidae and Varunidae.

Subphylum CRUSTACEA Brünnich, 1772

Class MALACOSTRACA Latreille, 1802

Subclass EUMALACOSTRACA Grobben, 1892

Superorder EUCARIDA Calman, 1904

Order DECAPODA Latreille, 1802

Suborder PLEOCYEMATA Burkenroad, 1963

Table 1. General Classification and genera wise species distribution of freshwater Decapod crustaceans in India

Infraorder/Section/Superfamily/Family	Genera	Number of species
Infraorder CARIDEA Dana, 1852 Superfamily ATYOIDEA de Haan, 1849 Family ATYIDAE de Haan, 1849	*Atyopsis* Chace, 1983	2
	Paratya Miers, 1882	2
	Caridina H. Milne Edwards, 1837[in H. Milne Edwards, 1834-1840]	26
Superfamily PALAEMONOIDEA Rafinesque, 1815 Family PALAEMONIDAE Rafinesque, 1815	*Arachnochium* Wowor and Ng, 2010	2
	Exopalaemon Holthuis, 1950	2
	Leander Desmarest, 1849	1
	Leandrites Holthuis, 1950	1
	Leptocarpus Holthuis, 1950	3

Infraorder/Section/Superfamily/Family	Genera	Number of species
Superfamily PALAEMONOIDEA Rafinesque, 1815 Family PALAEMONIDAE Rafinesque, 1815	*Macrobrachium* Bate, 1868	68
	Nematopalaemon Holthuis, 1950	2
	Palaemon Weber, 1795	6
	Rhopalaemon Ashelby and De Grave, 2010	1
	Troglindicus Sankolli and Shenoy, 1979	1
	Urocaridella Borradaile, 1915	1
Infraorder BRACHYURA Latreille, 1802 Section EUBRACHYURA de Saint Laurent, 1980 Superfamily GECARCINUCOIDEA Rathbun, 1904 Family GECARCINUCIDAE Rathbun, 1904	*Arcithelphusa* Pati and Sudha Devi, 2015	1
	Austrothelphusa Bott, 1969	1
	Baratha Bahir and Yeo,	2
	Barytelphusa Alcock, 1909	4
	Ceylonthelphusa Bott,	1
	Cylindrothelphusa Alcock, 1909	1
	Gecarcinucus H. Milne Edwards, 1844	2
	Ghatiana Pati & Sharma, 2014	4
	Globitelphusa Alcock, 1909	4
	Gubernatoriana Bott, 1970	5
	Lamella Bahir and Yeo, 2007	1
	Inglethelphusa Bott, 1970	1
	Liotelphusa Alcock, 1909	4
	Maydelliathelphusa Bott, 1969	5
	Oziotelphusa Müller, 1887	7
	Perbrinckia Bott, 1969	1
	Pilarta Bahir and Yeo, 2007	1
	Sartoriana Bott, 1969	2
	Snaha Bahir and Yeo, 2007	2
	Sommaniathelphusa Bott, 1968	1
	Spiralothelphusa Bott, 1968	3
	Travancoriana Bott, 1969	7
	Vanni Bahir and Yeo, 2007	7
	Vela Bahir and Yeo, 2007	3

Infraorder/Section/Superfamily/Family	Genera	Number of species
Superfamily POTAMOIDEA Ortmann, 1896 Family POTAMIDAE Ortmann, 1896 Subfamily POTAMINAE Ortmann, 1896	*Acanthopotamon* Kemp, 1918	3
	Alcomon Yeo and Ng, 2007	2
	Himalayapotamon Pretzmann, 1966	9
	Lobothelphusa Bouvier, 1917	1
Subfamily POTAMISCINAE Bott, 1970	*Eosamon* Yeo and Ng, 2007	1
	Indochinamon Yeo and Ng, 2007	5
	Larnaudia Bott, 1966	1
	Potamiscus Alcock, 1909	5
	Quadramon Yeo and Ng, 2007	1
	Tiwaripotamon Bott, 1970	1
	Trichopotamon Dai and Chen, 1984	1
Superfamily MAJOIDEA Samouelle, 1819	*Hymenicoides* Kemp, 1917	1
Family HYMENOSOMATIDAE MacLeay, 1838	*Neorhynchoplax* Sakai, 1938	1
Superfamily GRAPSOIDEA MacLeay, 1838 Family SESARMIDAE Dana, 1851	*Geosesarma* De Man, 1892	2
Family VARUNIDAE H. Milne Edwards, 1853	*Pyxidognathus* A. Milne-Edwards, 1879	1
	Varuna H. Milne Edwards, in Audouin *et al*., 1830	1
Total		**224**

Distribution: With the exception of Antarctica, freshwater caridean shrimps are available in all the main biogeographical region. The Oriental region is species rich and Nearctic region is having lowest species diversity (De Grave *et al*, 2008). In India the decapods are widely distributed and available in various types of inland aquatic habitats like Rivers, rivulets, lakes, streams, ponds, water seepages etc.

Endemism

Due to their restricted distribution and isolation, the freshwater decapods have a great number of endemic species. Being one of the mega biodiversity countries, India has numerous endemic species most of them are restricted to its biodiversity hotspots like Western Ghats and Northeastern Himalaya. Recently Raghavan *et al.*, (2015) made a detailed analysis on the Endemic freshwater decapod crustaceans of Western Ghats region and their study reveals that forty-nine species and six sub-species of caridean shrimps in four genera (*Caridina, Leptocarpus*, *Macrobrachium* and *Troglindicus*) and two families (Atyidae and Palaemonidae) occur in the Western Ghats region, of which 35 species and three sub-species (69%) are endemic. They have also emphasized that as far as the diversity and distribution of gecarcinucid crabs are concerned thirty-nine species belonging to 14 genera are known to occur in peninsular India, of which 36 species (92%) are endemic to the Western Ghats. The following decapod genera namely *Troglindicus* Sankolli and Shenoy, *Baratha* Bahir and Yeo, *Barytelphusa* Alcock, *Cylindrothelphusa* Alcock, *Gecarcinucus* H. Milne Edwards, *Ghatiana* Pati & Sharma, *Gubernatoriana* Bott, *Inglethelphusa* Bott, *Lamella* Bahir and Yeo, *Pilarta* Bahir and Yeo, *Snaha* Bahir and Yeo, *Travancoriana* Bott, *Vanni* Bahir and Yeo, *Vela* Bahir and Yeo, are endemic to India (Dev Roy, 2014). Apart from the species described under these genera there are many endemic species which are known only from their type locality. Many decapod species described from northeastern parts of India are also mostly narrow range endemics.

Biology and life Cycle

The females of both the caridean shrimps as well as the freshwater brachyuran crabs carry fertilized eggs, the availability of ovigerous females throughout the year shows that they are continuous breeders (Valarmathi,2009, Pathre and Meena, 2010) but they have specific season when the breeding activity is in peek. Many species of cardiean shrimps show abbreviated to a lengthy larval development. The highly abbreviated larval development is characterized by a minimum number of large size eggs where as the species with a huge number of small sized eggs shows prolonged larval development. The larval biology of Atyid and Palaemonid shrimps have been studied by many workers in India (Ravindranath, 1981, Jalihal *et al*., 1993, Almelkar *et al.,* 2006, Jalihal *et al*., 2006a,b,c, Mariappan and Richard, 2007). The primary freshwater crabs undergo direct development in which the large, yolky eggs hatch directly into juvenile crabs whereas the secondary freshwater crabs which are basically marine but adapted to the freshwater or semi terrestrial environments have highly abbreviated development or possess one or more larval stages (Kaur *et al.,* 2006, Yeo *et al.,* 2008).

Habitat: The decapod crustaceans are available in most of the lentic and lotic freshwater ecosystems like rivers, lakes, ponds, streams etc. They are mostly nocturnal and during the day they hide themselves under the small boulders, crevices, under the soil, vegetation debris etc. They are part of the macrobenthos and live among the aquatic vegetation, leaf litter etc. Shrimps are exclusively aquatic whereas the crabs are adapted to a semi terrestrial mode of life.

Significance

Freshwater decapods have many potential candidates which can be utilized in aquaculture, local wild fishing industries, aquarium trade, medicinal purpose etc. Holthuis (1912) identified many decapod custaceans which have commercial value. Jalihal *et al.* (1994) suggested the Atyid shrimps of the genus *Caridina* for experimental biology. Mariappan *et al.* (2002b) recommended *M. nobili* as a candidate species for rural nutrition. *M. rosenbergii* which is commonly known as scambi is wildly cultured in India and other countries *M. malcolmsonii* supports many aquaculture industries in south India. Apart from that *M. gangeticum, M. idella idella, M. idella georgii, M. divakarani, M. equidens, M. sulcatus, M. dayanum, M.lamarrei lamarrei, M. lamarrei lamarroides, M. mirabile, M. scabriculum, M.*

rude, M. villosimanus are either marketed locally or exported (Jayachandran and Indira, 2010). Rice cum prawn culture ('Oru Nellum oru Meenum' in Malayalam or One rice One fish programme developed by Kumarakom Unit of Kerala Agricultural University, under the leader ship of Dr. K.G. Padmakumar) is a win win Land Use model and in this system the rice and fish are grown alternatively or in sequence (Jayachandran and Indira, 2010). Recently Jayachandran (2006) and Jayachandran *et al.* (2005, 2006) have introduced the prawns and shrimps of ornamental value to the aquarium.

Freshwater crabs are consumed by many people because of their delicacy, medicinal and nutritive value. Paragonimiasis, also known as endemic haemoptysis, oriental lung fluke infection, pulmonary distomiasis, parasitical haemoptysis, parasitare haemopte, *Gregarinosis pulmonum*, *etc*. is one of the most important food-borne parasitic zoonoses caused by one or more of the trematode species of the genus *Paragonimus.* The freshwater crabs *Potamiscus manipurensis, Alcomon superciliosum* and *Maydelliathelphusa lugubris* were identified as a potential hosts of *Paragonimus*. Ingestion of undercooked crabs and raw crab extract were the major mode of infection and Paragonimiasis is reported in various parts of Northeastern states of India (Singh *et al*., 2012).

Threats and Conservation

The major threat for all the decapod crustaceans are habitat destruction, flow modification (from dams and alteration of drainage patterns), sedimentation (from soil erosion), pollution (from mining, pesticides, and fertilizers which leads to eutrophication and toxic algal blooms), over-harvesting of species and competition from introduced species (Cumberlidge, 2014). Almost all the freshwater ecosystems face serious threats due the anthropogenic activities like various kinds of pollution, sand mining, human occupancy and encroachment of freshwater ecosystems etc., which affect the freshwater decapods either directly or indirectly. Because of their nutritive and medicinal value and economic importance in some areas the shrimps and crabs have been over exploited by the locals and fishermen. Over exploitation and wastage of juveniles and small sized sub adults are common factors that we can observe in many areas. Mariappan and Balasundaram (1999) observed the mass mortality of *Macrobrachium* juveniles in River Cauvery. Jayachandran and Indira (2010) stated that in wild condition Vembanad Lake is the natural abode for *M. rosenbergii* and during the peak breeding season (June to December) nearly 40 to 60% of the catch constituted berried females. This is a major threat to the wild population of the species in the lake and they have also mentioned that freshwater prawns form an important dollar earning commodity, biologically rich in diversity, proper managerial planning is absolutely necessary for sustainable utilization of these resources. Most of the freshwater decapod crustaceans are narrow range endemics and the above said facts leads them to face serious threat. Recently Ragavan *et al.,* (2015) made an assessment on the threat and conservation of Western Ghat Decapod crustaceans. Their study reveals that *Macrobrachium gurudeve*, a Vulnerable palaemonid, restricted to a single location in the east-flowing Bhavani River in the state of Kerala. The two vulnerable species of crabs namely *Oziothelphusa biloba* is known from two closely located sites in Kerala and *O. wagrakarowensis* occurs in two locations in Karnataka.

Future Prospects

Among the crustaceans the decapods gain more attention due to its aquaculture potential and economic importance. Though we have more than 100 species of shrimps only a few species are considered for aquaculture and very less number of species are found supporting the local wild fisheries. Although many species have ornamental value at global level, in India the awareness and utility of ornamental shrimps is sporadic. Inspite of their medicinal value and protein content the conception of freshwater crabs is very limited and there are no reports of culture of any freshwater crabs. There are many beautifully colored freshwater crabs which can be considered for aquarium. Studies on the freshwater Decapod Crustaceans in India is very scanty and many areas are still unexplored. When compared to the global scenario, further extensive and intensive taxonomic, molecular, phylogenetic and other eco-biological investigations in India is essential.

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Decapod Crustaceans

Caridina simoni Bouvier, 1906

Macrobrachium lamarrei lamarrei (H. Milne Edwards, 1837)

Barytelphusa cunicularis (Westwood, in Westwood & Sykes, 1836)

Himalayapotamon babaulti (Bouvier, 1918)

Chapter 21

ARACHNIDA : ARANEAE (SPIDERS)

[1*]DHRUBA CHANDRA DHALI AND
[2]PAVITTU MEETHAL SURESHAN

ABSTRACT

Almost all extant spiders are terrestrial, living mainly on land. Some inhabit either its entire life under freshwater environments or for a few moments. From India, reports of such fauna are not available so far. There is no fossils record so far throughout the World too. Perusal of different literatures, news items, data on direct observations, photographs and material examined reveals that India hasabout six species (0.36% to the total) under six genera belonging to three families. The superfamilies Lycosoidea (83%) and Dictynoidea (17%) are those documented as freshwater spiders only. Superfamily Lycosoidea consists of two families i.e. Lycosidae and Pisauridae whereas Dictynoidea has only Cybaeidae. Family Pisauridae is most diverse (50%) followed by Lycosidae (33.33%) and Cybaeidae (16.67%). Freshwater semi-aquatic spiders are recorded from West Bengal, Goa, Maharashtra, Kerala and Chhattisgarh. In comparison to global scenario (0.05% to the total fauna) India is a better promising region for research regarding freshwater spider fauna.

Key words: Freshwater, semi-aquatic, spiders, India.

INTRODUCTION

Almost all extant arachnids including spiders are terrestrial, living mainly on land. However, some inhabit either its entire life under freshwater environments or for a few moments (Foelix, 2011). The diving bell spider, *Argyroneta aquatica* (Clerck, 1757) is one of the few species known to live almost entirely under water. Nyffeler and Pusey (2014) reported more than 80 incidences of fish predation by semi-aquatic spiders – observed at the fringes of shallow freshwater streams, rivers, lakes, ponds, swamps, and fens and opined that fish predation by semi-aquatic fauna are geographically widespread, occurring on all continents excepting Antarctica. They provided a checklist of 26 species (0.05% to the total fauna) under 12 genera belonging to nine families. From India, reports of such fauna are not available so far. Perusal of different literatures, news items, data on direct observations, photographs and material examined reveals that India has not less than six species (0.36% to the total) under six genera belonging to three families. In comparison to global scenario India is a better promising region for research regarding freshwater spider fauna.

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Fossil History

There is no fossil record so far known throughout the World (Dunlop *et al*., 2017).

Historical Resume

Clerck (1757) was the first to sketch the early history of Arachnida more so of spiders. Indian spiders were studied first by Blackwall (1864). The 20th century witnessed the publication of Fauna of British India: Arachnida by Pocock (1900) which is considered as the Bible of Indian spiders. Tikader (1987) provided a checklist of modern Indian spiders.

First freshwater spider, *Pardosa pseudoannulata* (Bösenberg & Strand) was photographed by Bhattacharjee (1931-32) from Kolkata, West Bengal. Gajbe (2003) provided a checklist of 186 species form Chhattisgarh including an aquatic of *Dolomedes* Latreille. Sebastian and Peter (2009) showed evidence that *Pardosa pseudoannulata* (Bösenberg & Strand) is semi-aquatic in nature. Sudhikumar (2014) reported an individual of *Cybaeus* Thorell. Kulkarnni *et al*. (2015) recorded and reported 14 species of spiders from aquatic vegetation of a small temporary pond, Pune, Maharashtra including two species of semi-aquatic nature. Adarsh and Nameer (2016) published a field photo of *Nilus albocinctus* (Doleschall) as aquatic from Chinnar Wild Life Sanctuary, Kerala.

Materials and Methods

During various field surveys by the authors (from November, 2015 to December, 2016) at different places of India, specimens were collected either by hand or by sweeping with an aquatic insect net and preserved temporarily in 70% alcohol as per recommendations of Tikader (1987), Alfred & Ramakrishna (2004). The examples were identified by consulting literatures of Tikader and Malhotroa (1980); Jose *et al.* (2003); Silva *et al.* (2015) and then photographed with the help of Stereo Zoom Binocular Microscopes, model Leica EZ4 HD. Specimens examined in the present study are deposited in the "National Zoological Collections of Zoological Survey of India, Western Ghat Regional Centre Calicut" (ZSIK).

A total of 16 incidences of semi-aquatic (freshwater) spiders were gathered (Table 3). Four (25%) of the incidences (Table 3) were previously reported in the scientific literature and rest of the observations included photographic documentation (25%) and material examined (50%).

Diversity

There are 26 species under 12 Genera belonging nine families so far reported from the World (Nyffeler and Pusey, 2014). The superfamilies Lycosoidea and Ctenoidea are those documented as preying upon fish under open-field conditions and all can be loosely categorized as hunting spiders (i.e., spiders that forage without the aid of a catching web). Approximately 80% of reports of fish predating freshwater spiders were attributable to Pisauridae (nursery web spiders), with Ctenidae (wandering spiders; 10.3%), Trechaleidae (longlegged water spiders; 4.5%), Lycosidae (wolf spiders; 1.1%) and Liocranidae (spinylegged sac spiders; 1.1%) comprising the remainder (Table 1). The most dominant group of fish-catching spiders are in the genus *Dolomedes* Latreille (Pisauridae) (Table 1).

Six species under six genera belonging to three families are known so far from India (Table 2). The superfamilies Lycosoidea (83%) and Dictynoidea (17%) are those documented as freshwater spiders only. Superfamily Lycosoidea consists of two families i.e. Lycosidae and Pisauridae whereas Dictynoidea has only Cybaeidae. Family Pisauridae is most diverse (50%) followed by Lycosidae (33.33%) and Cybaeidae (16.67%) (Table 2).

Table 1. Global diversity of freshwater spiders (Nyffeler and Pusey, 2014).

Sl. No.	Family	Genus	Species
1.	Ctenidae	*Ancylometes*	*bogotensis* (Keyserling)
			rufus (Walckenaer)
2.	Cybaeidae	*Argyroneta*	*aquatic* (Clerk)
3.	Desidae	*Desis*	*marina* (Hector)
4.	Liocranidae	*Agroeca*	*lusatica* (L. Koch)
5.	Lycosidae	*Pardosa*	*pseudoannulata* (Bösenberg & Strand)
6.	Pisauridae	*Dolomedes* Latreille	*dondalei* Vink & Dupérré
			facetus L. Koch
			fimbriatus (Clerck)
			mizhoanus Kishida
			okefinokensis Bishop
			plantarius (Clerck)
			raptor Bösenberg & Strand
			saganus Bösenberg & Strand
			scriptus Hentz
			sulfureus L. Koch
			tenebrosus Hentz
			triton (Walckenaer)
			vittatus Walckenaer
			sp. – photographed in Queensland (not *facetus* L. Koch)
		Nilus	spp.
		Tinus	sp.
7.	Sparassidae	*Heteropoda*	*natans* Jäger
8.	Theraphosidae	*Hemirrhagus*	*pernix* (Ausserer)
		Hysterocrates	*gigas* Pocock
9.	Trechaleidae	*Trechalea*	*tirimbina* Silva & Lapinski
	9	**12**	**26**

World Distribution

Freshwater aquatic spiders are geographically widespread, occurring in all continents excepting Antarctica i.e. in between 40°S and 40°N (Nyffeler and Pusey, 2014).

India

Freshwater semi-aquatic spiders are recorded from West Bengal, Goa, Maharashtra, Kerala and Chhattisgarh (Table 3; Fig. 1).

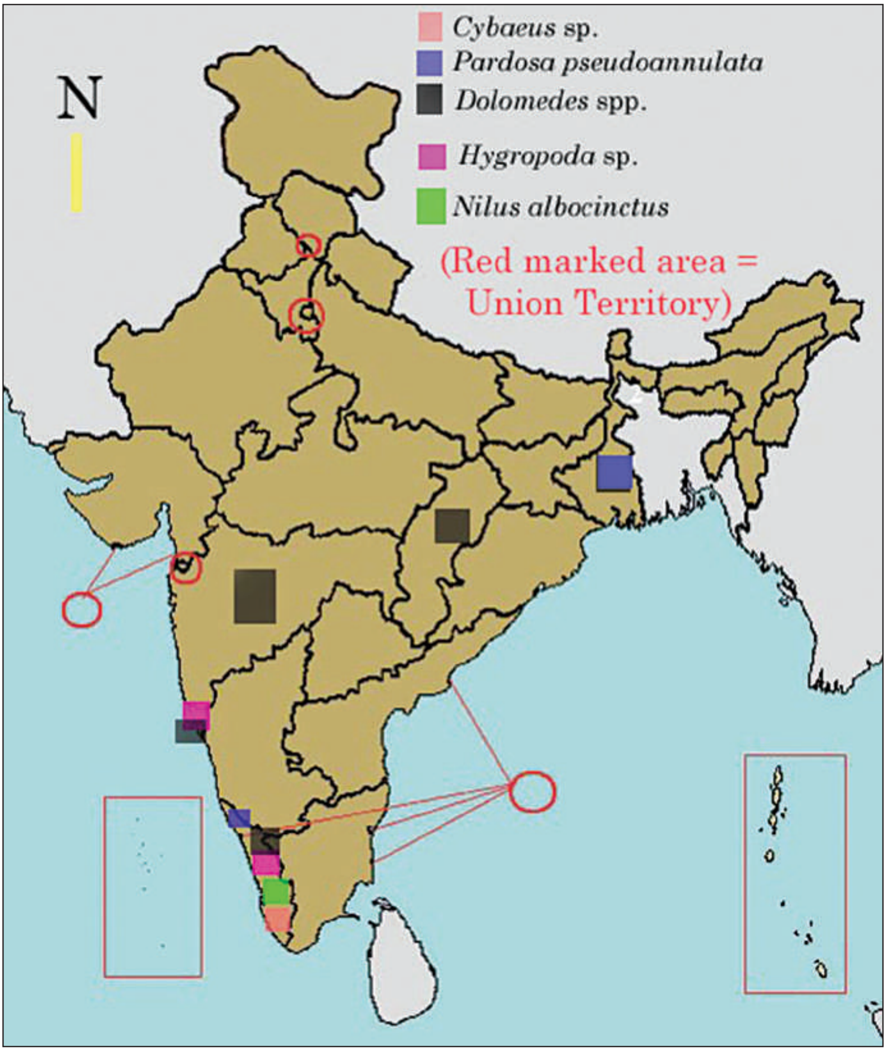

Fig. 1. Diversity and distribution of freshwater spiders throughout India.

Classification

Most recent updated classification of Dunlop and Penny (2011) and World Spider Catalog (2017) are followed.

Fig. 2. Photographs of freshwater spiders. A. Fish predation by *Pardosa pseudoannulata* (Bösenberg & Strand); B. *Cybaeus* sp. (Photo captured in Aranmula forest range by Sudhikumar); C. General Habitus (dorsal view) of *Dolomedes* sp.; D. General habitus (dorsal view) of *Pardosa pseudoannulata* (Bösenberg & Strand); E. General habitus (dorsal view) of *Hippasa* sp.; F. *Dolomedes* sp. (Photo captured in Sanjay Gandhi National Park by Alamy).

Fig. 3. Photographs of freshwater spiders. A. *Nilus albocinctus* (Doleschall) (Photo captured in Thattekad Bird Sanctuary by M. J. Palot); B. General Habitus (dorsal view) of *Nilus albocinctus* (Doleschall); C. *Hygropoda* sp. (Photo captured in Goa by Sahapedia); D. General habitus (dorsal view) of *Hygropoda* sp.

Table 2. Diversity across family genera and species of freshwater spiders in the Indian sub-continent (Fig. 2 & 3)

Sl. No.	Family	Genus	Species
1.	Cybaeidae Simon	*Cybaeus*	sp.
2.	Lycosidae Sundevall	*Pardosa*	*pseudoannulata* (Bösenberg & Strand)
		Hippasa	sp.
3.	Pisauridae Simon	*Dolomedes*	spp.
		Hygropoda	sp.
		Nilus	*albocinctus* (Doleschall)
	3	**6**	**6**

Endemism

Scanty knowledge.

Biology

The aquatic spiders of genera worldwide are semi-aquatic predators with a leg span of 6–9 cm and a weight of, 0.5–2 g (longer and weightier than normal terrestrial counterpart. Though the *Dolomedes* spp. appear to differ in their foraging time, some species are diurnal and others nocturnal, and that share a common foraging pattern in that they can swim, dive and walk on the water surface film (Nyffeler and Pusey, 2014). These spiders possess large strong chelicerae capable of piercing the skin of vertebrates (Uzenbaev and Lyabzina, 2009) and are equipped with powerful venom containing hundreds of different neurotoxins, some of which are specific to vertebrate nervous systems (McCormick *et al.,* 1993; Gregio *et al.,* 1998; Jiang *et al.,* 2013).

Habitat

Vegetations on the margins of freshwater streams, rivers, creeks, bayous, lakes, ponds, swamps, and fens.

Life cycle

Unknown so far.

Threats:

Habitat destruction i.e. engulfing of freshwater wetlands.

Conservation and Human Significance

There is no conservation steps taken either globally or nationally.

Generally, spiders are a bioresource all having venom (to their own preys) excepting uloborids and only few species are known lethal to human. They also exert considerable control to insect pests in the ecosystem by both lowering & stabilizing pest population. So, they are excellent candidates of biological pest management. Spider venom is a potential bioresource due to its pesticidal and medicinal value. Spider silk is also valuable due its tensile nature. *Pardosa* *pseudoannulata* (Bösenberg & Strand) is one of the most common wandering spiders in agricultural fields and a potentially good bio indicator for heavy metal contamination (Li *et al*., 2016). But, cases of direct significance of freshwater spiders to human are unknown so far.

Gaps in research

Globally the superfamilies Lycosoidea and Ctenoidea are documented as aquatic under open-field conditions and all can be loosely categorized as hunting spiders (i.e., spiders that forage without the use of a catching web) (Nyffeler and Pusey, 2014). Approximately 80% reports of aquatic species were attributable to Pisauridae (nursery web spiders), with Ctenidae (wandering spiders; 10.3%), Trechaleidae (longlegged water spiders; 4.5%), Lycosidae (wolf spiders; 1.1%) and Liocranidae (spinylegged sac spiders; 1.1%) comprising the remainder (Nyffeler and Pusey, 2014). The most dominant group of freshwater spiders is in the genus *Dolomedes* (Pisauridae).There is no documentation of aquatic species from India so far.

Expertise

There is none working on freshwater spider fauna in India and Abroad also. Who so ever reported aquatic spiders got the evidences during their field survey and photo shoot in wild.

Table 3. Reports of freshwater spiders under natural conditions in the field, based upon published literature, unpublished data and material examined from India (see Fig. 2 & 3).

Sl. No.	Predator (spider taxon)		Type of evidence	State	Source
	Species	Family			
1	*Pardosa pseudoannulata* (Bösenberg & Strand)	Lycosidae	Direct observation	West Bengal	Nyffeler and Pusey (2014)/ Bhattacharjee (1931-32)
2	*Pardosa pseudoannulata* (Bösenberg & Strand)	Lycosidae	Direct observation	West Bengal	Material examined
3	*Pardosa pseudoannulata* (Bösenberg & Strand)	Lycosidae	Direct observation / Photo	Kerala	Sebastian and Peter (2009)
4	*Pardosa pseudoannulata* (Bösenberg & Strand)	Lycosidae	Direct observation / Photo	Kerala	Spider India Yahoo Group and Spider India Flickr Pool
5	*Dolomedes* sp.	Pisauridae	Indirect observation	Chhattisgarh	Gajbe (2003): Zoos' Print Journal, 18 (10): 1223-1226.
6	*Dolomedes* sp.	Pisauridae	Photo	Maharashtra	Alamy

7	# *Hippasa* sp.	Lycosidae	Direct observation	Maharashtra	Kulkarni *et al.* (2015): Journal of Threatened Taxa, 7(6): 7196–7210.
	# *Nilus albocinctus* (Doleschall)	Pisauridae			
8	*Dolomedes* sp.	Pisauridae	Direct observation	Goa	Shapedia
9	*Dolomedes* sp.	Pisauridae	Direct observation	Kerala (Aralam WLS)	Material examined
10	*Hygropoda* sp.	Pisauridae	Direct observation	Goa	Shapedia
11	*Hygropoda* sp.	Pisauridae	Direct observation	Kerala (Kakkavayal)	Material examined
12	*Cybaeus* sp.	Cybaeidae	Indirect observation	Kerala (Aranmula)	The Hindu Newspaper (2014)
13	*Nilus albocinctus* (Doleschall)	Pisauridae	Photo and Direct observation	Kerala (Thattekad BS)	Material examined
14	*Nilus albocinctus* (Doleschall)	Pisauridae	Photo and Direct observation	Kerala (Aralam WLS)	Material examined
15	*Nilus albocinctus* (Doleschall)	Pisauridae	Photo and Direct observation	Kerala (Tushargiri, Kozhikode)	Material examined
16	*Nilus albocinctus* (Doleschall)	Pisauridae	Photo and Direct observation	Kerala (Kakkavayal, Kozhikode)	Material examined
17	*Nilus albocinctus* (Doleschall)	Pisauridae	Photo and Direct observation	Kerala (Chinnar WLS)	Adarsh and Nameer (2016): Journal of Threatened Taxa, 8(4): 8703–8713.

Though authors [Kulkarni *et al*. (2015)] recorded and reported 14 species under eight families, only two species of the superfamily Lycosoidea, were considered as semi-aquatic. Moreover, they mentioned that the collections were made from aquatic vegetation's and not directly from water. So, species marked (#) are included here in the list (Table 2 & 3).

REMARKS

There are no taxonomic notes on the genera *Dolomedes* Latreille and *Hygropoda* Thorell from India excepting report only of immature individuals. There might be several species freshwater species from the genus *Dolomedes* and other genera from the country. A better understanding of the diversity, biology, nutritional ecology of fresh aquatic spiders and their ecosystem role is needed.

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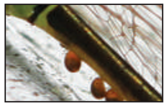
Chapter 22



ARACHNIDA : ACARI (MITES)

SHELLEY ACHARYA

ABSTRACT

In contrast to other arachnids, mites have invaded aquatic systems at least ten times , with some lineages giving rise to thousands of water dwelling species. The hydrachnida represent the most important group of arachnida in freshwater. Based on the available information this chapter has been prepared which reflects the global diversity of freshwater acari with its Indian diversity. Over 6,000 species have been described worldwide, representing 57 families, 81 subfamilies and more than 400 genera. In India, it includes 253 species in 70 genera and 25 families with 183 endemic species. Distribution of water mites has been shown in different Biogeographical regions of the world as well as in the Biogeographical zones of India.

Key Words: Water mite, Diversity, Biogeographic zones, Distribution

INTRODUCTION

In contrast to other arachnids, mites have invaded aquatic systems at least ten times, with some lineages giving rise to thousands of water-dwelling species. Every possible type of aquatic habitat contains mites, from temporary puddles on rocky outcrops to the stygian permanency of marine rifts. The Hydrachnida (water mites) also called Hydrachnellae, Hydracarina, represent the most important group of the arachnida in freshwater. Originating from terresetrial ancestors, they have colonized all kinds of freshwater habitats. Water mites are highly diversified both in lotic and lentic habitats as well as in springs and interstitial waters. Hydrachnida belong to the cohort Parasitengona (Actinedida), a group whose species are characterized by a complex life cycle involving a heteromorphic parasitic larva, two pupa-like resting stages and free living predacious deutonymphs and adults.

Hydracarina can usually be found around the edges of ponds and lakes, either swimming in the vicinity of submerged plants or foraging on their leaves and stems. They are often brightly coloured, most often some shade of red or green, although blue, yellow and tan colours are also seen. The adults are rarely larger than about 2mm or smaller than 0.5mm. The largest known varieties can reach 8mm. Having eight legs and a pair of palps, they can appear at first to resemble tiny spiders, but a closer inspection reveals that what would be cephalothorax and abdomen in a spider is fused into a single body part having no sign of segmentation in the water mites. They are almost exclusively freshwater in their habitat, and whilst a few are

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parasitic upon such creatures as the freshwater mussel, most are free-living and carnivorous. These seize upon worms, small crustaceans and small insects encountered in their foragings, and use their penetrating mandibles (homologous to the chelicera of the spiders) to pierce the cuticle of the prey and suck out its juices.

Aquatic oribatids, astigmatans and water mites have not altered their diet drastically from that of their terrestrial relatives. Some water mites share top predator rank with vertebrates in freshwater systems because they are almost immune to predation by fish. Therefore , they are likely to be useful as indicators of organic pollution, salinity and general ecosystem health.

REVIEW OF LITERATURE

Research on water mites from India started at the beginning of the 20th century with publications of K. Viets (1926a, b), followed later on by publications of Walter (1928) and Lundblad (1934). Cook (1967) published his comprehensive work on the water mites from India in which he summarized the water mite fauna of India until that time. He reported 173 species of water mites, describing many new species and genera. Cook's work as he stated gave "an adequate beginning to our knowledge of the water mite fauna of Maharashtra, Mysore (Karnataka), Madras (Chennai, Tamil Nadu) and Kerala". Lundblad studied the water mites from Calcutta (Kolkata, West Bengal) and Bombay (Mumbai, Maharashtra), resulting in his comprehensive paper published in 1968. Later on papers with records of water mites from India were published by Nayar (1969a, b), while Prasad (1974) in his A catalogue of mites of India reported 197 water mites from India. Tomar & Raychaudhury (1981, 1983b) studied mostly the water mites of the genus Arrenurus. During the 20th century and in the beginning of 21th century more authors published mostly ecological or faunistical studies on water mites (e.g., Kumar & Dobrigyal 1992), usually as part of a study of parasitism on invertebrate (insects and mollusks) fauna. Examples of these are Bishth (1979), Malahotra et al. (1983), Rajendran & Prasad (1992), John & Inasu (2005). In the first decade of 21th century the number of publications dealing with the systematics of water mites from India increased. Panesar studied water mites in the Indian Himalayas (Panesar 2004, Panesar & Gerecke 1994) and Smit & Pešić (2008) studied water mites of the genus Arrenurus. Recently, Pešić et al. studied water mites mostly from the Indian Himalayas (Pešić & Panesar 2008, 2009, Pešić & Gerecke 2008, Pešić et al. 2007a, b, 2008) although other regions of India were studied as well but to a much lesser extent (e.g., Pešić & Ranga Reddy 2009, Pešić et al. 2008, 2009) . The aim of this paper is to compile data on the Indian water mites and their current geographic distribution in India, which will be significant in understanding the gaps in our knowledge on the water mites of India.

MORPHOLOGY

Water mites are characterized by bright colours and a highly diversified morphology. Plesiotypically, body shape is globular but it may also be flattened dorso-ventrally or laterally, or elongated into a worm-like form (Fig. 1). Length ranges from 0.2 mm up to 10 mm, although most species are between 0.5 and 1.5 mm. As in all Acari, the body of a water mite is divided into two principal units, gnathosoma and idiosoma. The gnathosoma is a complex of trophic and sensory structures composed of a sclerotized capsule (capitulum) and two pairs of appendages (palps and chelicerae). The idiosoma, or body proper, may be soft-skinned or the integumental muscle-attachment sites are transformed to more or less extended sclerotized plates with tendencies to develop complete sclerotization. The idiosoma is also characterized by the presence of series of defensive glands and mechanoreceptive slit organs. The ventral side includes four pairs of sclerotized coxal plates (insertion points for legs and leg muscles), the genital field and the opening of the excretory system. The four pairs of legs of adults are six-segmented and usually bear one pair of terminal claws. Size and chaetotaxy of leg segments are modified in relation to modes of locomotion and reproduction.

METHODOLOGY

(a) *Handpicking*: The parasitic aquatic mites attached to the body of aquatic host is located with had lens and are collected with fine brush.

(b) *Dipping*: In most cases water mites are collected by this method. The collecting tools like white enamel bowl and wide mouthed pan with long handle are immersed in water and lifted with water with a quick movement. The water sample is then observed under binocular microscope and the mites are collected with fine brush.

(c) *Netting*: The free living water mites are collected with great success with nylon nets of narrow mesh fitted with an iron ring having a long handle. The visible water mites can be scooped up with the help of this net. Another type of net, the birge net, is also used for collection. A fine mesh nylon net fitted with a fine sieve at the wider mouth of a funnel, the narrow end of the funnel is open and a long wire is attached to this end which helps to put the net into deep water. The contents of the Birge net are examined with hand lens and mites are collected with a fine brush.

Table 1. Mites that spend the majority of their life in subaquatic freshwater habitats

Suborder	Family	Habitats
Mesostigmata	Dithinozerconidae	Moss in mountain streams
Oribatida	Hydrozetidae	On/in macrophytes in standing fresh water
	Trhypochthoniidae	Benthic in running fresh water
	Camisiidae	Benthic in streams
	Ameronothridae	Restricted to ephemeral pools

Suborder	Family	Habitats
Astigmata	Acaridae	Freshwater fish tanks
	Histiostomatidae	Freshwater fish tanks
	Hyadesiidae	Algae in freshwater, mussel beds
Prostigmata	Halacaroidea	Interstitial freshwater, freshwater decapods
	Hydracarina	Benthic and planktonic in standing and running freshwater, interstitial freshwater, inside freshwater mussels, snails and crayfish

GLOBAL DIVERSITY

The Hydrachnidia (water mites) represent the most important group of the Arachnida in fresh water. Over 6,000 species have been described worldwide, representing 57 families, 81 subfamilies and more than 400 genera (Di Sabatino *et al.,* 2008).

Based on available information, the Palaearctic region represents one of the better investigated areas with the highest number of species record (1,642 species). More than 1000 species have been recorded in each of the Neotropical (1,305 species) and Nearctic regions (1,025 species). Known species richness in lower in Afrotropical (787 species) and Australian (694 species) regions and lowest in the Oriental region(554 species). The total number of genera is not correlated with species richness and is distinctly higher in the Neotropical (164 genera); genera richness is similar in the Palearctic, Nearctic and Australian regions (128-131 genera) and is lower in the Afrotropical and oriental regions with 110 and 94 genera respectively.

Australian fauna is also characterized by the highest percentage of endemic genera(62%) followed by Neotropical (50.6%) and Afrotropical (47.2%) regions. Lower values are recorded for the Palearctic (26.9%), Oriental (24.4%) and Nearctic (21.4%). The palearctic and Nearctic have the highest faunistic similarity, some minor affinities are also evident for the generic diversification of Holarctic and Oriental famiies (Di Sabatino *et al.,* 2008).

Table 2. Genera richness of water mite families in each biogeographic region

Family	PA	NA	NT	AT	OL	AU	World
Stygothrombiidae	1	1	0	0	0	0	1
Hydrovolziidae	2	1	0	1	1	0	3
Acherontacaridae	1	1	0	0	1	0	1
Hydrachnidae	1	1	1	1	1	1	1
Limnocharidae	4	3	3	2	2	3	6
Eylaidae	1	1	2	1	1	1	2
Apheviderulicidae	1	1	0	0	0	0	1

Family	PA	NA	NT	AT	OL	AU	World
Piersigiidae	1	1	0	0	1	2	3
Hydrophantidae	27	23	12	9	13	10	50
Hydrodromidae	1	1	1	1	1	1	1
Teratothyadidae	0	0	0	1	1	0	2
Rhynchohydracaridae	0	1	3	0	0	0	3
Ctenothyadidac	0	0	0	0	1	1	2
Thermacaridae	1	1	1	0	1	0	1
Zealandothyadidae	0	0	0	0	0	2	2
Stygotoniidae	0	0	0	0	0	1	1`
Sperchontidae	2	2	4	1	1	1	4
Teutoniidae	1	1	0	0	0	0	1
Rutripalpidae	1	1	0	0	0	0	1
Anisitsiellidae	8	5	11	9	16	6	33
Lebertiidae	2	3	2	1	1	0	4
Acucapitidae	0	0	0	0	1	0	1
Oxidae	2	2	3	3	2	2	4
Tiorrenticolidae	4	4	5	3	5	1	6
Pontarachnidae	0	0	0	1	0	1	1
Limnesiidae	3	9	20	4	3	4	7
Omartacaridae	0	1	1	0	1	1	2
Hydgobatidae	5	6	33	19	5	24	7
Ferradasiidae	0	0	1	0	0	0	1
Pionidae	9	9	4	2	3	6	14
Astacorotonidae	0	0	0	0	0	1	1
Wettinidae	1	1	0	1	0	3	5
Frontipdopsidae	1	1	1	2	1	1	2
Aturidae	19	16	26	18	14	29	62
Lethaxonidae	1	2	1	1	1	0	2
Mideidae	2	1	0	0	0	0	2
Gretacaridae	0	0	0	0	0	1	1
Momoniidae	4	3	4	1	2	6	13
Mideopsidae	1	1	3	3	2	4	8
Nudomideopsidae	1	3	0	0	0	2	3
Uchidastygacaridae	2	3	0	0	0	1	4
Kantacaridae	1	0	0	0	0	0	1
Nipponacaridae	1	0	0	0	0	0	1
Neocaridae	1	2	1	0	0	0	2
Bogatiidae	1	1	0	0	0	0	2

Family	PA	NA	NT	AT	OL	AU	World
Chappuisididae	2	1	1	0	0	0	2
Krendowskiidae	1	2	3	1	1	0	4
Acalyptonotidae	1	2	0	0	0	0	2
Athienemanniidae	4	4	1	3	1	4	16
Harpagopalpidae	0	0	0	1	1	0	1
Hungarohydracaridae	3	0	1	1	2	0	4
Arenohydracaridae	0	1	1	0	0	0	1
Amoenoacaridae	0	1	0	0	0	0	1
Laversiidae	0	1	0	0	0	0	1
Arrenuridae	2	1	5	8	2	2	12
Total Genra	**131**	**131**	**164**	**110**	**94**	**128**	**428**
Total families	**42**	**44**	**31**	28	33	30	

Freshwater mite (Hydrachnidia) species and genera (SP/GN) per zoogeographic region : PA-Palaearctic; NA–Nearctic; NT–Neotropical; AT–Afrotropical; OL–Oriental; AU–Australian; PAC–Pacific Oceanic Islands; ANT–Antarctic (Di Sabatino, 2008)

DIVERSITY IN INDIA

Table 3. Total number of families, genera and species known so far from India is shown.It includes 253 species in 70 genera and 25 families of water mites of which 183 species are endemic to India. (After Pesic, 2008)

Superfamily	Family	Genus	Species	Endemicity
HYDROVOLZIOIDEA	Hydrovolziidae	2	3	3
EYLAOIDEA	Limnocharidae	2	2	1
	Eylaidae	1	3	1
HYDRACHNOIDEA	Hydrachnidae	1	5	1
HYDRYPHANTOIDEA	Hydrodromidae	2	5	1
	Hydryphantidae	9	15	13
LEBERTIOIDEA	Anisitsiellidae	11	25	21
	Bandakiopsidae	1	1	1
	Lebertiidae	1	2	2
	Oxidae	1	2	0
	Sperchontidae	2	9	7
	Torrenticolidae	4	9	16
HYGROBATOIDEA	Aturidae	10	35	30
	Feltriidae	1	10	8
	Frontipodopsidae	1	1	0
	Lethaxonidae	1	2	2

Superfamily	Family	Genus	Species	Endemicity
	Limnesiidae	3	8	6
	Hygrobatidae	3	29	24
	Pionidae	2	7	2
	Pontarachnidae	2	2	0
	Unionicolidae	3	26	10
ARRENUROIDEA	Arrenuridae	3	39	23
	Harpagopalpidae	1	1	0
	Hungarohydracaridae	2	8	8
	Mideopsidae	1	4	3
TOTAL	**25**	**70**	**253**	**183**

Note: Records of species of uncertain assessment from the study area and species from the study area of unknown origin are not included here.

Table 4. Distribution of water mites in different states/ Union Territories of India (After Pesic *et al.,* 2010)

States/UTs	No. of species	States/UTs	No. of species	States/UTs	No. of species
Andhra Pradesh	6	Kerala	80	Tripura	0
Arunachal Pradesh	0	Madhya Pradesh	0	Uttar Pradesh	13
Assam	21	Maharashtra	104	Uttaranchal	19
Bihar	5	Manipur	0	West Bengal	42
Chhattisgarh	0	Meghalaya	0	Andaman and Nicobar Islands	3
Goa	0	Mizoram	0	Chandigarh	0
Gujarat	2	Nagaland	0	Dadra and Nagar Haveli	0
Haryana	0	Orissa	0	Daman and Diu	0
Himachal Pradesh	27	Punjab	5	Lakshadweep	0
Jammu and Kashmir	10	Rajasthan	7	National Capital Territory of Delhi	0
Jharkhand	0	Sikkim	0	Puducherry	0
Karnataka	51	Tamil Nadu	31		

It is observed that water mite fauna are better studied in southern and western part of India while the central and north eastern parts are very incompletely known. The Indian water mite fauna is mostly represented by species (the number of species are given in parentheses) of the genera *Arrenurus* (32), *Atractides* (21), *Axonopsis* (16), *Neumania* (14) and *Monatractides* (15) (more than 35% of the whole fauna). From an ecological point of view, most work was done on running and standing waters. The highest number of water mites has been collected from streams. The large proportion (77 species) of thesespecies are known from the mountain areas: most records come from the Himalayas in the northern part of India, but also from the Ootacamund area of southern India which represent an island of temperate habitats urrounded by tropical condition. The lowland running water habitat is strongly affected by human impact in most areas, especially in the southern part of India, where most of the streams have been transformed for irrigation (Cook 1967). Probably, many of the older collecting sites have been destroyed in the past decades due to human impact. Fauna of standing water bodies, like lakes and ponds, includes 86 water mite species; most records come from the southern (Maharashtra, Kerala, Karnataka and Tamil Nadu) and eastern part of India (West Bengal), while the fauna of the Himalayas is still poorly studied (Pesic *et al,* 2010).

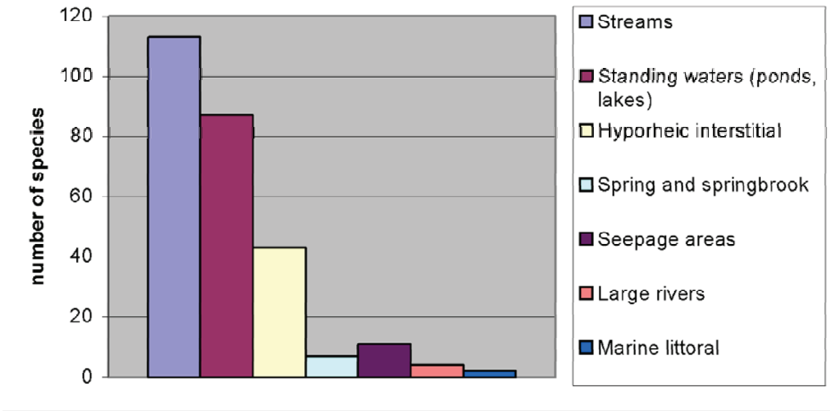

Fig. 3. Water mites of India: Number of species *vis* a *vis* habitat preferences (Pesic *et al.*, 2010)

Endemicity

Table 5. Numbers of endemic water mite families, subfamilies, genera and percentage of endemic genera in each biogeographic region

	PA	NA	NT	AT	OL	AU
Endemic families	2	2	2	–	1	4
Endemic subfamilies	4	3	12	1	2	3
Endemic genera	34	28	83	52	23	80
Percent endemic genera	26.9	21.4	50.6	47.2	24.4	62.0

PA: Palaearctic; **NA**: Nearctic; **NT**: Neotropical; **AT**: Afrotropical; **OL**: Oriental; **AU**: Australasian (Di Sabatino *et al.*, 2008)

In the Oriental region more than 500 species in 94 genera, 51 subfamilies and 33 families have been found (Di Sabatino *et al*., 2008). Our knowledge of the region is far from complete, many areas have hardly been explored. India is the country best investigated, but with large differences in the state of knowledge of different regions and a high percentage of endemic species. About 67% (183 species) of the species occur only in India. This situation reflects the unsatisfactory state of knowledge on water mites in India. As the freshwater acarine fauna of majority of the states of India still remain unexplored and whatever distributional data available are insufficient, it is rather difficult to make any comment on the degree of endemism in this taxon in India.

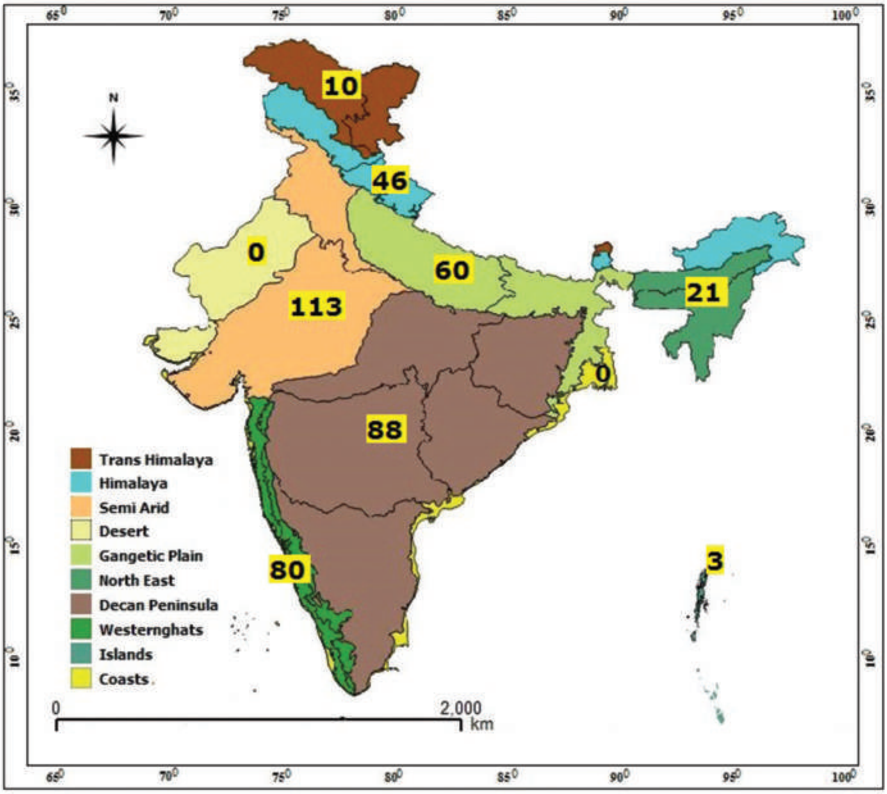

Fig. 5. Map showing distribution of water mites in different Biogeographical zones of India

VALUES

Mites have been employed as bioindicators in terrestrial systems but water mites are typically ignored in studies of freshwater health. Pieczynski (1976) studies show that water mites to be insensitive to long periods without oxygen, changes in temperature and dehydration. Gerecke and Schwoerbel (1991) stated that almost all studies of lotic mites show that they decline in polluted vs. unpolluted sections of streams. It is clear that physical factors play a great role in determining the distribution, abundance and variety of water mites in a body of water. The temperature, chemical constitution, depth, substrate and water velocity in an aqueous environment affect the nature of its hydracarine population.

Water mites depend on a diversity of other organisms for prey, hosts and even oviposition sites, the presence of certain mites may be used to indicate the presence of these other organisms.For example, if *Unionicola crassipes* (Unionicolidae) is present, then its oviposition and transformation sites- freshwater sponges- must also be present. *Hygrobates fluviatilis* (Hygrobatidae) emerged as a pollution indicator as its dominance of the water mite assemblages increased with increasing pollution. Gerecke and Schwoerbel(1991), their study indicates that this particular species is extremely tolerant of organic pollutants.

THREATS

Organic pollution may virtually eliminate the water mite fauna of a stream. It is observed that in the zones where pollution from the domestic sewage had increased, species richness had decreased drastically, whereas in areas where purification plants had improved water quality, species richness had also increased.

CONSERVATION STRATEGIES AND FUTURE STUDIES

As the population of mites of economic importance is considerably high, the loss of these tiny creatures has not yet attracted the attention of conservationists. But it is high time to formulate strategies for conservation of the taxon for the role they play in maintaining the ecological balance. So, the destruction of habitats should be checked and the use of poisonous chemicals either in the form of pesticides or fertilizers and discharge of industrial affluents must be controlled.

The studies in these field are incomplete in many aspects. An extensive study in the fields like taxonomy, bionomics and ecology are urgently needed. These studies will certainly enlighten ways for effective and useful conservation strategies needed for this taxon.

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Chapter 23

INSECTA : HEMIPTERA (AQUATIC BUGS)

SRIMOYEE BASU[1] AND K.A. SUBRAMANIAN[2]

ABSTRACT

India is represented by 325 species under 84 genera and 18 families of freshwater hemipterans. The Western Ghats and Central India are well explored, whereas, the Eastern Himalayan States and Western Himalayan regions of India are still unexplored. Systematic identification of these aquatic bugs through morphological studies has progressed rapidly. But, molecular identification involving DNA barcoding is still lacking in India. An intensive field survey is urgently required to update the baseline databases of freshwater hemipterans from India and to understand their regional diversity and distribution pattern in inland freshwater ecosystems.

Keywords: Hemiptera, Freshwater, India, Diversity, Distribution, Systematics

INTRODUCTION

Freshwater Hemipterans, commonly known as 'aquatic bugs', are secondarily adapted to aquatic ecosystems. However, their nymphal and adult stages are fully aquatic. The aquatic bugs, belonging to the suborder Heteroptera (true bugs) are encompassed under three Infraorders such as, Nepomorpha, Gerromorpha and Leptopodomorpha based on their niche and habitat preferences. They are an integral component of freshwater ecosystems and play a major role in the food web of the ecosystem as being predators, scavengers or collectors. The evolutionary history shows that all families were present in the Mesozoic and probably date back into the Triassic (Popov, 1971). The Nepomorphan has an extensive fossil record, while the Gerromorphan have less fossil record in comparison to Nepomorpha. Gerromorpha is a sister group to the Panheteroptera including Nepomorpha and Leptopodomorpha (Schuh and Slater, 1995) and all members of the aquatic bugs are predicted to be at least of the same age.

Nepomorphans are the true aquatic bugs, living underwater. Gerromorphans are semi-aquatic bugs, living on the surface water, whereas Leptopodomorphans are the shore dwellers, inhabiting the littoral zones or intertidal zones. They are hemimetabolous insects and both nymphs and adults of these bugs play a major role in sustainable management of aquatic habitat. These aquatic bugs are found in both lotic and lentic freshwater habitats ranging from mountainous lake, forested pools, ponds, hill streams, rivers, waterfalls, water splashed rocks, hot springs, cascades etc. Because of their habitat specificity and sensitivity, they are

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indicators of the changes in the freshwater ecosystem's health and ideal candidates for biomonitoring. Their size vary from 1 mm to about 100mm. They possess a specialized beak-like structure, rostrum, which helps in piercing and sucking.

Besides, the poor dispersal capabilities of these insects also serve as zoogeographical indicators (Jordon, 1951; Hungerford and Matsuda, 1958a, b; Thirumalai, 1999) and they are important indicators of long-term environmental changes. Knowledge on the diversity and distribution of this group helps in understanding the functional aspects of community structure and provides the baseline data required for developing a strategy for the effective conservation and management of the freshwater ecosystem. They have tackled the constraints of living in aquatic environments by possessing several morphological and physiological adaptations. Some of them (Corixidae, Nepidae, Geridae etc.) are efficient bio-control agents of harmful vector like mosquito larvae. Nepomorpha, Gerromorpha and Leptopodomorpha colonize new habitats as they are migratory in nature and many species are attracted to light (Fernando, 1961). However, they are encountered mostly in apterous forms. But, population living in temporary pools consists of macropterous forms.

Fossil History

The evolutionary history of aquatic Hemiptera dates back into the Mesozoic and Triassicera. However, the oldest fossil of Gerromorphan bug is *Karanabis kiritschenkoi* Bekker-Migdisova, 1962 from the Upper Jurassic which belongs to Mesoveliidae (Popov and Bechly, 2007). However, the rich fossil record of Nepomorpha in the Mesozoic creates a mystery on the habitat preferences of Gerromorpha due to the scarcity of Mesozoic Gerromorphan fossil (Grimaldi and Engel, 2005).

Historical Resume

The Heteroptera or true bugs are the largest and most diverse groups of insects. The most comprehensive work on this group, until now, is 'The Biology of Heteroptera' by Miller (1956, 1971). The taxonomic studies on aquatic Hemiptera was undertaken by Linnaeus (1758) in his 10th edition of *Systema Naturae*, which included 12 species from Neotropical, Afrotropical and Palaearctic regions. The earliest volume dealing with this group was Fabricius's *Systema Rhyngotorum* (1775). This was followed by Amyot and Serville (1843) in *Histoire naturelle des insectes hemipteres*. Stal (1868-1869) and (1870-1875) described 66 species of aquatic Hemiptera. Schuh and Slater (1995) discussed the systematic of these bugs. Reuter (1912) discussed and analyzed about their synonymy.

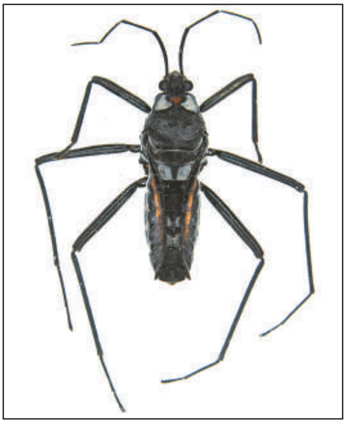
The Gerromorpha or semi-aquatic bugs are defined by the members having the ability to traverse the water surface film accompanied by four long and segmented antennae. Earlier, they were treated under the group Amphibicorisae (Dufour, 1833; Leston *et al*., 1954). But, recent treatment by Schuh and Slater (1995); Andersen (1982); Polhemus and Polhemus (2007, 2008); Henry (2009) showed that it consists of eight families placed among four super families. Among the 8 families, Hermatobatidae, Macroveliidae and Paraphrynoveliidae are not reported from

GERROMORPHA

Gerridae

Hydrometridae

Mesoveliidae



Veliidae

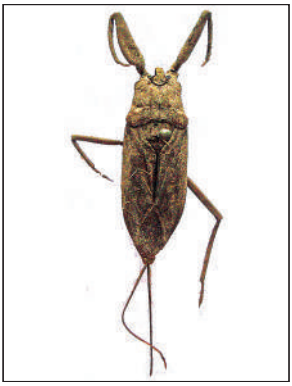
Hebridae

NEPOMORPHA


Aphelocheiridae


Belostomatidae


Corixidae

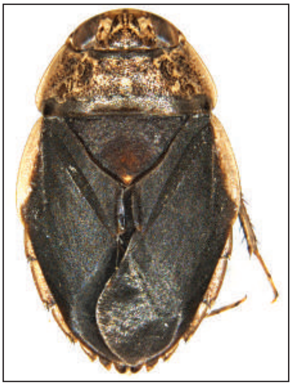

Nepidae


Micronectidae


Pleidae


Helotrephidae


Notonectidae


Naucoridae

NEPOMORPHA

Ochteridae

Gelastocoridae

LEPTOPODOMORPHA

Saldidae

Leptopodidae

India. Most of the information on morphology, classification, phylogeny and biogeography is derived from the monographic work of Andersen (1982); Spence and Andersen (1994). Faunistic knowledge on Gerromorpha is limited to the taxonomic studies by Distant (1903, 1910a and b), Annandale (1919), Bergroth (1915), Paiva (1919a and b), Dover (1928), Hafiz and Mathai (1938), Hafiz and Riberio (1939), Hafiz and Pradhan (1947), Pradhan (1950a, b and 1975), Gupta (1981), Roy *et al.* (1988), Ghosh *et al.* (1989), Polhemus and Starmuhlner (1990), Bal and Basu (1994, 1997, 2000), Chen and Zettel (1999), Thirumalai (1986, 1989, 1992, 1994a and b, 1996, 1999, 2000, 2002), Chandra *et al.*, (2012), Jehamalar and Chandra (2013a, b). The revisionary work of Andersen (1975, 1980, 1990 and 1993), Den Boer (1965), Hennig (1981), Polhemus and Andersen (1984), Hungerford and Matsuda (1958a and b, 1960, 1962, 1965), Polhemus (1994), Polhemus and Polhemus (1994, 1995), Chen and Nieser (1993a and b), Chandra and Jehamalar (2012a), Jehamalar and Chandra (2013c, d), Basu *et al.*, (2014, 2016) on few genera of Gerridae; Andersen (1981a, 1983, 1989), Polhemus (1990a), Lundblad (1936), Jehamalar (2015) on Veliidae; Andersen and Polhemus (1980) on Mesoveliidae; Hungerford and Evans (1934), Polhemus and Polhemus (1995), Jehamalr and Chandra (2014b) on Hydrometridae; Andersen (1981b) and Zettel (1998) on Hebridae of the World are important to understand the present scenario of Indian Gerromorpha.

The true water bugs or Nepomorpha occur all over the world except Antarctica, with about 2000 species altogether, was first recognized as a group by Latreille (1810) under the name Hydrocorisae. The taxa historically were placed in the Hydrocorisae (Dufour, 1833; Leston *et al.*, 1954) and are characterized by short antennae that are concealed in part or entirely by the eyes. Taxonomy, nomenclature, higher classification and phylogeny of Nepomorpha were reviewed by many workers and important contributions have been made by Popov (1971), Stys and Kerzhner (1975), Rieger (1976), Stys and Jansson (1988), Mahner (1993), Andersen (1995), Polhemus *et al.* (1995) and Hebsgaard *et al.* (2004). Thirumalai (2007) published a checklist on the Indian Nepomorpha, which enlisted 153 species under 34 genera of aquatic bugs found in India. However, the number increased to 157 species with the discovery of more new species under different families in recent years in India. The earlier knowledge on Indian aquatic bugs is mainly limited to taxonomic contributions by Distant (1903, 1906, 1910a and b), Annandale (1919), Paiva (1919a, b), Dover (1928), Hutchinson (1933, 1940), Hafiz and Mathai (1938), Hafiz and Riberio (1939), Hafiz and Pradhan (1947) and Pradhan (1950a). The revisionary work of Lundblad (1933), Chen (1960) and Wroblewski (1960, 1962, 1972) on the genus *Micronecta* (Micronectidae), Todd (1955) on the genus *Nerthra* (Gelastocoridae), Esaki and China (1928), Polhemus (1990b) and Papacek and Zettel (2003 and 2004) on the family Helotrephidae. Polhemus and Polhemus (1988), Sites *et al.*, (2011), Basu *et al.* (2013) on Aphelocheiridae, La Rivers (1971a and b, 1974) on Naucoridae, Lansbury (1972 and 1973) on the genera *Ranatra, Montonepa* and *Cercotmetus* (Nepidae), Hungerford (1933), Brooks (1951) and Lansbury (1968) on the genera *Notonecta, Anisops, Enithares* (Notonectidae) and Jaczewski (1934), Kormilev (1971), Chandra and Jehamalar (2012b) on the family Ochteridae of the world are noteworthy to understand the nepomorphan fauna of India. Consolidated information on the occurrence as well as the present status of aquatic bugs in India pertains to the works of Bal and Basu (1994, 1997, 2000, 2002, 2003, 2004), Ghosh *et al*. (1989), Nahar (2004), Papacek and Zettel (2004), Polhemus and Starmuhlner (1990). Ravishankar and Venkatesan (1988), Thirumalai (1983, 1986, 1989, 1994a, 1998, 1999, 2001, 2002, 2004 and 2007), Thirumalai and Raghunathan (1988), Thirumalai and Kumar (2005), Thirumalai *et al.* (2004, 2006), Venkatesan and Rao (1980) and Zettel (1997a, b, 1998, 2000 and 2001), Chandra *et al.*, (2012), Jehamalar and Chandra (2013a, b).

The major taxonomic work on the infraorder Leptopodomorpha has been carried out by Reuter (1912), Drake and Chapman (1952), Schuh *et al.* (1987), Cobben (1959, 1980, 1985), Polhemus and Polhemus (2007, 2012), Zettel *et al.*, (2013).

Diversity

Polhemus and Polhemus (2008) and Alder and Foottit (2009) mentioned that approximately 4656 species of aquatic and semi-aquatic bugs belonging to three infraorders, 20 families and 326 genera inhabit freshwater globally. In addition, more than 1100 species remain undescribed (Polhemus and Polhemus, 2007). Of these, 1103 species occur in the Oriental region. Whereas, the species richness is higher in Neotropical region and it is represented by 1289 species. India is represented by 318 species under 82 genera and 18 families (Thirumalai, 1999, 2002, 2007). Among these, the families like Veliidae, Gerridae, Corixidae, Micronectidae, Hebridae, Helotrephidae and Naucoridae are high species rich families. However the current number of species is 4940 globally. Global freshwater aquatic Heteroptera diversity is provided in Table 1.

Table 1. Global diversity of freshwater aquatic Heteroptera (Polhemus and Polhemus, 2008).

Infraorder	Family	Species
Gerromorpha	Gerridae	777
	Veliidae	1011
	Hebridae	230
	Hydrometridae	128
	Mesoveliidae	47
	Hermatobatidae	12
	Macroveliidae	3
	Paraphrynoveliidae	2
Nepomorpha	Belostomatidae	160
	Nepidae	271
	Notonectidae	406
	Corixidae and Micronectidae	613
	Pleidae	38
	Aphelocheiridae	84
	Naucoridae	404
	Ochteridae	69
	Gelastocoridae	111
	Helotrephidae	181
	Potamocoridae	10
Leptopodomorpha	Leptopodidae	41
	Saldidae	335
	Omaniidae	6
	Aepophilidae	1
	Total	**4940**

Classification of Aquatic bugs of Indian Subregion

Infraorder Gerromorpha

Superfamily Gerroidea

Family GERRIDAE

Subfamily Rhagadotarsinae

Subfamily Trepobatinae

Subfamily Gerrinae

Subfamily Eotrechinae

Subfamily Cylindrostethinae

Subfamily Ptilomerinae

Subfamily Halobatinae

Family VELIIDAE

Subfamily Microveliinae

Subfamily Rhagveliinae

Subfamily Haloveliinae

Subfamily Veliinae

Subfamily Perittopinae

Superfamily Mesovelioidea

Family MESOVELIIDAE

Subfamily Mesoveliinae

Superfamily Hydrometroidea

Family HYDROMETRIDAE

Subfamily Hydrometrinae

Superfamily Hebroidea

Family HEBRIDAE

Subfamily Hebrinae

Subfamily Hyrcaninae

Infraorder Nepomorpha

Superfamily Nepoidea

Family NEPIDAE

Subfamily Nepinae

Subfamily Ranatrinae

Family BELOSTOMATIDAE

Subfamily Belostomatinae

Subfamily Lethocerinae

Superfamily Ochteroidea

Family GELASTOCORIDAE

Subfamily Nerthrinae

Family OCHTERIDAE

Superfamily Corixoidea

Family CORIXIDAE

Subfamily Corixinae

Subfamily Cymatinae

Family MICRONECTIDAE

Subfamily Micronectinae

Superfamily Naucoroidea

Family APHELOCHEIRIDAE

Subfamily Aphelocheirinae

Family NAUCORIDAE

Subfamily Cheirochelinae

Subfamily Laccocorinae

Subfamily Naucorinae

Superfamily Notonectoidea

Family NOTONECTIDAE

Subfamily Anisopinae

Subfamily Notonectinae

Superfamily Pleoidea

Family PLEIDAE

Family HELOTREPHIDAE

Subfamily Fischerotrephinae

Subfamily Helotrephinae

Infraorder Leptopodomorpha

Family LEPTOPODIDAE

Family SALDIDAE

Family wise diversity is summarized **Table 2.**

Table 2. Aquatic bugs diversity across family, genera and species in the Indian subregion

Sl. No.	Infraorder	Family	No. Genera	No. Species
I	Gerromorpha			
1		Gerridae	26	93
2		Veliidae	13	33
3		Hydrometridae	1	5
4		Hebridae	4	22
5		Mesoveliidae	1	3
II	Nepomorpha			
6		Aphelocheiridae	1	8
7		Nepidae	3	24
8		Naucoridae	7	20
9		Notonectidae	4	32
10		Corixidae	7	20
11		Micronectidae	2	27
12		Pleidae	1	4
13		Helotrephidae	6	13
14		Ochteridae	1	2
15		Gelastocoridae	1	5
16		Belostomatidae	2	5
III	Leptopodomorpha			
17		Leptopodidae	2	2
18		Saldidae	2	7
		Total	**84**	**325**

Distribution

Aquatic and semi-aquatic hemipterans are distributed in a wide range of freshwater habitats ranging from pond, lake, forested small temporary pool, rivers, hill streams, canal within agricultural field, waterfalls, cascades, mountainous lake or stream etc. They occur on all continents except Antarctica and more diverse in tropical areas. High diversity of water bugs is found in the pristine habitats of Eastern Himalaya and Western Ghats. However, many families especially of the Infraorder Leptopodomorpha are yet to be completely documented. They are also found in the high altitudinal regions and show variance in diversity across altitudinal gradients and land use pattern. Hence, they are the ideal candidates for zoogeographical, ecological and biomonitoring studies. Nevertheless, the documentation of the updated list of species is still incomplete and many more species are yet to be described.

Endemism

A high percentage of tropical endemic species are found. Although several species are cold adapted and associated with stream or waterfalls with high structural complexity (Polhemus *et al.*, 1992) Due to poor dispersal capabilities, they serve as zoogeographical indicators (Thirumalai, 1999). Some species has wide habitat distribution and few are restricted to either lentic or lotic habitats. The Oriental realm especially the Indian subregion supports a wide variety of aquatic bugs due to its complex biogeographic past. Though an intensive study is presently focused on this area, resulting in a good number of new taxa, which are mostly endemics.

Biology

Aquatic and semi-aquatic bugs mainly inhabit inland freshwater habitats, though several species are associated with intertidal brackish water and marine habitats. They are predaceous or scavengers except family Corixidae (detritivore), feeding on other aquatic insects. Few species of the family Belostomatidae, Aphlocheiridae, Naucoridae, Nepidae and Gerridae are known to predate on other aquatic insects of their own size, and even tadpoles, fish, molluscs, frogs etc. by immobilizing preys. They have sexual dimorphism and males are often smaller than females. All members of the aquatic bugs migrate to new habitats and some of them are attracted to light. They mostly encountered in apterous forms. However, the temporary pools are mainly dominated by macropterous population. Species diversity is affected with the land use pattern altitude, habitat and microhabitat.

Life cycle

The aquatic Hemipterans are hemimetabolous insects i.e., they undergo incomplete metamorphosis. The life cycle stages consist of egg, nymph and adult. They produce one or two or sometimes several generations per year. In general, the overwintered adults lay eggs in springs, develop in summer and further replicate their cycle. Though, several studies have been undertaken on life histories of these bugs in laboratory conditions. Usually, eggs are laid and glued on the rocks and plants or sometimes on the back of the males (Belostomatidae). The eggs are relatively tough, hexagonal, oval or spindle shaped with button-like or peg like micropylar processes. There are five nymphal instars and the nymphs are morphologically alike to adults, but without reproductive development. The entire life cycle of these bugs may take 2 to 3 months (Leong, 1962). In some species life cycle starts from mid May to July and new generations appear in late August to October and overwinter until March to April (Ohba and Goodwyn, 2010). However, their life cycle depends on the temperature and availability of food resources. They usually found to mate throughout the year, but mating increased during February. They stridulate to attract their mates. Most of them have well-developed forelegs with tooth or spines for grasping females. Although, surface ripples also attract mates (Wilcox, 1969), in a few species of water striders, mating occur on the surface water and the pair copulate for several hours or even days (Birch *et al.*, 1979). In true aquatic bugs (Nepomorpha), they complete their entire life cycle including mating underwater.

Longevity

The life span of adult usually lasts for one to six months. However, it varies according to species and depends on temperature of the aquatic habitat.

Threats

The major threat is the impact of anthropogenic disturbances on inland freshwater ecosystems. Habitat destruction, deforestation, rapid urbanization, changes in the land use pattern such as dam construction, encroachment, siltation, weed infestation, industrial or pesticidal pollution, over exploitation and electrofishing to catch fishes in streams or rivers, which also affects other aquatic insects are the real threats to these bugs inhabiting in such ecosystems. On the other hand, introduction of exotic insect species to control weeds causes loss of native insect population. Climate change and global warming are immediate threats to this freshwater ecosystem, especially in Tropics.

Conservation and Significance

The first and principal actions necessary for conservation of these bugs, are the restoration and management of inland freshwater habitats through protection and preservation of bio-resources of the habitats. The effective conservation of species requires understanding of how and where population occurs in a landscape and what are the factors affecting this population. One of the major attempts to protect the aquatic fauna is to set priorities among the several deserving candidates of aquatic habitats and to find out the factor responsible for their decline. The major approaches to conserve should be a combination of ecological, biotechnological and socio-cultural and legal. The ecological and biotechnological approach involves rapid identification through taxonomic studies and DNA Barcoding of them and their different life stages. The awareness creation among local communities and to involve them in management of freshwater habitats is also required.

Gaps in research

Several species especially of the family Leptopodidae, Saldidae, Helotrephidae, Micronectidae, Veliidae are still unknown from India. Many freshwater ecosystems of India are under surveyed and unexplored, mainly the Eastern Himalayan Biodiversity Hotspots and the Western Himalaya. However, major work on wetlands of Western Ghats has already been undertaken by Thirumalai (1986, 1989, 1992, 1994, 2004) and Thirumalai and Kumar (2005). However, the molecular studies involving DNA barcoding technique is still lacking and initiative is required. Though, few species were barcoded recently and published at NCBI databases by Basu and Venkatesan (2016).

Future dimensions

An intensive survey in the unexplored areas of India is required to update the baseline information and to understand their pattern of distribution.

Combined approaches of both morphological and molecular systematic studies and phylogenetic analysis are needed.

Studies on impact of several ecological and environmental factors and the impact of anthropogenic disturbances on species of freshwater Hemipterans should be one of the priorities.

Studies on cryptic species population and to resolve the problem through molecular study is also obligatory.

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Chapter 24

INSECTA : COLEOPTERA (AQUATIC BEETLES)

KAILASH CHANDRA[1], DEEPA JAISWAL[2] & DEVANSHU GUPTA[3]

ABSTRACT

The aquatic beetle fauna of India consists of 776 species belonging to 137 genera, and 17 families under 3 suborders. The suborder Polyphaga includes 371 species, Adephaga 353 species, and Myxophaga 7 species. Dytiscidae includes maximum numbers of species 256, followed by Hydrophilidae (212 species), Scirtidae (75 species), Gyrinidae (73 species), Hydraenidae (45 species), Elmidae, Psephenidae (24 species each), Noteridae (16 species), Haliplidae, Dryopidae (10 species each), Georissidae, Helophoridae (7 species each), Hydroscaphidae, Hydrochidae (5 species each), Epimetopidae (4 species), Spercheidae (3 species), and Sphaeriusidae (2 species). In terms of biogeographic distribution, the highest diversity of aquatic beetles is present in the Indian Himalayan Landscape (357 species), followed by Deccan Peninsula (193 species), Western Ghats, Northeast (171 species, each), Gangetic Plains (167 species), Semi-Arid (64 species), Islands (43 species), Coasts (37 species), Trans-Himalaya (26 species) and Desert (24 species).

Key words : Aquatic Coleoptera, Diversity, Biogeography, Distribution.

INTRODUCTION

The order Coleoptera includes hard bodied beetles which are holometabolous in nature with complex metamorphosis, their forewings are folded into chitinous elytra, hind wings membranous, protected under elytra while in resting stage. They are characterized by mandibulate mouthparts, antennae with 11 or fewer antennomeres, larvae worm-like, and the male aedeagus and the female ovipositor are retracted into the abdominal apex when not in use. Based on the number of described animal diversity, the beetles are the most species-rich animal group existing on the Earth. Slipinski *et al*. (2011) estimated that there are about 3,86,500 species belonging to 29,500 genera and 176 families under 4 suborders (Archostemata, Myxophaga, Adephaga, and Polyphaga), representing 40% of the total animal diversity of the world. Grove & Stork (2000) hypothesized that about 70–95% of all the beetle species are yet to be discovered and described and also emphasized that it would take 200 years to explore the entire beetle fauna of the world. The beetles are found everywhere and in almost all ecosystems where animals can thrive with the exceptions of arctic snow and the sea water.

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Jäch & Balke (2008) in his global assessment of water beetles estimated that the planet earth harbors about 12,600 species of Coleoptera, thriving solely on aquatic ecosystems in part of their life cycle. Aquatic beetles or water beetles live in almost all kinds of aquatic habitats, such as rivers, springs, lakes, ditches, puddles, seepages, and ground water. Based on their association with aquatic life as of adults and of immature stages, the aquatic beetles can be classified into following six groups: 1. True Water Beetles, 2. False Water Beetles, 3. Phytophilous Water Beetles, 4. Parasitic Water Beetles, 5. Facultative Water Beetles, and 6. Shore Beetles (Jäch, 1998). The adults of the true water beetles remain submerged for most of the time in water whereas their larvae and pupae may be aquatic or terrestrial. The species in this group are highly adapted to aquatic life showing important morphological adaptations such as swimming hairs on legs, divided eyes, plastron, large claws, and streamlined body form. In false water beetles, only the juvenile stages are aquatic, the adult stage is always predominantly terrestrial. Parasitic water beetles come in association with water only when their hosts are submerged whereas facultative water beetles and shore beetles are predominantly terrestrial beetle families with their juveniles live in very wet habitats (Jäch, 1998).

Out of 4 suborders of Coleoptera, the suborder Myxophaga is truly aquatic whereas 8 of the 11 extant families of Adephaga are regarded as truly aquatic (Gyrinidae, Haliplidae, Meruidae, Noteridae, Amphizoidae, Aspidytidae, Hygrobiidae, Dytiscidae). As far as Polyphaga is concerned, the largest suborder of Coleoptera, only 13 of the 150 families are regarded as truly aquatic (Helophoridae, Epimetopidae, Hydrochidae, Spercheidae, Hydrophilidae, Hydraenidae, Scirtidae, Elmidae, Dryopidae, Lutrochidae, Psephenidae, Cneoglossidae, and Eulichadidae) Jäch & Balke (2008).

The beetle fauna of India is highly diverse and holds about 4.66% of all known species of the world, with about 17,431 species belonging to 113 families under 3 suborders (Adephaga, Myxophaga, and Polyphaga) (Ramakrishna & Alfred, 2007). Out of them, seventeen families can be said to be truly aquatic: Hydrophilidae, Scirtidae, Gyrinidae, Hydraenidae, Elmidae, Psephenidae, Noteridae, Haliplidae, Dryopidae, Georissidae, Helophoridae, Hydroscaphidae, Hydrochidae, Epimetopidae, Spercheidae, and Sphaeriusidae.

The available information on the aquatic beetles of the families; Dytiscidae, Haliplidae, Gyrinidae, and Noteridae of India is mainly because of the works done by Vazirani (1952, 1955, 1964, 1966, 1969a, b, c; 1970, 1973a, b; 1975, 1976a, b, c, 1977a, b, c, d, e, f, g, 1980, 1981, 1984). Vazirani (1977a) published catalogue of Dytiscidae of India which was recently updated by Ghosh & Nilsson (2012), reporting 254 species from India. Vazirani (1984) in his concluding contribution wrote the fauna of India of Gyrinidae and Haliplidae. Further contributions have been made mainly by Biswas & Mukhopadhyay (1995), Mukhopadhyay *et al*. (2000), Mukhopadhyay & Ghosh (2003, 2007, 2010), Mukhopadhyay & Sengupta (2004), Mukhopadhyay (2007, 2010), Ghosh *et al.* (2000, 2014) and Deepa *et al*. (2015). The world catalogues of aquatic families have been published by Hansen (1998, Hydraenidae; 1999, Hydrophiloidea), Nilsson & Vondel (2005, Haliplidae, Noteridae), Jäch *et al*. (2016, Elmidae) and Nilsson (2011, Noteridae; 2015, Dytiscidae). The catalogues of Palearctic Coleoptera have been compiled by Löbl & Smetana (2003, Myxophaga, Adephaga; 2004, Hydrophiloidea; 2006, Byrrhoidea).

Except the families, Dytiscidae, Gyrinidae, and Haliplidae, dealt in various publications, the information on the diversity and distribution of aquatic beetles, especially in the families, Hydrophilidae, Scirtidae, Hydraenidae, Elmidae, Psephenidae, Noteridae, Dryopidae, Georissidae, Helophoridae, Hydroscaphidae, Hydrochidae, Epimetopidae, Spercheidae, and Sphaeriusidae is completely lacking.

Thus, in the present chapter, an attempt has been made to study the current status of diversity and distribution of aquatic beetles in different bio-geographic zones of India. The chapter dealt with the families which come under true or false water beetle categories as classified by (Jäch, 1998). The families representing phytophilous water beetles, parasitic water beetles, facultative water beetles, and shore beetles are not included. The detailed information of each taxa, reported in the chapter is as follows.

STATUS OF AQUATIC BEETLES (COLEOPTERA) OF INDIA

Species Diversity

The aquatic beetle fauna of India consists of 776 species belonging to 137 genera, and 17 families under 3 suborders (Tables 1). The suborder Polyphaga includes 371 species, Adephaga 353 species, and Myxophaga 7 species (Table 1). Dytiscidae includes maximum numbers of species 256, followed by Hydrophilidae (212 species), Scirtidae (75 species), Gyrinidae (73 species), Hydraenidae (45 species), Elmidae, Psephenidae (24 species each), Noteridae (16 species), Haliplidae, Dryopidae (10 species each), Georissidae, Helophoridae (7 species each), Hydroscaphidae, Hydrochidae (5 species each), Epimetopidae (4 species), Spercheidae (3 species), and Sphaeriusidae (2 species) (Table 1). Seven genera were found to be monotypic: *Rhantaticus* (Dytiscidae), *Laorina*, *Macronychoides*, *Paramacronychus* (Elmidae), *Monstrosostea* (Dryopidae), *Ophthalmocyclus*, *Morastus*, and *Pseudocercyon* (Hydrophilidae) (Table 2).

Suborder ADEPHAGA

Adephaga includes 44,990 species (18% aquatic) under 11 families globally (Jäch & Balke, 2008; Slipinski *et al*., 2011). The families, Gyrinidae, Haliplidae, Meruidae, Noteridae, Amphizoidae, Hygrobiidae, and Dytiscidae are truly aquatic in nature. Among them, the members of the following 4 families; Gyrinidae, Haliplidae, Noteridae, and Dytiscidae are found in India, which are a major component of water beetle fauna with a total of 353 species, reported from all the biogeographic zones of the country. Meruidae, Amphizoidae, and Hygrobiidae are not yet recorded from India. Though one species of Amphizoidae was reported from India, but it was later shifted in the family Dytiscidae (Nilsson & Vondel, 2005).

1. Family GYRINIDAE

The beetles in this family show peculiar swimming behavior where adults rapidly revolve around a fixed point on the surface of the water. They are found in static or moderately running water and preferably live in the habitats with rich oxygen contents. The beetles are commonly known as whirligig beetles and can be distinguished from the other Adephagan families by following characters: compound eyes divided completely, so placed with upper pair on the dorsal surface of the head, remains above the water line and the lower pair on the ventral surface of the head, remains below the water line when the beetle swims; antennae short with a broad, cup-shaped scape, subtriangular pedicel and elongate but compact flagellum, and meso- and metathoracic legs broadly expanded and fringed with setae for swimming (Roughley, 2001a).

Gyrinidae with its worldwide distribution consists of about 1,000 species under 25 genera globally (Slipinski *et al*., 2011). The Indian fauna is represented by 73 species belonging to 5 genera under 3 subfamilies; Gyrininae (5), Enhydrinae (5) and Orectochilinae (63) (Tables 1, 2). Orectochilinae is the most diverse subfamily in the region, which includes 63 species under a single genus, *Orectochilus* representing 33.3% of the global diversity of the genus (Table 2). Vazirani (1984) in the fauna of India of family Gyrinidae reported that the members of this genus generally occur in running waters, streams and occasionally in perennial ponds. In the subfamily Gyrininae, the genus *Gyrinus* consists of 3 species, and the genera *Aulonogyrus* and *Metagyrinus* each with a single species. Enhydrinae is represented by the genus *Dineutus*, which consists of only 5 species (105 species worldwide) from the country.

2. Family HALIPLIDAE

The family Haliplidae is a comparatively small group of inconspicuous, small water-dwelling beetles, which are commonly termed as crawling water beetles. The features that distinguish these beetles from other families are: extremely large meta-coxal plates which cover most of the abdominal ventrites, tarsal formula 5-5-5 and body form adapted for aquatic life (Roughley, 2001b). The members of this family are moderate swimmers, may be found in diverse freshwater habitats such as in brackish water, in the static or moderately-running water of pools, ponds, lakes, marshes, ditches, canals, and rivers etc. The availability of the beetles depend on the climatic conditions and they can breathe through microtracheal gills in juvenile stages at the water surface.

Haliplidae consists of 220 species under 5 genera: *Algophilus*, *Apteraliplus*, *Brychius*, *Peltodytes*, and *Haliplus* (Nilsson & Vondel, 2005). The Indian fauna of this family is represented by 10 species belonging to the genus *Haliplus* (Table 2) (Vazirani, 1984; Vondel, 1993). The genus *Haliplus* is widely distributed in Australian, Afrotropical, Nearctic, Neotropical, Oriental and Palaearctic regions. The *Haliplus* species from India belong to the subgenus *Liaphlus*, which was revised from the oriental region by Vondel (1993). *H. angustifrons* Régimbart, 1892 was the first species, described from India with its type locality situated in Konbira, Ranchi district, Bihar (now in Jharkhand). This species has also been widely reported from Nepal, Sri Lanka and Myanmar (Nilsson & Vondel, 2005).

3. Family DYTISCIDAE

The beetles in this family are adapted well to aquatic life. The adults and larvae live in water and can be found in any aquatic ecosystems. They mostly feed on aquatic invertebrates and fish eggs. This is why they are commonly called as 'predacious diving beetles'. The streamlined and flattened body of the adults along with the flattened or paddle-like tibia, femur and/or tarsi of metathoracic legs, give them a characteristic shape to adapt to aquatic life. They can be distinguished from the beetles in the family Hydrophilidae by 1st visible abdominal sternum and short palpi whereas lack of prosternal platform differentiates them from Noterids and a single pair of eyes from Gyrinids (Roughley & Larson, 2001).

This family is worldwide in distribution with about 4,303 species belonging to 190 genera so far described globally (Nilsson, 2015). The Indian fauna of this family is represented by 254 species (7.3%) belonging to 36 genera under 6 subfamilies; Hydroporinae, Copelatinae, Dytiscinae, Laccophilinae, Agabinae, and Colymbetinae (Table 2) (Ghosh & Nilsson, 2012). Out of 190 genera, reported worldwide, 36 (18.9%) have been recorded from India (Table 1). The maximum species diversity is reported in the subfamily Hydroporinae (96 species), followed by Copelatinae, Dytiscinae, (46 species each), Laccophilinae (31 species), Agabinae (27 species), and Colymbetinae (8 species) (Table 2). The following genera of Hydroporinae are widely distributed in India: *Hydrovatus* (18 species), *Hyphoporus* (13 species), *Hydroglyphus* (12 species), and *Microdytes* (10 species). Copelatinae with 46 species is composed of only 2 genera: *Copelatus* and *Lacconectus* (23 species each). *Lacconectus* shows Oriental and Palearctic distribution and is highly diverse in the Indian region, representing 32.4 percent of the global diversity of the genus (Nilsson, 2015). Laccophilinae includes only 2 genera: *Laccophilus* (22 species) and *Neptosternus* (9 species). In Agabinae, the genera *Agabus* and *Platambus* include 12 species, each whereas *Platynectes* consists of 2 species and *Hydronebrius* 1 species.

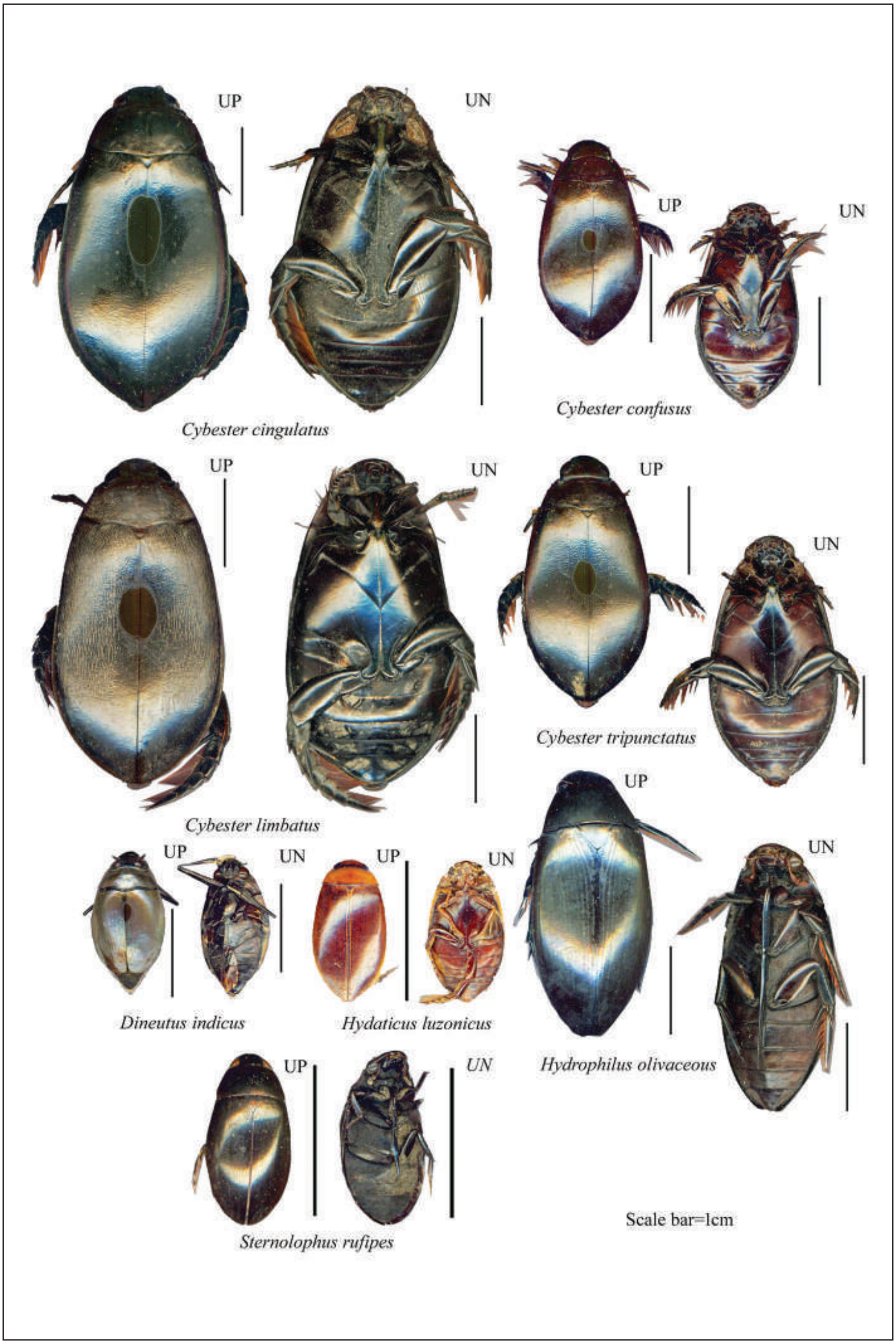
4. Family NOTERIDAE

The members of this family are called as burrowing water beetles. They are usually found in large numbers in sunny, and shallow lentic habitats, and generally avoid the situations where they need to burrow (Miller, 2009).

Globally the family includes 258 species belonging to 16 genera under 3 subfamilies; Noterinae (240 species), Notomicrinae (11 species), and Phreatodytinae (7 species) (Nilsson, 2011). The Indian fauna is represented by 16 species (6.2%) belonging to 4 genera under the subfamily Noterinae. The highest numbers of species are reported in the genus *Canthydrus* (7 species), followed by *Neohydrocoptus* (5 species), *Noterus* (3 species) and *Hydrocanthus* (1 species).

Suborder MYXOPHAGA

Myxophaga includes 84 species under 4 families from the world: Lepiceridae (2 species), Torridincolidae (60 species), Hydroscaphidae (22 species), and Sphaeriusidae (23 species) (Jäch, 1998; Jäch & Balke, 2008; Slipinski *et al*., 2011). The two known species of Lepiceridae are reported from Mexico and Venezuala (Jäch, 1998) whereas Torridincolidae occurs in South America, Africa and with few species from Asia. The members of Hydroscaphidae and Sphaeriusidae are worldwide in distribution and are also reported from India.



Some Aquatic Coleoptra (Photo K.A. Subramanian)

5. Family HYDROSCAPHIDAE

The beetles in this family are small sized and commonly called as skiff beetles. They can be distinguished by the presence of a distinct notopleural suture and of their aquatic life (Hall, 2001). They are found on algal mats, over which a thin water film flows (Vanin *et al*., 2005). The world fauna of this family includes about 22 species under 3 genera: *Scaphydra* (3 species), *Yara* (2 species), and *Hydroscapha* (17 species) globally (Fikáček & Šípková, 2009). The Indian fauna of this family is relatively rich with about 5 species belonging to the genus *Hydroscapha*, representing 22.7% of the total described diversity of the family (Löbl & Smetana, 2003; Fikáček & Šípková, 2009). Fikáček & Šípková (2009) recently described 2 new species *H. khasiorum* and *H. rajani* from the state of Meghalaya and reported *H. monticola* Löbl, 1994 as new to the fauna of India. The other two species are reported from Uttarakhand state (Löbl & Smetana, 2003).

6. Family SPHAERIUSIDAE

The beetles in this family are called as minute bog beetles which can be distinguished from other families of the suborder by their comparatively large and prominent head, capitate antennae, design of meso- and metasternum, large posterior coxal plates and unequal length of visible abdominal sternites. They are found in mud, under stones, or on algae along the edge of streams and rivers, among the roots of plants, in mosses associated bogs or inhabiting moist leaf litter further away from the bodies of water (Hall, 2001). This monogeneric family is widely distributed, and includes 23 species belonging to the genus, *Sphaerius* from the world (Jäch & Balke, 2008). The Indian fauna consists of 2 species; *S. gustavlohsei* (Löbl, 1995) from Sikkim and *S. laeviventris* Champion, 1923 from Uttarakhand (Löbl & Smetana 2003).

Suborder POLYPHAGA

7. Family ELMIDAE

The beetles in this family are commonly called as riffle beetles and they can be both aquatic and semi-aquatic in nature. The slender antennae, hairless eyes, and nonswimming legs with large claws distinguish them from other families of superfamily Byrrhoidea (Shepard, 2002a). Till date, 1498 species belonging to 147 genera under 2 subfamilies Elminae and Larainae have been described from the world (Jäch *et al*., 2016). The Indian fauna includes about 24 species belonging to 12 genera in the subfamily Elminae (Jäch *et al*., 2016). The genus *Stenelmis* includes maximum number of species 7 followed by *Podelmis* (4 species), *Grouvellinus, Rudielmis*, and *Leptelmis* (2 species, each). The other genera of the family are represented by only a single species each. The adults and juvenile stages of the subfamily Elminae live totally aquatic habitats and on occasions leave water (Shepard, 2002a). The subfamily Larainae is centered in Afrotropical and Neotropical regions with lower diversity in the Oriental region.

8. Family DRYOPIDAE

The beetles in this family are commonly called as long-toed water beetles which can be separated from other families of superfamily Byrrhoidea by the presence of short antennae with most segments broader than long (Shepard, 2002b). There are about 300 species belonging to 33 genera, occurring in almost all the bio-geographical regions of the world except in Australian continent (Jäch & Balke, 2008). The species in this family are found in forest litter and the adults of the most of the species live aquatic life (Shepard, 2002; Jäch & Balke, 2008). The Indian fauna of this family is poorly known with only 10 species belonging to 6 genera *Sostea* (3 species), *Helichus* (2 species), *Pachyparnus*, *Dryops*, *Elmomorphus*, and *Monstrosostea* (1 species, each) so far reported from the country.

9. Family PSEPHENIDAE

The beetles in this family are called as water penny beetles. They can be easily distinguished from related families of superfamily Byrrhoidea by their soft body, serrate to pectinate antennae, anterior coxae with exposed trochantin and their association with streams (Shepard, 2002c). The adults remain active during the summer months, and males are generally found on the banks of the rivers whereas the females may lay eggs on rocks below the water (Shepard, 2002). The larval stages are purely aquatic, and the larvae are found in running water (Jäch & Balke, 2008). There are 290 species belonging to 35 genera under 4 subfamilies: Eubrianacinae, Eubriinae, Psepheninae, and Psephenoidinae, worldwide. The Indian fauna is represented by 24 species belonging to 9 genera under 3 subfamilies, Eubriinae (17 species), Psephenoidinae (6 species), and Psepheninae (1 species).

10. Family SCIRTIDAE

The beetles in this family are known as plate-thigh beetles, distinguished by other families by their compact and elliptical body with greatly enlarged metathoracic coxal plates and saltatorial behavior (Young, 2002). The larval stages are aquatic, but in some cases it has been reported that the scirtid larvae may be found in wet soil and on rotten logs. There are about 800 species belonging to 35 genera of family Scirtidae occuring on all continents (Slipinski *et al*., 2011). So far as Indian fauna of this family is concerned, it includes about 75 species under 8 genera: *Cyphon* (24 species), *Hydrocyphon*, *Scirtes* (12 species each), *Elodes* (8 species), *Exochomoscirtes* (6 species), *Ora*, *Ypsiloncyphon* (5 species each), and *Sacodes* (3 species).

11. Family HYDROPHILIDAE

The members of this family are called as water scavenger beetles and are characterized by long maxillary palpi, even longer than antennae, may be confused for antennae; antennae short clavate, inserted in front of eyes, 6-9 segmented with a 3 segmented pubescent club (Tassell, 2002). Globally, there are about 2835 species belonging to 169 genera under 4 subfamilies: Horelophinae (1 species), Horelophopsinae (2 species), Hydrophilinae (1852) and Sphaeridiinae (980 species) (Short & Fikáček, 2011). The Indian fauna of family Hydrophilidae is represented by 212 species belonging to 41 genera under 2 subfamilies: Hydrophilinae (138 species) and Sphaeridiinae (74 species). In terms of generic diversity, Sphaeridiinae is represented by 20 genera and Hydrophilinae by 21 genera from India. The most diverse genera of Hydrophilinae are: *Laccobius* (48 species), *Enochrus*, *Helochares*, *Berosus* (10 species, each), *Hydrophilus* (8 species), *Agraphydrus*, *Anacaena*, *Oocyclus* (7 species each), *Pelthydrus* (5 species), *Allocotocerus* and *Sternolophus* (4 species, each). Whereas the major genera of subfamily Sphaeridiinae are: *Cercyon* (17 species), *Coelostoma*, *Sphaeridium* (9 species, each), *Dactylosternum* (7 species), *Pachysternum* (5 species), and *Oosternum* (4 species).

12. Family GEORISSIDAE

The beetles in this family are called as minute mud-loving beetles. The species are generally riparian in all stages (Jäch, 1998). Georissidae includes 80 species under a single genus, *Georissus*, which are found in all major bio-geographic regions of the world (Jäch, 1998; Hansen, 1999). Jäch (1998) proposed that the species in the family have reverted to terrestrial habits from aquatic ancestors. The Indian fauna is represented by 7 species with most of them restricted to Indian Himalayan Landscape.

13. Family HELOPHORIDAE

Helophoridae is a relatively small family of superfamily Hydrophiloidea with about 192 species classified into a single genus, *Helophorus* globally (Short & Fikáček, 2011). The adults of the genus *Helophorus* can be easily differentiated by their elongate body and 5 longitudinal furrows on pronotum. The majority of the species occur mostly on Palaearctic and Nearctic regions and only a few species are known from the Afrotropical and Oriental regions (Hansen, 1999; Short & Fikáček, 2011). The Indian fauna is represented by 7 species, constituting 3.6% of the total diversity of the genus as of family (Hansen, 1999).

14. Family HYDROCHIDAE

This family is represented by 181 species under a single genus, *Hydrochus* from the world (Short & Fikáček, 2011). Among them, 5 species (2.8%) have been so for reported from India (Hansen, 1999). The species in this family are purely aquatic in nature and are present in all continents. The beetles live in static water with full of vegetation or they may be found near the edges of moderately flowing water (Jäch & Balke, 2008).

15. Family EPIMETOPIDAE

This family includes 29 species under 3 genera worldwide: *Epimetopus* (19 species), *Eumetopus* (8 species), *Eupotemus* (2 species) (Short & Fikáček, 2011). *Epimetopus* occur in the new world, *Eupotemus* in Africa, and *Eumetopus* in Asia (Jäch & Balke, 2008). There are only 4 species belonging to the genus, *Eumetopus* so far reported from India.

16. Family SPERCHEIDAE

The species in this family are called as filter feeding water scavenger beetles. The adults and larval stages generally live in static water (Jäch, 1998). Out of the total 18 species under a single genus, *Spercheus*, 3 species have been so far recorded from India, constituting 16.7% of the total diversity of the world (Hansen, 1999).

17. Family HYDRAENIDAE

The beetles in this family are called as minute mass beetles which can be distinguished by their abdominal structure, having 6 or 7 visible abdominal sterna, a small intercoxal sternite between metacoxae and antennal club in many species with 5 pubescent antennomeres which in case of hydrophilids are 3 (Perkins, 2001).

Globally, Hydraenidae includes 1600 species under 42 genera, occurring on all continents. The Indian fauna is represented by 45 species under 8 genera, constituting 2.8% of the total diversity. The maximum number of species (18) are in recorded in the genus *Ochthebius*, followed by *Hydraena* (12 species), *Limnebius* (6 species), *Davidraena* (3 species), *Gondraena*, *Protochthebius* (2 species, each), *Laeliaena*, and *Aulacochthebius* (1 species, each).

BIOGEOGRAPHICAL DISTRIBUTION

The distribution of the aquatic beetles in different bio-geographic regions of India is summarized in Table 3. The highest diversity of aquatic beetles is present in the Indian Himalayan Landscape (357 species), followed by Deccan Peninsula (193 species), Western Ghats, Northeast (171 species, each), Gangetic Plains (167 species), Semi-Arid (64 species), Islands (43 species), Coasts (37 species), Trans-Himalaya (26 species) and Desert (24 species) (Table 3, Fig. 1). The families Dytiscidae and Hydrophilidae, representing more than 50% of the total aquatic beetle diversity of India, are distributed in all the bio-geographical zones of the country. Gyrinidae has not been reported from the Coasts and Trans-Himalayan regions. The Trans-Himalaya, Coasts, Islands, Semi-Arid and, Desert fauna is less

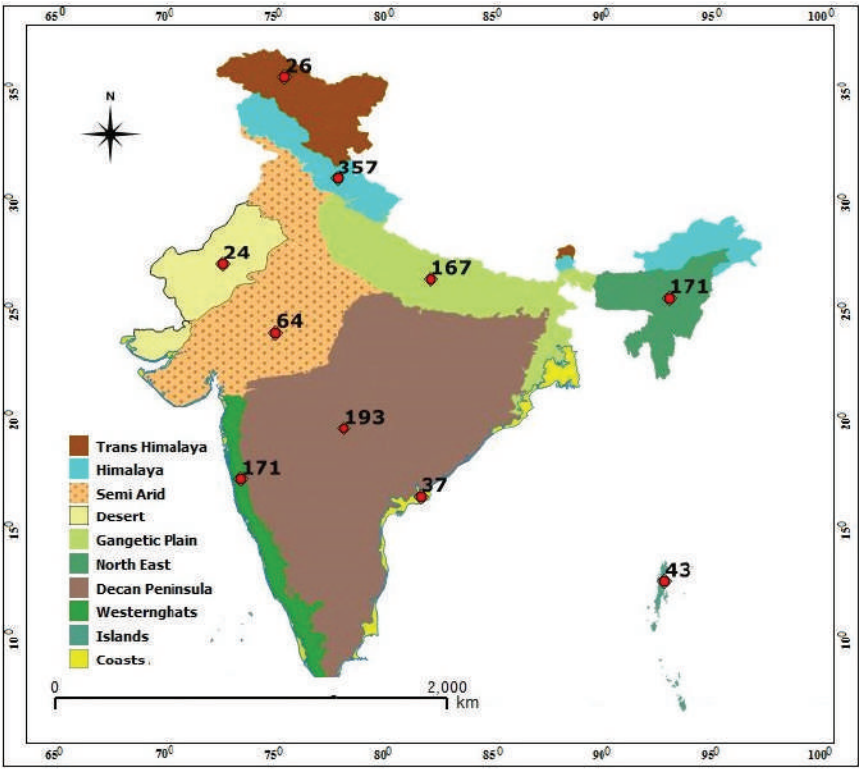


Fig. 1. Bio-geographical distribution of Aquatic Beetles in India.

explored whereas the fauna of Indian Himalayan Landscape, Gangetic-Plains, Northeast, Peninsular and Western Ghats has been explored well (Fig. 1).

CONCLUSION AND FUTURE PROSPECTS

The aquatic beetle fauna of India consists of 776 species belonging to 137 genera, and 17 families under 3 suborders. The suborder Polyphaga includes 371 species, Adephaga 353 species, and Myxophaga 7 species. Dytiscidae include maximum numbers of species 256, followed by Hydrophilidae (212 species), Scirtidae (75 species), Gyrinidae (73 species), Hydraenidae (45 species), Elmidae, Psephenidae (24 species each), Noteridae (16 species), Haliplidae, Dryopidae (10 species each), Georissidae, Helophoridae (7 species each), Hydroscaphidae, Hydrochidae (5 species each), Epimetopidae (4 species), Spercheidae (3 species), and Sphaeriusidae (2 species).

In terms of taxonomic studies, the fauna of the aquatic beetles of India needs revisionary works especially at generic level, focusing more on advanced tools of identification and species delimitation such as use of male genitalia and DNA barcodes for better understanding of differences in the population, inhabiting in different ecological zones of the country. Most of the taxonomic works on the aquatic beetles of India is focused mainly on two major families, Hydrophilidae and Dytiscidae. Whereas, the fauna of the families, Haliplidae, Dryopidae, Georissidae, Helophoridae, Hydroscaphidae, Hydrochidae, Epimetopidae, Spercheidae, Elmidae, and Psephenidae have been less worked out. If the taxonomic studies focusing on these less explored families will be conducted in future, it will surely enhance our knowledge of the aquatic beetle fauna of India with lots of new discoveries and new findings.

Moreover, very less work has also been carried out on the biology and ecology of these beetles from India in comparison to the world. There is need to explore this aspect of aquatic beetle ecology for assessing their potential use in sustainability of the aquatic ecosystems. Being indicator taxa, the aquatic beetles are vulnerable to even small changes in the environment, therefore, they can be used as model organisms for assessing the effect of climate change especially on freshwater ecosystems. There is need to explore the diversity of these beetles in less surveyed areas such as Trans-Himalayas, Coasts, Islands, Semi-Arid and Desert areas. Surveying these areas will undoubtedly reveal the hidden diversity of these beetles in the area with many a species as new to science.

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Table 1. Generic and species level diversity of aquatic beetles families (Coleoptera) in India with respect to their global status.

Sl. No.	Family	Genera			Species		
		World	**India**	**%**	**World**	**India**	**%**
		Suborder ADEPHAGA					
1.	Gyrinidae[1]	25	5	20.0	1,000	73	7.3
2.	Haliplidae[2]	5	1	20.0	220	10	4.5
3.	Noteridae[3]	16	4	25.0	258	16	6.2
4.	Dytiscidae[4]	190	36	18.9	4,303	254	6.0
		Suborder MYXOPHAGA					
5.	Hydroscaphidae[5]	3	1	33.3	22	5	22.7
6.	Sphaeriusidae[6]	2	1	50.0	23	2	10.0
		Suborder POLYPHAGA					
		Superfamily BYRRHOIDEA					
7.	Elmidae[7]	149	12	8.0	1,498	24	1.6
8.	Dryopidae[8]	33	6	18.1	300	10	3.3
9.	Psephenidae[9]	35	9	71.4	290	24	8.3
		Superfamily SCIRTOIDEA					
10.	Scirtidae[10]	35	8	22.9	800	75	9.4
		Superfamily HYDROPHILOIDEA					
11.	Hydrophilidae[11]	169	41	24.3	2,835	212	7.5
12.	Georissidae[12]	1	1	100.0	80	7	8.8
13.	Helophoridae[13]	1	1	100.0	192	7	3.6
14.	Epimetopidae[14]	3	1	33.3	29	4	13.8
15.	Hydrochidae[15]	1	1	100.0	181	5	2.8
16.	Spercheidae[16]	1	1	100.0	18	3	16.7
		Superfamily STAPHYLINOIDEA					
17.	Hydraenidae[17]	42	8	19.0	1,600	45	2.8
	Total	**711**	**137**	**19.2**	**13,649**	**776**	**5.7**
	World Data: [1, 2, 5, 6, 8, 9, 10, 17] Spilinski (*et al.*, 2011); [3]Nilsson (2011); [4]Nilsson (2015); [7]Jäch (2016); [11-16]Short and Fikáček (2011).						

Table 2. Number of species in genera of aquatic beetles (Coleoptera) from India and the World.

S.N.	Family	Subfamily	Genus	Number of species		%
				World	India	
	Suborder ADEPHAGA					
1.	Gyrinidae	Gyrininae	*Aulonogyrus*	55	1	1.8
2.	Gyrinidae	Gyrininae	*Gyrinus*	188	3	1.6
3.	Gyrinidae	Gyrininae	*Metagyrinus*	3	1	33.3
4.	Gyrinidae	Enhydrinae	*Dineutus*	105	5	4.8
5.	Gyrinidae	Orectochilinae	*Orectochilus*	195	63	32.3
6.	Haliplidae	-	*Haliplus*	161	10	6.2
7.	Noteridae	Noterinae	*Canthydrus*	65	7	10.8
8.	Noteridae	Noterinae	*Hydrocanthus*	52	1	1.9
9.	Noteridae	Noterinae	*Neohydrocoptus*	29	5	17.2
10.	Noteridae	Noterinae	*Noterus*	7	3	42.9
11.	Dytiscidae	Agabinae	*Agabus*	172	12	7.0
12.	Dytiscidae	Agabinae	*Hydronebrius*	4	1	25.0
13.	Dytiscidae	Agabinae	*Platambus*	64	12	18.8
14.	Dytiscidae	Agabinae	*Platynectes*	46	2	4.3
15.	Dytiscidae	Colymbetinae	*Colymbetes*	21	1	4.8
16.	Dytiscidae	Colymbetinae	*Rhantus*	106	7	6.6
17.	Dytiscidae	Copelatinae	*Copelatus*	431	23	5.3
18.	Dytiscidae	Copelatinae	*Lacconectus*	71	23	32.4
19.	Dytiscidae	Dytiscinae	*Cybister*	100	21	21.0
20.	Dytiscidae	Dytiscinae	*Dytiscus*	27	2	7.4
21.	Dytiscidae	Dytiscinae	*Eretes*	4	2	50.0
22.	Dytiscidae	Dytiscinae	*Hydaticus*	140	15	10.7
23.	Dytiscidae	Dytiscinae	*Rhantaticus*	1	1	100.0
24.	Dytiscidae	Dytiscinae	*Sandracottus*	16	5	31.3
25.	Dytiscidae	Hydroporinae	*Clypeodytes*	39	5	12.8
26.	Dytiscidae	Hydroporinae	*Geodessus*	2	2	100.0
27.	Dytiscidae	Hydroporinae	*Hydroglyphus*	89	12	13.5
28.	Dytiscidae	Hydroporinae	*Leiodytes*	27	6	22.2
29.	Dytiscidae	Hydroporinae	*Peschetius*	9	2	22.2
30.	Dytiscidae	Hydroporinae	*Pseuduvarus*	2	1	50.0
31.	Dytiscidae	Hydroporinae	*Uvarus*	65	2	3.1

S.N.	Family	Subfamily	Genus	Number of species		%
				World	India	
32.	Dytiscidae	Hydroporinae	*Yola*	46	3	6.5
33.	Dytiscidae	Hydroporinae	*Allopachria*	45	1	2.2
34.	Dytiscidae	Hydroporinae	*Boreonectes*	16	1	6.3
35.	Dytiscidae	Hydroporinae	*Deronectes*	57	1	1.8
36.	Dytiscidae	Hydroporinae	*Herophydrus*	43	2	4.7
37.	Dytiscidae	Hydroporinae	*Hydroporus*	182	2	1.1
38.	Dytiscidae	Hydroporinae	*Hydrovatus*	205	18	8.8
39.	Dytiscidae	Hydroporinae	*Hygrotus*	73	3	4.1
40.	Dytiscidae	Hydroporinae	*Hyphoporus*	18	13	72.2
41.	Dytiscidae	Hydroporinae	*Hyphydrus*	138	6	4.3
42.	Dytiscidae	Hydroporinae	*Methles*	7	1	14.3
43.	Dytiscidae	Hydroporinae	*Microdytes*	45	10	22.2
44.	Dytiscidae	Hydroporinae	*Nebrioporus*	58	5	8.6
45.	Dytiscidae	Laccophilinae	*Laccophilus*	262	22	8.4
46.	Dytiscidae	Laccophilinae	*Neptosternus*	99	9	9.1
	Suborder MYXOPHAGA					
47.	Hydroscaphidae	–	*Hydroscapha*	17	5	29.4
48.	Sphaeriusidae	–	*Sphaerius*	23	2	8.7
	Suborder POLYPHAGA					
	Superfamily BYRRHOIDEA					
49.	Elmidae	Elminae	*Grouvellinus*	35	2	5.7
50.	Elmidae	Elminae	*Heterlimnius*	14	1	7.1
51.	Elmidae	Elminae	*Indosolus*	2	1	50.0
52.	Elmidae	Elminae	*Laorina*	1	1	100.0
53.	Elmidae	Elminae	*Leptelmis*	26	2	7.7
54.	Elmidae	Elminae	*Macronychoides*	1	1	100.0
55.	Elmidae	Elminae	*Macronychus*	11	1	9.1
56.	Elmidae	Elminae	*Paramacronychus*	1	1	100.0
57.	Elmidae	Elminae	*Podelmis*	15	4	26.7
58.	Elmidae	Elminae	*Rudielmis*	2	2	100.0
59.	Elmidae	Elminae	*Stenelmis*	42	7	16.7
60.	Elmidae	Elminae	*Zaitzevia*	18	1	5.6
61.	Dryopidae	–	*Dryops*	79	1	1.3

S.N.	Family	Subfamily	Genus	Number of species		%
				World	India	
62.	Dryopidae	–	*Elmomorphus*	16	1	6.3
63.	Dryopidae	–	*Helichus*	36	2	5.6
64.	Dryopidae	–	*Monstrosostea*	1	1	100.0
65.	Dryopidae	–	*Pachyparnus*	14	2	14.3
66.	Dryopidae	–	*Sostea*	49	3	6.1
67.	Psephenidae	Eubriinae	*Dicranopselaphus*	40	4	10.0
68.	Psephenidae	Eubriinae	*Granuleubria*	8	3	37.5
69.	Psephenidae	Eubriinae	*Macroeubria*	22	1	4.5
70.	Psephenidae	Eubriinae	*Microeubria*	8	4	50.0
71.	Psephenidae	Eubriinae	*Schinostethus*	28	5	17.9
72.	Psephenidae	Psephenoidinae	*Afropsephenoides*	3	1	33.3
73.	Psephenidae	Psephenoidinae	*Odontanax*	5	1	20.0
74.	Psephenidae	Psephenoidinae	*Psephenoides*	8	4	50.0
75.	Psephenidae	Psepheninae	*Mataeopsephus*	12	1	8.3
	Superfamily SCIRTOIDEA					
76.	Scirtidae	–	*Cyphon*	350	24	7.8
77.	Scirtidae	–	*Elodes*	103	8	7.8
78.	Scirtidae	–	*Exochomoscirtes*	46	6	6.9
79.	Scirtidae	–	*Hydrocyphon*	95	12	13.0
80.	Scirtidae	–	*Ora*	10	5	50.0
81.	Scirtidae	–	*Sacodes*	17	3	17.6
82.	Scirtidae	–	*Scirtes*	250	12	4.8
83.	Scirtidae	–	*Ypsiloncyphon*	67	5	7.5
	Superfamily HYDROPHILOIDEA					
84.	Hydrophilidae	Hydrophilinae	*Agraphydrus*	18	7	38.9
85.	Hydrophilidae	Hydrophilinae	*Allocotocerus*	27	4	14.8
86.	Hydrophilidae	Hydrophilinae	*Ametor*	5	2	40.0
87.	Hydrophilidae	Hydrophilinae	*Anacaena*	111	7	6.3
88.	Hydrophilidae	Hydrophilinae	*Berosus*	273	10	3.7
89.	Hydrophilidae	Hydrophilinae	*Chaetarthria*	49	2	4.1
90.	Hydrophilidae	Hydrophilinae	*Crenitis*	41	1	2.4
91.	Hydrophilidae	Hydrophilinae	*Enochrus*	222	10	4.5
92.	Hydrophilidae	Hydrophilinae	*Helochares*	180	10	5.6
93.	Hydrophilidae	Hydrophilinae	*Hydrobiomorpha*	55	3	5.5

S.N.	Family	Subfamily	Genus	Number of species		%
				World	India	
94.	Hydrophilidae	Hydrophilinae	*Hydrochara*	23	2	8.7
95.	Hydrophilidae	Hydrophilinae	*Hydrophilus*	48	8	16.7
96.	Hydrophilidae	Hydrophilinae	*Laccobius*	245	48	19.6
97.	Hydrophilidae	Hydrophilinae	*Notionotus*	16	3	18.8
98.	Hydrophilidae	Hydrophilinae	*Oocyclus*	48	7	14.6
99.	Hydrophilidae	Hydrophilinae	*Ophthalmocyclus*	1	1	100.0
100.	Hydrophilidae	Hydrophilinae	*Paracymus*	81	2	2.5
101.	Hydrophilidae	Hydrophilinae	*Pelthydrus*	63	5	7.9
102.	Hydrophilidae	Hydrophilinae	*Regimbartia*	10	1	10.0
103.	Hydrophilidae	Hydrophilinae	*Sternolophus*	9	4	44.4
104.	Hydrophilidae	Hydrophilinae	*Thysanarthria*	10	1	10.0
105.	Hydrophilidae	Sphaeridiinae	*Amphiops*	20	3	15.0
106.	Hydrophilidae	Sphaeridiinae	*Armostus*	13	2	15.4
107.	Hydrophilidae	Sphaeridiinae	*Australocyon*	19	1	5.3
108.	Hydrophilidae	Sphaeridiinae	*Cercyon*	259	17	6.6
109.	Hydrophilidae	Sphaeridiinae	*Coelostoma*	104	9	8.7
110.	Hydrophilidae	Sphaeridiinae	*Cryptopleurum*	24	3	12.5
111.	Hydrophilidae	Sphaeridiinae	*Dactylosternum*	77	7	9.1
112.	Hydrophilidae	Sphaeridiinae	*Gillisius*	2	2	100.0
113.	Hydrophilidae	Sphaeridiinae	*Mircogioton*	8	1	12.5
114.	Hydrophilidae	Sphaeridiinae	*Morastus*	1	1	100.0
115.	Hydrophilidae	Sphaeridiinae	*Noteropagus*	4	1	25.0
116.	Hydrophilidae	Sphaeridiinae	*Oosternum*	28	4	14.3
117.	Hydrophilidae	Sphaeridiinae	*Pachysternum*	21	5	23.8
118.	Hydrophilidae	Sphaeridiinae	*Paracymus*	81	2	2.5
119.	Hydrophilidae	Sphaeridiinae	*Paromicrus*	14	1	7.1
120.	Hydrophilidae	Sphaeridiinae	*Paroosternum*	9	1	11.1
121.	Hydrophilidae	Sphaeridiinae	*Peratogonus*	3	2	66.7
122.	Hydrophilidae	Sphaeridiinae	*Protosternum*	9	2	22.2
123.	Hydrophilidae	Sphaeridiinae	*Pseudocercyon*	1	1	100.0
124.	Hydrophilidae	Sphaeridiinae	*Sphaeridium*	42	9	21.4
125.	Georissidae	–	*Georissus*	80	7	8.6
126.	Helophoridae	–	*Helophorus*	192	7	3.6
127.	Epimetopidae	–	*Eumetopus*	8	4	50.0

S.N.	Family	Subfamily	Genus	Number of species		%
				World	India	
128.	Hydrochidae	–	*Hydrochus*	181	5	2.8
129.	Spercheidae	–	*Spercheus*	**18**	3	16.7
	Superfamily STAPHYLINOIDEA					
130.	Hydraenidae	Hydraeninae	*Davidraena*	3	3	100.0
131.	Hydraenidae	Hydraeninae	*Gondraena*	3	2	66.7
132.	Hydraenidae	Hydraeninae	*Hydraena*	673	12	1.8
133.	Hydraenidae	Hydraeninae	*Laeliaena*	3	1	33.3
134.	Hydraenidae	Hydraeninae	*Limnebius*	127	6	4.7
135.	Hydraenidae	Ochthebiinae	*Aulacochthebius*	11	1	9.1
136.	Hydraenidae	Ochthebiinae	*Ochthebius*	422	18	4.3
137.	Hydraenidae	Ochthebiinae	*Protochthebius*	4	2	50.0
			Total	**9,064**	**776**	**8.6**

Table 3. Bio-geographical distribution of the families of aquatic beetles (Coleoptera) in India.

Sl. No.	Family	Trans Himalaya	Himalayas	Semi-Arid	Desert	Gangetic Plains	North-east	Deccan Peninsula	Western Ghats	Coasts	Islands
1.	Gyrinidae	-	30	7	2	34	22	32	14	-	4
2.	Haliplidae	-	5	2	2	4	1	4	-	-	-
3.	Noteridae	-	4	-	-	1	1	5	-	1	1
4.	Dytiscidae	20	112	37	19	48	71	42	52	35	33
5.	Hydroscaphidae	-	2	-	-	-	3	-	-	-	-
6.	Sphaeriusidae	-	2	-	-	-	-	-	-	-	-
7.	Elmidae	-	11	-	-	7	1	8	3	-	-
8.	Dryopidae	-	4	-	-	1	3	2	-	-	-
9.	Psephenidae	-	20	-	-	1	5	1	-	-	-
10.	Scirtidae	-	27	-	-	2	13	7	7	-	-
11.	Hydrophilidae	6	97	16	3	52	43	81	90	1	4
12.	Helophoridae	-	6	-	-	-	1	-	-	-	-
13.	Epimetopidae		1	-	-	-	1	2	1	-	-
14.	Georissidae	-	6	-	-	1	-	-	-	-	-
15.	Spercheidae		1	-	-	2	-	1	-	-	-
16.	Hydrochidae		2		-	1	4	-	-	-	-
17.	Hydraenidae		27	2	-	13	2	8	4	-	1
	Total (Number of species)	**26**	**357**	**64**	**24**	**167**	**171**	**193**	**171**	**37**	**43**

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Chapter 25

INSECTA : ODONATA (DAMSELFLIES AND DRAGONFLIES)

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ABSTRACT

Dragonflies and Damselflies (Insecta: Odonata) are key components of wetland ecosystem. Indian fauna is represented by 482 species, about 50 subspecies in 150 genera and 18 families. High diversity and endemism is found in the hill streams and rivers of Western Ghats and eastern Himalaya. The taxonomy of adult is well worked out, however the descriptions of larva and their ecology remains as a major gap area, especially for several elusive hill stream breeding species. Geographically, the central India, eastern ghats, eastern Himalaya and Andaman Nicobar islands remains under explored where new species and records are still expected to be scientifically documented.

Key Words: Dragonflies, damselflies, India, diversity, aquatic insects

INTRODUCTION

The order Odonata is one of the ancient groups of insects. Fossil evidences suggest that origin of this group dates back to Permian (250 million years BP). The word "Odonata" is derived from the Greek word "*odontos*" meaning the toothed, which highlights the toothed nature of mandibles of this insect group. The adults are terrestrial and the larvae aquatic. The adult dragonflies are characterized by long slender abdomen, large globular eyes, long wings with nodus and pterostigma, and a unique mechanism of sperm transfer. The sperms are produced in the gonads situated in the last abdominal segment and transferred to the secondary genitalia at the second abdominal segment before copulation.

Based on their morphology, the order Odonata is divided into three groups, *viz*. damselflies (Zygoptera), Anisozygoptera and dragonflies (Anisoptera). The suborder Anisozygoptera is a living fossil with four species of which *Epiophlebia laidlawi* is known from Eastern and Central Himalaya. Dragonflies and damselflies can easily be distinguished and they differ significantly in morphology. However, their general life history is comparable, and so they are treated together further.

Odonata larvae live in freshwater habitats and only a few species can tolerate brackish waters. They are highly specific to particular aquatic habitat, and utilize both running and standing waters for breeding. This habitat specificity makes them an ideal model system to address questions in ecology, evolutionary biology, biogeography and for monitoring health of freshwater ecosystems.

Fossil History

The oldest fossils of Odonata belong to the Protodonata, a basal group which is now extinct. These fossil records are from Upper Carboniferous (Pennsylvanian)

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sediments of Europe which are about 325 million years old. The Protodonata were fast flying with a wingspan up to 75 centimeters and spiny legs, which presumably aided in capturing their prey. About the time when dinosaurs started appearing in the Triassic, Protodonata went extinct.

Another fossil group of Odonata is the Protoanisoptera (Family: Meganeuridae), which have been found in Kansas, USA and Commentry, France. The Meganeuridae in contrast to modern Odonata lacked a nodus and pterostigma and were very large species with a wing span of over 50cm. The lower Permian fossils of Odonata which were over 250 million years old belong to small Protoanisopterans and Zygopterans. Fossil records of larvae are found from Mesozoic and some workers have suggested that aquatic larval stages of Odonata started during Lower Permian.

Historical Resume

Pre-1900: Drgonflies are commonly mentioned in folklores and stories from time immemorial in different Indian cultures. In fact, in the dry plains of southern India, it is widely believed among farmers and common people that the swarms of *Pantala flavescens* are harbingers of rains. The first scientific descriptions available on odonates found in India are that of *Neurobasis chinensis* Linnaeaus (1758), *Aeshna juncea* (Linnaeus, 1758), *Libellula quadrimaculata* Linnaeus, 1758, *Orthetrum cancellatum* (Linnaeus, 1758) and *Sympetrum vulgatum* (Linnaeus, 1758). These species descriptions were based on specimens collected beyond the biogeographic boundaries of Indian subcontinent. However, *Rhyothemis variegata* (Linnaeaus, 1763) was the first dragonfly to be described scientifically based on specimens from India. During 18^{th} century, Drury (1770, 1773) and Fabricius (1775-1798) described many species from India. Numerous species were described by Selys-Longschamps (1840-1891) and Rambur (1842).

1901-1947: After Selys, Laidlaw and Fraser contributed significantly to the knowledge on Indian Odonata. In addition to Laidlaw and Fraser workers like Williamson, Ris, Lieftinck, Asahina contributed to the knowledge on Indian Odonata. Between 1920 and 1935 Fraser published a series of papers in *Records of Indian Museum*, *Memoires of Indian Museum* and *Journal of Bombay Natural History Society* which was eventually compiled into three volumes of *Fauna of British India-Odonata* (Fraser, 1933-1936). These volumes still remain as a basic reference source for identification of Indian Odonata. The studies by Laidlaw (1914-1932) were mostly confined to some families of dragonflies and damselflies. Both Fraser and Laidlaw restricted their studies mostly in Western Ghats and Eastern Himalaya. A significant contribution to Indian Odonatology during this period was the discovery of Anisozygoptera species, *Epiophlebia laidlawi* by Tillyard (1921) from Darjeeling. Other significant worker during this period was Needham.

1948 to 2017: Immediately after independence, workers like Bhasin (1953), Singh (1955), Singh and Baijal (1954), Singh *et al.* (1955) contributed to the knowledge on Indian Odonata. The several new species descriptions of Singh and Baijal from the Himalaya were later found to be synonyms of widespread common species by subsequent workers. Between 1978-1994 Asahina conducted several studies on odonates from western and eastern Himalaya and described several new taxa. After this period, the focus was on to survey unexplored and under explored areas of the country. The scientists of ZSI surveyed many conservation areas, wetlands and states to document the odonate fauna. In Zoological Survey of India, scientists viz., Kumar, Lahiri, Mitra, Prasad, Singh, Sinha, Srivastrava, Ram, Kulkarni, Radhakrishnan, Emiliyamma, Babu, Gaurav Sharma, Supriya Nandi, Subramanian, Jaffer and Talmale published fauna of many states and conservation areas. (Babu *et al.,* 2013; Emiliyamma *et al.,* 2007; Kumar and Prasad, 1981; Mitra, 2002a,b, 2003; Mitra and Babu, 2010; Prasad, 1996a,b, 2001, 2004, 2007a,b; Prasad and Varshney, 1988, 1995; Ram *et al.,* 2000) . The contributions on Odonata of eastern India by Mitra and Lahiri are worth special mentioning. (Lahiri, 1987, 2003; Lahiri *et al.,* 2007; Mitra, 2002b). They also described several new species and new records from Eastern India. Recently, researchers from other organizations such as Krushnamegh Kunte, Shantanu Joshi, Parag Rangnaker, Raymond Andrew, Ashish Tiple, David Raju, Pankaj Khorpade and others has contributed to the growth of knowledge on Indian Odonata diversity. Prof. Tembhare and his student Prof. Raymond Andrew at Hislop College, Nagpur contributed significantly to the endocrine system, reproductive anatomy and Odonata fauna of Central India. Dr. G. K. Walia and her students from Punjabi University, Patiala made substantial progress to the cytogenetics Odonata of India. Hämäläinen (2002, 2011, 2013) also contributed significantly to the growth of Indian Odonata.

Diversity of Odonata

Globally 6233 species in 685 genera of odonates are known of this, 482 species, about 50 subspecies in 150 genera and 18 families exist in India. Extant Odonata is broadly divided into three suborders the Zygoptera or damselflies, Anisozygoptera and the Anisoptera or dragonflies. The Anisozygoptera with four relict species was earlier recognized as a third suborder of Odonata. However, recent studies groups Anisozygoptera with Anisoptera and some authors bring them together under a new name Epiprocta (Anisoptera + Anisozygoptera) (Trueman, 1996, 2007; Lohmann, 1996; Rehn, 2003; Kalkaman *et al*., 2008). An over view of extant global, Oriental and Indian Odonata diversity is provided in table-1 (Schorr and Paulson, 2017).

Table-1. Diversity of Odonata.

Suborder	Family	World		India	
Zygoptera		Genera	Species	Genera	Species
	Hemiphlebiidae#	1	1	0	0
	Perilestidae#	2	19	0	0
	Synlestidae	9	38	1	6
	Lestidae	9	153	5	26
	Platystictidae	9	262	3	15
	Amphipterygidae#	1	5	0	0
	Argiolestidae#	20	114	0	0
	Calopterygidae	21	180	6	9
	Chlorocyphidae	20	155	7	22

Suborder	Family	World		India	
Zygoptera		**Genera**	**Species**	**Genera**	**Species**
	Devadattidae#	1	13	0	0
	Dicteriadidae#	2	2	0	0
	Euphaeidae	9	75	6	18
	Heteragrionidae#	2	57	0	0
	Hypolestidae#	1	3	0	0
	Lestoideidae#	2	9	0	0
	Megapodagrioniidae#	3	29	0	0
	Philogangidae	1	4	1	1
	Philogeniidae#	2	40	0	0
	Philosinidae#	2	12	0	0
	Polythoridae#	7	60	0	0
	Pseudolestidae#	1	1	0	0
	Rimanellidae#	1	1	0	0
	Thaumatoneuridae#	2	5	0	0
	Isostictidae#	12	45	0	0
	Platycnemididae	43	452	14	52
	Coenagrionidae	122	1350	12	61
	Genera *Incertae sedis*	14	71	1	1
Anisozygoptera					
	Epiophlebiidae	1	4	1	1
Anisoptera					
	Austropetaliidae#	4	11	0	0
	Aeshnidae	54	473	13	47
	Petaluridae#	5	11	0	0
	Gomphidae	100	1004	29	83
	Chlorogomphidae	3	52	3	11
	Cordulegastridae	3	55	3	8
	Neopetaliidae#	1	1	0	0
	Synthemistidae	26	147	2	15
	Macromiidae	4	123	2	17
	Corduliidae	21	164	2	2
	Libellulidae	144	1032	39	87
Total Diversity		685	6233	150	482

Note: Families in '#' are not represented in India.

CLASSIFICATION OF ODONATA OF INDIA

Order ODONATA Fabricius, 1793

Suborder ZYGOPTERA Selys, 1854

Superfamily LESTOIDEA Calvert, 1901

Family SYNLESTIDAE Tillyard, 1917

Family LESTIDAE Calvert, 1901

Superfamily PLATYSTICTOIDEA Kennedy, 1920

Family PLATYSTICTIDAE Kennedy, 1920

Superfamily CALOPTERYGOIDEA Selys, 1850

Family CALOPTERYGIDAE Selys, 1850

Family CHLOROCYPHIDAE Cowley, 1937

Family EUPHAEIDAE Yakobson & Bainchi, 1905

Family PHILOGANGIDAE Kennedy, 1920

Superfamily COENAGRIONOIDEA Kirby, 1890

Family PLATYCNEMIDIDAE Yakobson & Bainchi, 1905

Family COENAGRIONIDAE Kirby, 1890

Genera *Incertae sedis*

Suborder ANISOZYGOPTERA Handlirsch, 1906

Superfamily EPIOPHLEBIOIDEA Muttkowski, 1910

Family EPIOPHLEBIIDAE Muttkowski, 1910

Suborder ANISOPTERA Selys, 1854

Superfamily AESHNOIDEA Leach, 1815

Family AESHNIDAE Leach, 1815

Superfamily GOMPHOIDEA Rambur, 1842

Family GOMPHIDAE Rambur, 1842

Superfamily CORDULEGASTROIDEA Needham, 1903

Family CHLOROGOMPHIDAE Needham, 1903

Family CORDULEGASTRIDAE Hagen, 1875

Superfamily LIBELLULOIDEA Leach, 1815

Family MACROMIIDAE Needham, 1903

Family CORDULIIDAE Selys, 1850

Family SYNTHEMISTIDAE Tillyard, 1917

Family LIBELLULIDAE Leach, 1815

Distribution

Diversity: Though 482 species of Odonata are found in India, high diversity and endemism is restricted to southern Western Ghats, Eastern Himalaya, Western Himalaya and Andaman and Nicobar islands. Western Ghats and Eastern

Himalaya have 191 and 256 species respectively. High diversity is found in hill streams, and forested riverine habitats and most of the endemic species are restricted to this habitat. Habitats like ponds, lakes, coastal marshes, irrigation canals and paddy fields have common and wide spread species (Mitra *et al.*, 2011; Subramanian, 2009, 2012; Subramanian *et al.,* 2011).

Endemism: One hundred and eighty six taxa, including subspecies belonging to 69 genera are endemic to India. Highest endemism is found in Western Ghats and Sri Lanka. Within Western Ghats, high endemism is found in mountains south of Coorg in Karnataka. Here, the streams and rivers of Coorg, Wayanad, Nilgiris, Anamalai's, Cardamom Hills and Agasthyamalai are rich in endemic species. High endemism is found in family Gomphidae and genera such as *Protosticta*, *Macromia* and *Idionyx*. In the Eastern Himalaya, high endemism is found in Khasi Hills, and Darjeeling-Sikkim Himalaya. Species of Platycnemididae and Gomphidae are highly diversified here with many endemics (Babu *et al.*, 2013; Mitra, 2002a; Subramanian, 2007). The Distribution of endemic species across different regions of India is provided in Table 2.

Table 2. Distribution of Endemic Species

Superfamily	Family	Eastern Himalaya	Western Himalaya	Western Ghats	Andaman & Nicobar	Peninsular India
Coenagrionoidea	Coenagrionidae	4	3	6	1	4
	Platycnemididae	10	1	14	1	7
Platystictoidea	Platystictidae	2	1	10	1	-
Lestoidea	Lestidae	4	-	2	-	1
	Synlestidae	2	-	-	-	-
Calopterygoidea	Calopterygidae	2	-	2	-	1
	Chlorocyphidae	3	-	2	3	1
	Euphaeidae	6	-	4	-	1
	Genera *incertae sedis*	1	-	-	-	-
Aeshnoidea	Aeshnidae	7	1	-	2	3
Gomphoidea	Gomphidae	17	4	28	2	7
Cordulegasteroidea	Chlorogomphidae	3	-	2	-	-
	Cordulegasteridae	-	1	-	-	-
	Corduliidae	1	-	-	-	-
Libelluloidea	Macromiidae	2	1	8	-	2
	Synthemistidae	3	-	12	-	-
	Libellulidae	3	2	4	-	-

Biology

Habitat: Odonates are primarily aquatic insects and their life is closely tied with water bodies. They use a wide range of flowing and stagnant water bodies. Even though species are usually highly specific for a habitat, some have adapted to urbanization and use man-made water bodies. This habitat specificity has an important bearing on the distribution and ecology of odonates. Species using restricted habitats like hill streams tend to be narrowly distributed when compared to pool breeders, which are widespread.

Life cycle

Eggs: Odonates lay their eggs in a wide range of aquatic habitats, which is species specific: from damp soil to thundering waterfalls. Females select the egg-laying site mainly by physical characters such as length of shoreline. Species breeding in rivers prefer long straight shores. It is observed that long straight shores of lakes are tend to be colonised by riverine species. Visual cues also play an important part in oviposition. It has been observed that many pool breeders are deceived by smooth shining surfaces, such as bonnets of cars and wet roads and they try to lay their eggs in these unnatural sites.

Damselflies insert their elongate and cylindrical eggs into a plant body. Their elaborate ovipositor is serrated and adapted for making incisions in the tissues of plants and placing the eggs in them. Some are generalists and some are specific in their selection of the plant for egg laying. Dragonflies lay their broad and elliptical eggs either in flight or by perching on an overhanging vegetation or rock. Eggs are laid in successive batches: a damselfly lays about 100-400 eggs and dragonflies, usually about several hundreds to thousands per batch. Eggs hatch immediately in the tropics, usually in 5-40 days. In many stream dwelling dragonflies the eggs are invested with gelatinous substance which expands and becomes adhesive on contact with water. This helps the egg from being carried away far from its habitat by water current.

Small parasitic Hymenoptera belonging to the families *Mymaridae*, *Tetragrammidae* and *Trichogrammidae* parasitise eggs of damselflies. Parasitizing females climb or swim beneath the water to search for the eggs in the submerged plants and lay their eggs.

Larval stages: The larva is a sophisticated predator. Their cryptic colouration and keen eyesight makes them a full-fledged predator. Larvae are generally ambush predators, that is they wait for their prey to come close before striking. But some systematically stalk their prey. When they are in the striking range they shoot-out their formidable jaws which virtually stabs the prey. They are gluttonous and feed on any moving and seizable prey including their own kind. Last instar larvae of bigger species are known to catch small fishes, tadpoles and even freshly emerged adults of their own species.

A larva completes its development in two months. The number of larval instars is very variable within and between species and is usually 9-15. When they are ready to moult, they stop feeding and crawl up to emergent vegetation or rock. This usually happens after sun set and the larvae moult into adults just before sunrise. The newly emerged adults are wet and delicate, and as the day warms up, they become dry and robust for their maiden flight. Species of the tropics and warm temperate latitudes complete one or more generations per year.

Adult stage: Newly emerged males and females leave their emergence site and occupy nearby landscapes. Generally males travel farther than females. In a few species maturation period serves as a resting stage and lasts about 8-9 months.

Damselflies complete their maturation period in about three weeks or less where as dragonflies takes two weeks. During the maturation period, sequential changes occur in the colour of the body and wings.

Flight: Odonates surpass all other groups of insects in their flying skills. Odonates have uncoupled wings unlike moths, butterflies, wasps and bees. In uncoupled wings, fore and hind wings are unattached to each other and they beat independently. The powerful thoracic muscles help them in long sustained flight and good maneuverability. Odonates can hover and turn 180° while in flight. Dragonflies are stronger fliers than damselflies and they can reach a speed up to 25-30 km per hour. This difference in flying abilities influences their dispersal and geographic distribution. It is generally observed that big powerful fliers have wider geographic range than small weak fliers do.

Like many other organisms, dragonflies also migrate. One of our most common species, *Pantala flavescens* migrates immediately after the monsoons. Large swarms of these dragonflies move through prominent clearings in the landscapes such as highways and railway tracks. Recent studies show that *Pantala flavescens* migrate across the Arabian Sea to reach east African shores using winds of Inter Tropical Convergence Zone (ITCZ). Generally it is observed that dragonflies which breed in temporary pools migrate.

Larval stages of water mite (Hydrachnidia) parasitise odonates. For example, *Arrenurus cupidator* is a common ectoparasite of coenagrionid damselflies. The mite larvae seek the final instar host larvae by random tactile search. The larvae briefly feed on host larva and when adult damselfly emerges, the mite larvae get attached to the adults. Mite larva pierces the host body and start feeding. The larvae detach only when the host comes back to water for oviposition. The detached larvae complete two more larval stages as predator before moulting into an adult.

Feeding: Adult dragonflies are aerial predators and catch small insects like mosquitoes, midges, small butterflies, moths and bees on wing. Most of the dragonflies are day flying but a few actively hunt during twilight hours. Dragonflies capture their prey by perching at a vantage-point and making short sallying flights or by flying continuously. Large number of adults sometime congregate especially during dawn and dusk near tree canopies to feed on swarming insects. They feed in flight, using the legs to capture the prey and transfer it to the jaws. The legs are highly specialized for this purpose, particularly with regard to its position, relative length, articulation and complement of spines. Their vision is well developed as in butterflies and as far as dragonflies are concerned, the whole head is an eye.

Reproduction: Sexually matured dragonflies return to the breeding habitat from their foraging or roosting site. Usually males mature earlier than females and reach the breeding habitat first. Matured males hold territory, but species may or may not show pronounced site fidelity. Resident males show aggressive behaviour towards conspecific males, which enter their territory. Aggressive behaviour may be simple "wing warning" by perched males and a display of abdomen. More elaborate aggressive encounters occur in flight, progressing from mutual threat display to physical fighting.

Odonates are sexually dimorphic. Newly emerged males and females are similarly coloured. Males acquire bright colouration as they become reproductively mature. Colours and patterns in the wings and body may play an important role in territoriality and courtship. Courtship is more evident in damselflies than in dragonflies. It ranges from simple submissive posture by males towards approaching females to elaborate displays where the male flies towards an egg laying site and allows itself to be carried by the water current for a short distance. Competition over sexually receptive females is very intense among male odonates.

A receptive female adopts a characteristic posture towards a potential male and pairing follows immediately. The last abdominal segments of the male have claspers, which are used to hold the female by her thorax. The structure of the female thorax is such that the male clasper fits exactly into it. This "hardware key" prevents mating between closely related species. During copulation or just before that, the male transfers his sperms into an accessory genital organ at the second abdominal segment. This accessory genitalia has a complicated harpoon shaped structure, which removes sperms of previously mated male before insemination. Multiple mating in both males and females is common among odonates.

Egg laying: Egg laying commences immediately after copulation. The male continues to hold the female and flies with her to an egg-laying site or just accompanies her. It is usually observed that territory holding males accompany females and non-territory holding males maintain physical contact with the female while laying eggs. Usually during this period the female is very vulnerable to the attack by other males. Non mated males attack the mated pair and try to hijack the female. Some damselflies lay eggs in submerged plants. In such cases the hovering male anchors the egg-laying female.

Longevity: Most of the records of longevity in nature refer only to reproductive period. During this, most damselflies live up to 8 weeks and dragonflies up to 6 weeks. If we include maturation period, it may extend up to 7-9 and 8-10 weeks, respectively. Dragonflies encounter a large number of predators throughout their life. Fishes are important predators during the larval stage. Birds such as Falcons, Hawks, Bee-eaters, Kingfishers, Herons and Terns have been observed to feed on odonates. Large dragonflies, robberflies (Asilidae) and spiders are important invertebrate predators.

Threats: Recent studies conducted in Eastern Himalaya and Peninsular India demonstrats that odonate fauna of the subcontinent is threatened due to anthropogenic activities such as habitat destruction, agricultural expansion, pesticide and industrial pollution. Recent IUCN assessment have categorized eight species as Vulnerable and 17 species as Near Threatened from the subcontinent.

Conservation and Human Significance

Odonates are a dominant group of aquatic insects. They are one of the dominant invertebrate predators in the wetland ecosystem. Being predators both at larval and adult stages, they have a significant role in the wetland food chain. Adult odonates feed on mosquitoes, blackflies and other blood-sucking flies and act as an important biocontrol agent for these harmful insects. Many species of odonates inhabiting in agro ecosystems play a crucial role in controlling pest populations.

In addition to the role of odonates in ecosystem function, their value as indicators of quality of the biotope is now being increasingly recognised. Recent studies have shown how species assemblages of dragonflies change with levels of human disturbance. Dragonflies found at undisturbed habitats with good riparian vegetation were specialists with narrow distribution. On the other hand, species recorded at industrial land or urban areas with disturbed riparian vegetation were generalists with wide habitat preference and distribution. These studies also show that dragonflies are sensitive not only to the quality of the wetland but also to the major landscape changes, especially changes in the riparian zone.

Current IUCN Redlist Assessment (2016) categorizes two Endangered, fifteen Vulnerable and eight Near Threatened species (Table 3) from India.

Table 3. IUCN Threat Status of Indian Odonata (Version 2016-3)

Sl. No.	Species	IUCN Status
1	*Idionyx galeata*	Endangered
2	*Libellago balus*	Endangered
3	*Anormogomphus kiritshenkoi*	Near Threatened
4	*Asiagomphus personatus*	Near Threatened
5	*Elattoneura atkinsoni*	Near Threatened
6	*Epiophlebia laidlawi*	Near Threatened
7	*Heliogomphus promelas*	Near Threatened
8	*Idionyx optata*	Near Threatened
9	*Indocypha vittata*	Near Threatened
10	*Indolestes indicus*	Near Threatened
11	*Indothemis carnatica*	Near Threatened
12	*Megalogomphus hannyngtoni*	Near Threatened
13	*Melanoneura bilineata*	Near Threatened
14	*Merogomphus martini*	Near Threatened
15	*Neallogaster ornata*	Near Threatened
16	*Phylloneura westermanni*	Near Threatened
17	*Planaeschna intersedens*	Near Threatened
18	*Bayadera hyalina*	Vulnerable
19	*Chlorogomphus xanthoptera*	Vulnerable
20	*Chloropetalia selysi*	Vulnerable
21	*Coeliccia fraseri*	Vulnerable
22	*Disparoneura apicalis*	Vulnerable
23	*Libellago andamanensis*	Vulnerable
24	*Platysticta deccanensis*	Vulnerable
25	*Protosticta sanguinostigma*	Vulnerable

Gaps in research

Detailed taxonomic description of adults of Indian Odonata is available. However many regions of eastern Himalaya, western Himalaya, central Indian highlands, Eastern Ghats, Andaman & Nicobar islands are un or under explored. Many species are known only from type specimens collected nearly a century ago. Hence it is important to assess the current status of these species by fresh field studies. Further, information gaps exist on description of larval stages and their ecology. Larval stages of only about 80 Indian species are known and full life history is worked out only less than 25 species. A good understanding of larval ecology is crucial to assess wetland health. This paucity of ecological information is a serious lacuna when designing any biomonitoring tool. Future studies on dragonflies may be directed to have a comprehensive understanding of their distribution, ecology including that of larval stages and their value as a conservation tool.

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PLATE I


Caconeura risi


Davidoides martini


Disparoneura quadrimaculata


Drepanosticta carmichaeli


Esme mudiensis


Euphaea dispar

PLATE II

Gomphidia kodaguensis

Onychogomphus nilgiriensis

Libellago andamanensis

Phylloneura westermanni

Tramea transmarina

Chapter 26

INSECTA : TRICHOPTERA (CADDISFLIES)

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ABSTRACT

Trichoptera of India comprised 1,227 species belonging to 102 genera and 28 families. Systematic studies placing the Indian species in a global context have progressed rapidly in the last few decades. However, much remains to be done in terms of the morphological and molecular characterization of the fauna at species level. Trans Himalaya, Central Himalaya, North East, Gangetic plain and the Western Ghats are reasonably well explored with regard to species diversity and distribution of the Trichoptera. Intensive surveys are needed to generate data on spatio-temporal distribution dynamics and associate unknown larval and adult stages of many species. Indian literature pertaining to work done on importance of Trichoptera and impact from climate change and biomonitoring potential of caddisflies are briefly presented. Aspects of research on future dimensions are also indicated.

Key words: conservation, diversity, biomonitoring, caddisflies, India

1. Caddisflies –the "underwater architects"

Caddisflies (Trichoptera) are among the most diverse holometabolous aquatic insects which along with dragonflies, mayflies, stoneflies and dobsonflies are primary invaders of freshwaters. They are distributed in every continent except Antarctica. They are exceeded in number of species only by aquatic Diptera (Mackay and Wiggins, 1979). Trichoptera are closely related to the Lepidoptera and the two orders together form the superorder Amphiesmenoptera (Kristensen, 1991). Their eggs, larvae and pupae are usually found in or very near freshwater bodies. Imagos are aerial and perch on leaves and twigs of riparian flora. They are moth-like insects with wings covered by hairs, not scales, a diagnostic feature of the Lepidoptera. In fact, the word Trichoptera is derived from the Greek word '*trichos*' meaning hairs, and "*pteron*" meaning wing i.e., wings covered with hairs. Adult antennae are usually prominent, in some species exceptionally long and have well developed maxillary and labial palps, but never with coiled proboscis, diagnostic of adult Lepidoptera (de Moor and Ivanov, 2008).

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Also like Lepidoptera, larvae of Trichoptera have exploited silk in constructing retreats and larval cases of marvellous bioarchitecture that are keystone adaptations accounting for the ecological diversity and success of the order as a whole (Wiggins, 2004). Fittingly, caddisfly larvae are called “underwater architects” (Wiggins, 2004). Trichoptera larvae can be distinguished from all other insects with segmented thoracic legs, by the presence of a pair of anal prolegs, each with a single curved terminal claw and very short antennae consisting of a single segment. The pupa is exarate and possesses a pair of strong functional mandibles, non-functional in the adult. The abdomen has a number of segments adorned with characteristic sclerotized, dorsal hook-bearing plates. Larval and pupal stages entirely depend on an aquatic environment. The larvae have exploited every conceivable microhabitat of the freshwater systems from montane springs, streams both intermittent and perennial, rivers, big and small, the splash zones of waterfalls and the depth of lakes to temporary waters and even rain water-filled treeholes (phytotelma). Their larvae are an important and beneficial component of the trophic dynamics and energy flow in lentic and lotic waters they inhabit and are extensively utilized in biomonitoring surveys along with other benthic macroinvertebrates (Lenat, 1993). Trichoptera, like the Ephemeroptera and Plecoptera are ideal objects for biogeographic, phylogenetic and phylogegraphic analyses.

The order Trichoptera inhabit a diverse array of freshwater habitats in all continents excluding Antarctica (Morse (ed.) 2017). At present, around 49 families of Trichoptera have been recognized over the globe comprising 616 genera and 14,548 species (Morse (ed.) 2017). Globally, Oriental region is species rich with, 5,313 (405 spp./Gm2) species of which most of them are endemic to the region (Morse, 2016). From India, 28 families encompassing 102 genera and 1,227 species are recorded.

Being a holometabolous order of inland water insects, it is difficult and laborious to correlate the different life stages, and with extreme dearth of specialists in this speciose taxon in India, the “Fauna of India on Trichoptera” has so far not seen the light of the day. Traditionally, morpho-taxonomical investigations on Trichoptera are almost on imagos since structures for identification of caddisfly species are found almost exclusively in the adult stage, and largely in genital morphology (Wiggins, 2004). However, the caddisfly larval assemblages are vital for the ecological integrity of freshwaters. Unfortunately, there is acute paucity of work on larval taxonomy not to mention about larval-adult association which is practically absent. Hence priority attention needs to be paid to the multifaceted study of Trichoptera in India including extensive spatial and temporal field explorations

2. Historical Perspectives

Though European workers have been pioneers in caddisfly research followed by North Americans and experts from other developed countries, there has not been enough progress on Trichoptera in India. Kolentini (1859), Walker (1852), Mac Lachlan (1875) and Hagen (1864-1873) initiated study of Indian Trichoptera In the latter half of eighteenth century. Subsequently Morton (1900-1902), Banks

(1911, 1913-1939) and MacLachlan (1916) added significantly to knowledge in the early nineteenth century. Martynov (1935-36) worked on the collections of the Indian Museum (Zoological Survey of India) followed by Mosely (1935, 1936, 1938) on some Indian Trichoptera. Taxonomic investigations on adult caddisflies of India were continued by Kimmins (1950-1957), Schmid (1968, 1969, 1971, 1983, 1984, 1995), Wiggins (1968) and Malicky and his group (1979-2012). Schmid personally collected adults from Arunachal Pradesh, Sikkim, Assam, Manipur, West Bengal, Kerala, Tamil Nadu, Karnataka, Uttar Pradesh and other places and published several monographs. He predicted that there would be more than ten thousand species of Trichoptera which remain to be unpublished from inland waters of India (Schmid, 1984). Though perhaps this appears to be slightly an overestimate, India's unexplored species diversity of caddisflies is undoubtedly explosive. Recently Saini and his co-workers, Parey, Pandherand Kaur (2011, 2013) published extensively on more than forty species of adult Trichoptera of Indian Himalaya. Ghosh and Chaudhury (1987) from ZSI published on a new species of Phryganeidae. Malicky (1979) published on Caddisflies of Andamans. Sharma and Chandra (2009) updated the checklists of Higler (1992), Saini et al., (2001). Recently Parey (2015) has updated the checklist of Plenitentoria Group of caddisflies. Saini and Kaur (2012) collated scattered information on published literature on Indian Trichoptera. Work on larval Trichoptera of India remain scanty with a few exceptions viz., caddisfly larvae of the larvae of Great Nicobar Biosphere Reserve (Chandra and Jehamalar, 2013), spatiotemporal distribution of larvae of the genera of the Western Ghats of peninsular India (Dinakaran and Anbalagan, 2010), larval descriptions on a new species of *Lepidostoma* from Alagar hills (Dinakaran et al., 2013) and sporadic reports from southern eastern Ghats (Dinakaran and Anbalagan, 2007). Dr.Morse of Climson University, South Carolina is motivating caddisfly workers from India to continue systematic work on this taxon.

3. Taxonomic diversity, Endemism and Patterns of distribution

Biodiversity among caddisflies is a reflection of the effectiveness of natural selection in subdividing resources of energy in freshwater ecosystems. Taxonomy provides the vocabulary that opens doors to interpreting the diversity evident in ecology, phylogeny and biogeography (Wiggins, 2004). Much of the biological diversity of Trichoptera is revealed at the level of family. As mentioned earlier, around 45 extant families are now recognized in the world and 28 of them are represented in India. Details of recorded genera and species of Trichoptera within India are presented in Table 1.The caddisflies are extensively distributed in the Himalayan belt especially in the Himalaya, Indo-Burmese and the Western Ghats biodiversity hotspot. Details of larval generic distribution in the Western Ghats are found in Dinakaran and Anbalagan (2010).

The available data is inadequate to estimate the extent of endemism precisely. According to Ghosh (1998) more than 80% of species are endemic to India. It is also impossible at this point of time to provide information on threatened species as the faunistic explorations and even alpha taxonomic work on this taxon in India has not progressed much.

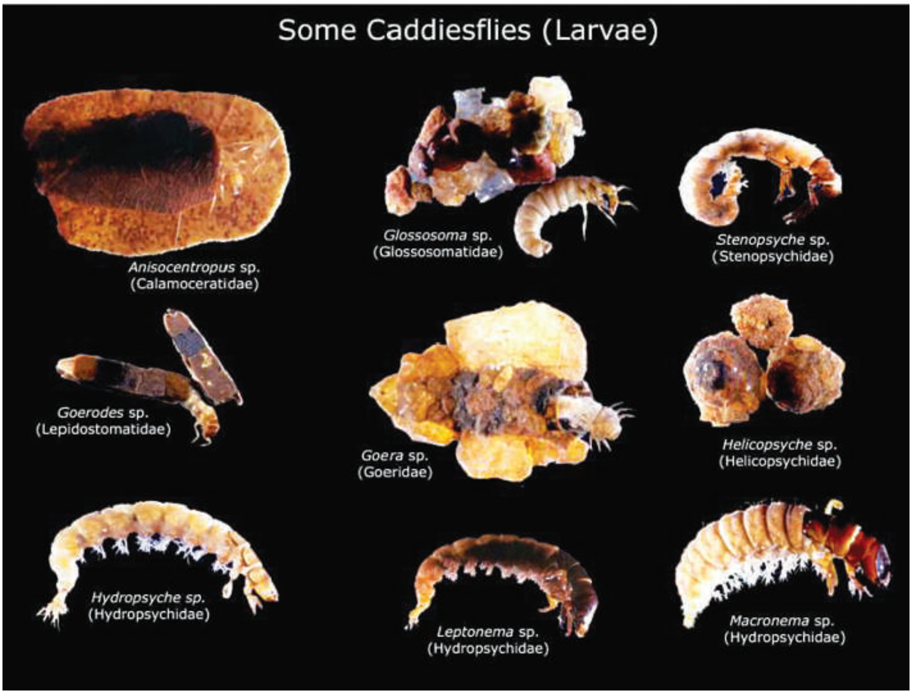
Table. 1. Current status of Indian Trichoptera

Suborder	Infraorder	Family	Genus	Species
ANNULIPALPIA		Hydropsychidae	15	96
		Philopotamidae	7	130
		Stenopsychidae	1	14
		Dipseudopsidae	2	13
		Ecnomidae	1	8
		Polycentropodidae	5	17
		Pseudoneureclipsidae	1	9
		Psychomyiidae	5	71
		Xiphocentronidae	5	45
INTEGRIPALPIA	BREVITENTORIA	Calamoceratidae	2	6
		Leptoceridae	13	297
		Limnocentropodidae	1	3
		Molannidae	2	8
		Odontoceridae	1	2
		Helicopsychidae	1	28
		Sericostomatidae	4	6
	PLENITENTORIA	Apataniidae	4	22
		Goeridae	2	31
		Limnephilidae	7	44
		Uenoidae	1	5
		Brachycentridae	2	12
		Lepidostomatidae	3	65
		Phryganeidae	2	10
		Phryganopsychidae	1	1
SPICIPALPIA		Glossosomatidae	3	25
		Hydroptilidae	8	52
		Hydrobiosidae	1	12
		Rhyacophilidae	2	193
TOTAL		**28**	**102**	**1,227**

4. Ecological diversity and Adaptive trends

Caddisflies are known primarily for the ability of their larvae to construct cases and carry them while procuring food as an adaptive strategy to protect from predators and to enhance respiratory efficiency (Wiggins, 2004). Fifteen families from India are portable case-makers (Integripalpia). Nine families from India are retreat-makers (Annulipalpia) forming a second major lineage. Four families are cocoon-making (Spicipalpia). They prefer cool running waters for the most part. Plate 1 provides the diagnostic features of some Indian families of Trichoptera based on larval architecture. Four principal functional feeding groups (FFG) were recognized viz., scraper, shredder, collector and predator. Each genus was assigned to a functional feeding group. Burton and Sivaramakrishnan (1993) categorized the FFG's of caddisfly larvae of Silent valley streams along with other aquatic insects.

PLATE - 1



5. Evolution and Biogeography

Invasion of freshwater during Triassic was the essential innovation for Trichoptera, probably due to selection pressure from terrestrial predators as evidenced from fossil history. As on date there has been no fossil study of Trichoptera of India. However, two fossil caddisfly species from Burmese amber dated to Cretaceous-late-Albian are known: *Palerasnitsynus ohlhoffi* Wichard, Ross, & Ross 2011 (Psychomyiidae) and *Burminoptila bemeneha* Botosaneanu 1981 (Hydroptilidae) (Morse, 2016). The hypothesis of Wiggins (2004) for the evolution of construction behaviour in American families of Trichopteran larvae appears applicable to Indian families as well and investigation on morphological and molecular phylogenies of Indian caddisfly fauna should also be in the priority list to arrive at a holistic picture. Same is true with regard to the biogeographic and phylogeographic history of Trichoptera of India to test the origin and biogeographic diversification patterns of Trichoptera in India.

6. Biomonitoring Potential

Worldwide, caddisfly larvae are a well-represented group with high species diversity in montane streams and rivers and are widely used in water quality assessment. Sivaramakrishnan et al., (1996) made pioneering investigations on the utility of benthic macroinvertebrate assemblages on biomonitoring of Kaveri river catchment. Subramanian and Sivaramakrishnan (2005) prepared a working manual on biomonitoring techniques using aquatic insects of Indian genera. The biomonitoring potential of the larvae of trichopteran genera of India are highlighted in these publications.

7. Climate Change Impacts

Trichopteran communities are highly vulnerable to global climatic changes including global warming and this study is gaining momentum throughout the world. Selvakumar et al., (2015) have made preliminary investigation on this aspect adopting a trait –based approach on the river basins of the Western Ghats. More in-depth studies on the impact of climate change on imperilment and vulnerability of caddisfly species are urgently needed in India.

8. Conservation Priorities and Modalities

We are presently in an "Era of anthropogenic megaextinction". Habitat fragmentation, global climate change impacts and alien species invasion have created a '"biodiversity crisis" in our fragile lentic and lotic inland waters jeoperdizing the "biotic integrity" of lakes, streams and rivers. Ecological, biotechnological, socio-cultural and legal conservation measures are to be promoted to protect the precious biological heritage of our inland waters including aquatic insects of which the larval caddisfly species assemblages constitute a dominant component. Prioritization of caddisfly taxa and microhabitats for conservation is yet another important research area.

9. Future Dimensions

Future caddisflies workers should concentrate on following accepts of Indian Trichoptera

- Detailed morphological descriptions of life stages.
- Habitat, microhabitat associations and biogeographic studies.
- Rapid identification methods, DNA Barcodes and life stage associations.
- Molecular phylogenetic and phylogeographic studies.
- Origin and diversification of evolutionary lineages.
- "Cryptic species" conservation to safeguard hidden subspecific diversity – role of conservation genetics
- Microsatellite loci, Evolutionary Significant Units
- Next Generation Sequencing

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Chapter 27

INSECTA : PLECOPTERA (STONEFLIES)

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ABSTRACT

Stoneflies (Insecta: Plecoptera) are restricted to cold hill streams. Indian fauna is represented by 128 species, 24 genera and 8 families with 91 endemic species. High diversity and endemism is found in Himalayan streams. Stoneflies are very sensitive to water quality and are reliable indicators of ecosystem health. Several parts of the Western Ghats, eastern ghats and Himalaya are still unexplored and taxonomy of adults and larva are need to be worked out in detail.

Key Words: Stoneflies, India, aquatic insects, diversity

INTRODUCTION

Plecoptera is a small monophyletic order of hemimetabolous insects, commonly called stoneflies with around 3625 described species globally included under 303 genera and 16 families (De Walt *et al*., 2017). Stoneflies are distributed over all continents except Antarctica and constitute a significant ecological component of running water ecosystems (Fochetti and Tierno de Figueroa, 2008). Stonefly larvae are generally found in high altitude cold temperate streams, though some genera have penetrated to the cooler areas of subtropics and tropics. The larvae are distributed in stony streams attached to the surfaces of boulders and the adults are found near the streams or on tree trunks, stones and bushes (Plate 1). They are not conspicuous insects except the Chloroperlidae which are bright green in colour. The larvae play vital role in the food chain of freshwater ecosystems. Adults are week fliers and prefer to run to elude predators. They are diurnal except a few species of Setipalpia which are nocturnal. Food of the adults consists of algae, lichen and foliage, though many species may not feed at all as adults and live only for a few weeks. The composition of stonefly fauna varies in different seasons and in different habitats. Brachyptery or winglessness is usually found during the winter season.

Stoneflies have been the object of scientific study in Europe for a very long time, with the first species being described by Linnaeus in 1758 and placed within the genus *Phryganea* of the Trichoptera. Burmeister first proposed the order name Plecoptera in 1839. The order name Plecoptera comes from the latin “plecto”, meaning feather or wing meaning plaited or folded and the greek “pteron”,

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meaning feather or wing, and refers to the ability of the adult to fold its wings over their back. Species diversity of Plecoptera is highest in cold, fast flowing and rocky streams (Sivec and Yule, 2004).

Fossil History

The ancient insect order Plecoptera diverged as early as in the early Late Carboniferous and the fossil record of Plecoptera is considered relatively complete. Stem-relatives of most of its constituent families have been recovered from Mesozoic strata. Recent discovery of a new fossil species of the pteronarcyid stonefly, *Pteroliriope sinitshenkovae* from the middle Jurassic Daohugon locality in China provides additional support to the view that divergence of most stonefly families took place very early, probably in the Triassic or even in the Permian (Cui *et al*., 2016). Global fossil records of Plecoptera are presented in Table 1. However, no fossil stonefly has so far been excavated from India.

Table 1. Global Fossil Stoneflies (†No living species) (De Walt *et al*., 2017)

Suborder	Superfamily	Family	Genera	Species
Antarctoperlaria	Eusthenioidea	Eustheniidae	1	1
	Gripopterygoidea	†Euxenoperlidae	4	9
	”	Gripopterygidae	2	3
	”	†Siberioperlidae	6	18
Arctoperlaria	Nemouroidea	†Baleyopterygidae	5	16
	”	Capniidae	2	4
	”	Leuctridae	1	1
	”	†Mesoleuctridae	4	11
	”	Nemouridae	1	1
	”	†Palaeonemouridae	8	32
	”	†Perlariopseidae	15	54
	”	†Pronemouridae	3	7
	”	Taeniopterygidae	7	9
	”	Genera Incertae sedis	2	2
	Perloidea	Chloroperlidae	1	2
	”	†Palaeoperlidae	4	7
	”	Perlidae	2	2
	”	Perlodidae	3	3
	”	†Platyperlidae	1	8
	”	†Tshekardoperlidae	2	8
	”	**Genera Incertae sedis**	12	19
	Pteronarcyoidea	Pteronarcyidae	1	1
	Not assigned	†Gulouidae	1	1
	”	†Perlapsocidae	1	1
	”	†Perlopseidae	1	3
	Genera Incertae sedis		6	6
			96	229

Historical Resume (Review of literature)

Needham (1909) was the first American Entomologist who worked on Indian Plecoptera. Taxonomic publications regarding Indian species of Plecoptera include Aubert (1959, 1967), Banks (1895, 1898, 1914, 1918, 1920, 1939), Burmeister (1839), Classen (1924), Enderlein (1909), Fitch (1847), Frison (1929, 1935, 1942), Grubbs and Stark (2004), Grubbs and DeWalt (2012), Hagen (1861), Harper (1974, 1977), James (1974), Jewett (1958, 1960, 1970, 1975), Kawai (1968), Kimmins (1946, 1950a, b), Kondratieff and Kirchner (1988), Mason and Stark (2015), Muranyi and Li (2013, 2016), Muranyi *et al.* (2015), Navas (1922), Needham (1909), Needham and Classen (1925), Newman (1838, 1839), Pictet (1841), Provancher (1878), Ricker (1952), Ricker and Ross (1968), Say (1823), Shimizu (1997), Singh and Ghosh (1969), Stark (1989), Stark and Brown (1991), Stark and Sivec (1991, 2007, 2008, 2014, 2015), Surdick (1981), Walker (1852), Wu (1923), Zwick (1981, 1982a, b), Zwick and Sivec (1980) and Zwick *et al.* (2007).

TAXONOMIC DIVERSITY, ENDEMISM AND PATTERNS OF DISTRIBUTION IN INDIA

Stonefly fauna of India encompasses 128 valid species included under 24 genera and 8 families (Table 2). Of the eight families of Plecoptera known from mountainous north of India viz., Capniidae, Leuctridae, Nemouridae, Taeniopterigidae, Chloroperlidae, Perlidae, Perlodidae and Peltoperlidae, only one family, Perlidae (possibly with one species of Amphinemurinae: Nemouridae) is recorded so far from southern India (Sivaramakrishnan *et al*., 2011).

Table 2. Global diversity of Stoneflies (World genera and species)*
(De Walt *et al*., 2017)

Sl. No.	Suborder	Superfamily	Family	World		India	
				Genera	Species	Genera	Species
1	**Antarctoperlaria**	Eusthenioidea	Diamphipnoidae	2	6	-	-
2	”	”	Eustheniidae	6	22	-	-
3	”	Gripopterygoidea	Austroperlidae	10	15	-	-
4	”	”	Gripopterygidae	53	308	-	-
5	**Arctoperlaria**	Nemouroidea	Capniidae	21	288	**1**	**7**
6	”	”	Leuctridae	12	364	**1**	**1**
7	”	”	Nemouridae	20	673	**7**	**67**
8	”	”	Notonemouridae	23	120	-	-
9	”	”	Taeniopterygidae	13	106	**2**	**2**
10	”	Not assigned	Scopuridae	1	8	-	
11	”	Perloidea	Chloroperlidae	20	196	**1**	**2**
12	”	”	Perlidae	53	1090	**8**	**40**
13	”	”	Perlodidae	55	339	**2**	**3**
14	”	Pteronarcyoidea	Peltoperlidae	10	68	**2**	**6**
15	”	”	Pteronarcyidae	2	12	-	-
16	”	”	Styloperlidae	2	10	-	-
				303	3625	24	128

**nomen dubium, species inquirenda,* temporary names and subspecies are not included.

Distribution of Plecoptera in different states of India is presented in Table 3 and 4. Highest number of species were recorded from the state of Arunachal Pradesh (34 species of two families), followed by West Bengal (24 species of four families, mostly from North Bengal), Meghalaya with twenty two species of three families and Himachal Pradesh with 21 species of six families. All the species reported from the Western Ghats region are endemic to India. Out of 19 species reported, 17 species are endemic to the Western Ghats. Among eight families of stoneflies reported from India, six families are recorded from Trans-Himalayan and four families each from the Himalayan and North East Indian biogeographic zones (Table 5).

Table 3. Distribution of Stoneflies in different States of India along with endemic species

Sl. No.	State / Union Territory	Family	Genus	Species	Endemic
1	Andaman & Nicobar Islands	-	-	-	-
2	Andhra Pradesh	-	-	-	-
3	Arunachal Pradesh	2	8	34	26
4	Assam	4	9	19	14
5	Bihar	-	-	-	-
6	Chhattisgarh	-	-	-	-
7	Delhi	-	-	-	-
8	Goa	-	-	-	-
9	Gujarat	-	-	-	-
10	Haryana	-	-	-	-
11	Himachal Pradesh	6	12	21	12
12	Jammu & Kashmir	4	6	9	1
13	Jharkhand	-	-	-	-
14	Karnataka	1	4	10	10
15	Kerala	1	2	8	8
16	Madhya Pradesh	1	1	1	1
17	Maharashtra	1	2	2	2
18	Manipur	2	5	13	11
19	Meghalaya	3	7	22	14
20	Mizoram	1	1	1	-
21	Nagaland	-	-	-	-

Sl. No.	State / Union Territory	Family	Genus	Species	Endemic
22	Odisha	1	1	2	2
23	Pondicherry	-	-	-	-
24	Punjab	-	-	-	-
25	Rajasthan	-	-	-	-
26	Sikkim	4	5	7	4
27	Tamil Nadu	2	3	12	12
28	Telangana	-	-	-	-
29	Tripura	-	-	-	-
30	Uttarakhand	1	1	1	-
31	Uttar Pradesh	-	-	-	-
32	West Bengal	4	12	24	10

Table 4. Distribution of various families of stoneflies in different States of India

S. No.	State	No. of Species							
		1	2	3	4	5	6	7#	8
1	Arunachal Pradesh	-	-	-	29	5	-		-
2	Assam	-	-	1	10	1	7		-
3	Himachal Pradesh	3	-	1	10	1	5		1
4	Jammu and Kashmir	2	2	-	4	-	-		1
5	Karnataka	-	-	-	-	-	10	-	-
6	Kerala	-	-	-	-	-	8	-	-
7	Madhya Pradesh	-	-	-	-	-	1	-	-
8	Maharashtra	-	-	-	-	-	2	-	-
9	Manipur	-	-	-	12	1	-		-
10	Meghalaya	-	-	1	17	-	4		-
11	Mizoram	-	-	-	1	-	-		-
12	Odisha	-	-	-	-	-	2	-	-
13	Sikkim	2	-	-	-	-	3	1	1
14	Tamil Nadu	-	-	-	1	-	11	-	-
15	Uttarakhand	-	-	-	-	-	1		-
16	West Bengal	-	-	1	12	2	9		-

1. Capniidae, 2. Chloroperlidae, 3. Leuctridae, 4. Nemouridae, 5. Peltoperlidae, 6. Perlidae, 7. Perlodidae, 8. Taeniopterygidae

Perlodidae: India: Himalaya, but exact locality unknown for two species.

Table 5. Distribution of Stoneflies in different bio-geographic zones of India

Sl. No.	Family	Common Name	Trans –Himalayan (N 32°-37°)	Himalayan (N 28°-32°)	Desert (N 24°-28°)	Semi-arid (N 22°-28°)	Western Ghats (N 08°-22°)	Deccan Peninsula (N 12°-18°)	Gangetic plain (N 24°-28°)	North East India (N 21°-28°)	Islands (N 07°-14°)	Coasts (N 08°-22°)
1	Capniidae	Small winter stoneflies	✓	-	-	-	-	-	-	-	-	-
2	Chloroperlidae	Green stoneflies	✓	-	-	-	-	-	-	-	-	-
3	Leuctridae	Rolled-winged stoneflies	-	✓	-	-	-	-	-	✓	-	-
4	Nemouridae	Spring stoneflies	✓	✓	-	-	✓	-	-	✓	-	-
5	Peltoperlidae	Roachlike stoneflies	-	✓	-	-	-	-	-	✓	-	-
6	Perlidae	Common Stoneflies	✓	✓	-	-	✓	✓	-	✓	-	-
7	Perlodidae	Perlodid stoneflies	✓	-	-	-	-	-	-	-	-	-
8	Taeniopterygidae	Winter stoneflies	✓	-	-	-	-	-	-	-	-	-

(- Data not available)

SYSTEMATIC OVERVIEW

The order Plecoptera includes 16 families of which 4 families are included in the suborder Antarctoperlaria present only in the southern Hemisphere (hence, not represented in India) and the remaining 12 families are included in the suborder, Arctoperlaria distributed mostly in the Northern Hemisphere. The stonefly (Plecoptera) fauna of India distinctly differs between the areas north and south of the Indo-Gangetic plain: there are 8 families known from the northern states, while only a single species of Nemouridae (Kimmins 1950a) and members of 4 Perlidae genera occur in the southern region of India (Stark and Sivec, 2014; Zwick 1981, 1982a; Zwick and Sivec, 1980). In a nutshell, diversity of Indian stonefly genera and species increases progressively from southern peninsular tropics towards the northern subtropical, temperate and alpine upper Himalayas (Das 1991; 1998). Sivaramakrishnan *et al*. (2011) have made a brief systematic overview of the families of Plecoptera of India and the present account provides recent updates.

Family CAPNIIDAE

Seven species of Capnia viz., *C. bifida*, *C. gibbera*, *C. hingstoni*, *C. longicauda*, *C. manii*, *C. montana* and *C. pedestris* are recorded from India. All the species are recorded only from Himachal Pradesh and Jammu and Kashmir of Western Himalaya.

Family LEUCTRIDAE

Jewett (1958) described *Rhopalopsole magnicerca* from India. Zwick and Sivec (1980) recorded this species from Meghalaya and West Bengal. Nymphs occur in swift, rocky-bottomed streams.

Family NEMOURIDAE

The family Nemouridae popularly called 'spring stoneflies' is ranked first in terms of plecopteran species richness in India distributed mostly in the Himalayan ranges (De Walt *et al*., 2017). Totally around 67 described species from 7 genera are known from India of which 46 species are endemic. Both the subfamilies viz., Amphinemurinae and Nemourinae are represented in India. However, our knowledge of this family is sparse and there are great differences in the number of species reported from the states. Hitherto no Neumouridae were reported from Sikkim (Tierrno de Figueroa and Fochetti, 2003), while there are records of 29 species from Arunachal Pradesh (Kimmins, 1950b; Aubert, 1967). Recently, while describing a new species of *Amphinemoura* from Darjeeling district of West Bengal, India and a new species of *Sphaeronemoura* from the West Garo Hills district of Meghalaya, India, Muranyi and Li (2013) have provided an exhaustive checklist of the family Nemouridae from the Indian Subcontinent with zoogeographical comments.

Family TAENIOPTERYGIDAE

Subfamily Brachypterainae is represented in Himalayas in India by *Kyphopteryx sp*. and *Mesyatsia sp*. whereas subfamily Taeniopteryginae is not recorded so far from India.

Family CHLOROPERLIDAE

This family is represented by two species viz.,*Xanthoperla acuta* and *X. kishanganga* and recorded from Western Himalayas (Jammu and Kashmir) of India.

Family PERLIDAE

The taxonomic situation of this family was cleared by the significant publication entitled *"Synopsis of the World Genera of Perlinae"* by Sivec *et al*. (1988). The family Perlidae is divided into two subfamilies namely, Perlinae and Acroneurinae. The genera of Perlinae recorded from India are *Chinoperla* (1 species), *Kammimuria* (4 species), *Neoperla* (14 species), *Perla* (4 species), *Phanoperla* (11 species) and *Tyloperla* (1 species) (Chandra and Sharma, 2009). Since then, many new species of Perlinae are described. From a historical perspective, our knowledge of the diversity and distribution of Indian *Neoperla* has accumulated slowly since Needham's (1909) and Klapálek's (1909) nearly simultaneous publication of the species name *N. indica*. Needham's description gained priority (Zwick and Sivec, 1980). However, the type material is missing and identity of this species remains in doubt (Stark and Sivec, 2015). The current list of Indian *Neoperla* includes 16 species documented by Jewett (1975), Zwick and Sivec (1980), Zwick (1981), Zwick *et al*. (2007), and Stark and Sivec (2015- Table 1). Recently, records and descriptions are provided for a formally recognized species of *Neoperla* collected in India bringing the number of described species from India to 19. *Neoperla agumbe* from Karnataka State, *N. emarginata* from Madhya Pradesh State and *N. orissa* from Orissa State are described as new and new records of several Indian States are given for *N. asperipenis, N. biseriata, N. hamata, N. nitida, N. ochracea* and *N. schlitz*. Four additional species represented by females with eggs are described under informal designations and the putative female and eggs are described for *N. schlitz* (Stark and Sivec, 2015).

Genus *Phanoperla* Banks, 1938, currently includes 50 species (DeWalt *et al*., 2017) widely distributed over mainland Southeast Asia, the Indian Subcontinent and several Asian islands including Borneo, the Philippines and Sri Lanka (Mason and Stark, 2015). The most recent major systematic treatments are those of Zwick (1982a, b) in which 34 species were formally recognized, including a minimum of 7 endemic Sri Lankan and 8 additional species from India (Mason and Stark, 2015- Table 1). Zwick (1982a) and others have demonstrated the value of egg morphology in the systematic study of *Phanoperla* and recently Mason and Stark (2015) have studied the egg morphology of *P. peniculus* Kawai (1968) from light trapping materials from Agumbe Ghats, Karnataka, India. They have also provided a revised key for Indian and Sri Lankan *Phanoperla* males.

Tyloperla is a small genus of Asian stoneflies which currently includes 15 species (Stark and Sivec, 2014- Table 1) of which only 4 species viz., *T. agumbe, T. barog, T. karnataka* and *T. schmidi* are known from India. Stark and Sivec (2014) have presented a key for species known from the Indian Subcontinent.

The subfamily Acroneurinae Klapálek, 1914 was established for Perlidae Latreille, 1802 taxa having hammer on male sternum 9. The distribution of Acroneurinae covers all of the Nearctic, Neotropics and Oriental realms and the eastern part of the East Palaearctic (DeWalt *et al*., 2017). The tropical or subtropical stonefly genus, *Brahmana,* a member of the subfamily Acroneurinae in the family Perlidae was established by Klapálek (1914). Members of *Brahmana* are known from insular and peninsular Southeast Asia to Indian subcontinent, including China, Nepal and the Himalayas (Klapálek, 1916). Five species are known from the region of which 3 are recorded from India viz., *B. benigna* (Needham 1909) from Sikkim, *B. chrysostoma* Klapálek (1916) from Sikkim and northern area of West Bengal, and *B. microphthalma* Klapálek (1916) from Meghalaya. All these 3 species are described based only on the female adult and the locations of the type specimens are not specified (Cao and Bae, 2013). This Oriental genus is valid but poorly known, apparently closely related to *Acroneuria*. Recently Murányi and Li (2016) presented an annotated checklist of the subfamily Acroneuriinae from the Oriental realm with comments on their status and distribution.

Family PERLODIDAE

Subfamily Perlodinae is represented in Himalayas in India by *Filchneria amabilis*, *Filchneria shobhaae* and *Neofilchneria uncata*. Adults are similar to perlid stoneflies. They are often greenish or yellowish but sometimes darker.

Family PELTOPERLIDAE

Although the Peltoperlidae extend into the Oriental Region, the distribution of the family as a whole is centred on Palaearctic East Asia and North America (Illies, 1965). Stark (1989) placed Asian peltoperline stoneflies in 5 genera. They are ‘cockroach-like’. Thorax is much wider than either head or abdomen. Five species of *Cryptoperla* and one species of *Peltopteryx* are recorded from India. Stark and Sivec (2007) presented a checklist of Asian Peltoperlidae.

Endemism

Around 91 species of stoneflies are endemic to India. Among these 56 species are endemic to the Eastern Himalaya, 12 species to the Western Himalaya, 17 species to the Western Ghats and one species is endemic to the Eastern Ghats and Central India. A total of 40 species of the family Perlidae in particular are recorded from India, among these 90% are endemic. Furthermore, 46 out of 67 species of family Nemouridae are endemic to India (Figure 1).

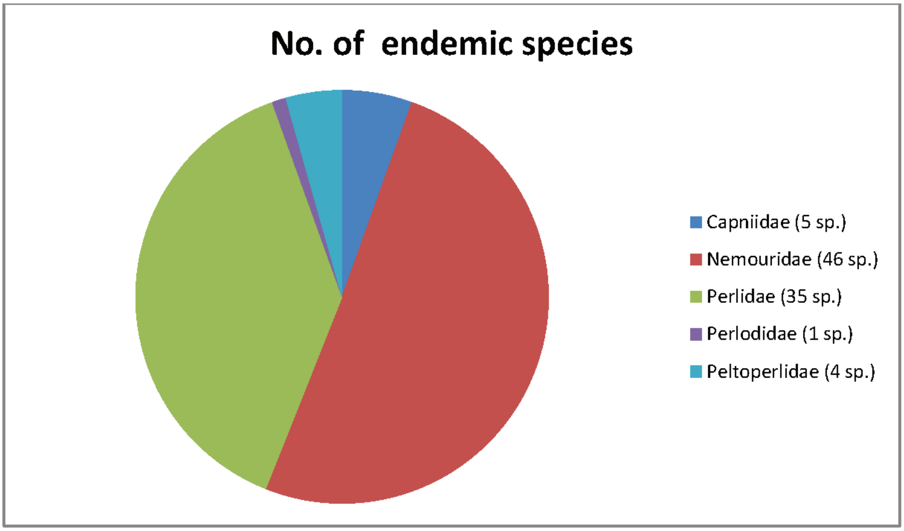

Fig. 1. Endemic stoneflies of India

Biology and life cycle pattern

There is dearth of information on seasonality, life cycles, egg incubation strategies and general bionomics of tropical stonefly species in general and Indian species in particular. It is still a mystery whether the numerous morphospecies that are presently recorded from the tropics are true biospecies or are there regional variation and morphoclines over vast tropical areas (Zwick, 2003). In tropical Asia, stonefly life cycles appear to be a seasonal with adult emergence throughout the year, while stoneflies in temperate regions typically have highly synchronized life cycles, with emergence of the entire population occurring within a few weeks. Life cycle studies on Indian stoneflies are virtually absent. Many stoneflies remain in the vicinity of the stream or lake, mate on or near the ground under stones or in vegetation and therefore do not need the capacity of flight. This applies to alpine Himalayan species where low air temperatures restrict flight activity. Sexual dimorphism occurs in several species whereby the males are short-winged, while females have wings of normal length. This saves the males energy which can be utilized elsewhere, while normal-winged females once mated are able to function as the dispersal agent (Brittain, 1990). Egg structure is mostly species specific.

Evolution and Biogeography

According to Illies (1965), Banarescu (1990) and Zwick (1990, 2000), Arctoperlaria and Antarctoperlaria originated as independent lines at the splitting of Pangea and the subsequent separation of Gondwanaland and Laurasia, at the end of Triassic Period. Antarctoperlaria possibly began their diversification before the continents separated, producing some sister-groups distributed in South America and New Zealand. The absence of Antarctoperlaria from South Africa and India may be interpreted as a later extinction event. These lands became warmer and drier during their northward journey after separation from Antarctica and Australia. The Oriental stonefly fauna inclusive of that of India was colonized from close Palearctic areas, as suggested by the decrease in species numbers towards the South. The first penetration was by members of 3 families viz., Nemouridae, Peltoperlidae and Perlidae that extended down into the rain forests of Southeast Asia, thus having somewhat overcome the usual aversion of the Order Plecoptera for warmer climates.

Biomonitoring potential and Climate change impacts

Stoneflies are an essential component of the aquatic biodiversity of high elevation montane streams and rivers of India, being sensitive biological indicators of water quality and assessing the regional effects of climate change along with mayflies and caddis flies. Accurate identification of stoneflies and other aquatic insects is crucial for employing biotic indices as sensitive tools in bio-monitoring. Unfortunately larvae and female specimens of stoneflies are very difficult to identify to species level which precisely compromises our ability to accurately assess water quality and to conduct ecological and conservation assessments of individual species (Gattolliat *et al*., 2016).

Conservation

Extensive exploration in developed nations undoubtedly reveal that stonefly species have vanished from parts of landscape and in the context of absence of extensive survey of stoneflies in many eco-region of India, we really do not know how many of our stonefly species have become locally extinct and how many species are really threatened. Improvements in land and water management may bring them back through natural recolonization. Though holistic study of freshwater biota is far more desirable compared to taxon focused ecology, stoneflies warrant attention as vital components of lotic zoobenthos since they also provide different environmental information than other aquatic insect orders (Heino *et al*., 2003; Park *et al*., 2003). Unfortunately no conservation measures are initiated yet in India to conserve this precious biological heritage.

Future priorities in Plecoptera Research

The future research priorities should focus on exploration of under and unexplored areas, especially in the North East Himalaya, Western Himalaya and Western Ghats, DNA barcoding studies to delineate species boundaries, establish larva-adult associations and species biology studies. A study in the lines of Gattolliat *et al*. (2016) is very much needed to completely document species diversity of Plecoptera.

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PLATE I

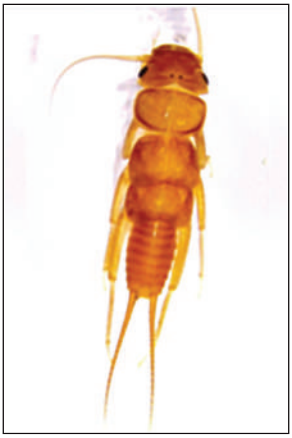
Nymphal sampling in hill stream

Adult sampling using light trap

Nymphal sampling (Leaf debris)

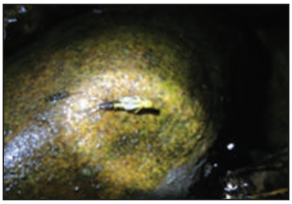
Nymphal sampling (Under stones)

Neoperla sp.



Phanoperla sp.

Cryptoperla sp.



Perlid Adult emergence

Perlid Adult

A mating pair

Chapter 28

INSECTA : EPHEMEROPTERA (MAYFLIES)

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ABSTRACT

Ephemeroptera of India comprises 146 species belonging to 58 genera and 13 families. Systematic studies placing the Indian species in a global context have progressed rapidly in the last few decades. However, much remains to be done in terms of the morphological and molecular characterization of the fauna at species level. The Western Ghats region, Central Himalayas region and the Gangetic plain are reasonably well explored with regard to species diversity and distribution of the Ephemeroptera. To date, the Deccan peninsula, North East, Trans Himalaya and Andaman and Nicobar Islands are under-explored. The remaining biogeographical regions are practically unexplored and intensive survey is urgently needed to generate data on spatio-temporal distribution dynamics and unknown of larval and adult stages of several species of mayflies.

Key words: Ephemeroptera, India, current status, diversity, distribution.

INTRODUCTION

Ephemeroptera, popularly known as mayflies are most primitive and ancient of the extant insect groups. Their evolutionary history dates back to Carboniferous or Permian about 290 million years ago and they attained the highest diversity during Mesozoic. Ephemeroptera together with Odonata is traditionally considered as Paleoptera i.e., sister group of Neoptera or all other orders of insects. However, recent molecular phylogentic studies suggests that Ephemeroptera is a sister group to Odonata and other Neopteran insect orders. Ephemeroptera are primarily aquatic insects. The larval stages are completely aquatic and adults are terrestrial. Ephemeroptera undergo hemimetabolous metamorphosis and have a unique maturation phase (subimago) between nymph and adult. Adults have transparent wings and glossy abdomen which ends in three abdominal cerci. Males have extended forelegs to grasp the female during mating. They have very short adult life span extending from few hours to few weeks. Mayflies highly habitat species and are found both in lotic and lentic habitats. Their high habitat specificity and sensitivity to water quality makes them an ideal candidate for biomonitoring studies.

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Fossil History

Fossil history of Ephemeroptera date back to Lower Carboniferous. The mayfly larvae of this period roughly resembled modern Siphlonuridae with 9 pairs of gills and articulated wing pads with complete venation. From Mesozoic some extinct families such as Mesephemeridae, Hexagenitidae and several recent lineages have been documented. A Fossil Prosopistomatidae described from Burmese amber was dated about 100 million years ago. It is inferred that during Cretaceous-Tertiary mass extinction, many ancient lineages went extinct and Tertiary mayfly fauna was similar to recent Ephemeroptera.

Historical Resume

Pre-1900: The first mayfly from India was described as early as 1843, when *Palingenia indica* (*Ephoron indicus*) was described by Pictet. Subsequently, Walker (1853) described *Caenis perpusilla* and *Cloeon debilis* (*Procloeon debilis*) based on the specimens at British Museum and on the collections of W.W. Saunders. During this period, Hagen (1858) worked on baetine mayflies of Sri Lanka. Up to 1900 two species of Ephemeridae and Palingenidae and one species of Heptageniidae was described.

1901-1947: During this period, important workers such as Needham (1909), Ulmer (1920), Chopra (1924, 1927), Navas (1931), Hafiz (1937) and Traver (1939) described many species. Needham worked on Ephemeroptera in the collection of Indian Museum and Ulmer described *Ecdyonurus bengalensis* from Darjeeling, West Bengal. Chopra worked on Ephemeroptera of Chilka lake and described four species. He also worked on Palingeniidae and Ploymitarcyidae. Hafiz and Traver worked on Ephemeroptera of the subcontinent.

1948-2016: Tremendous progress was made on the knowledge of Indian Ephemeroptera during this period. Workers like Gilles (1949, 1951, 1957), Kimmins (1947), Kapur and Kriplani (1963), Dubey (1970, 1971), Kaul and Dubey (1970), Peters (1967, 1975), McCafferty (1973), Hubbard and Peters (1978), Srivastava (1980, 1990), Sivaramakrishnan (1981-2016), Venkataraman and Sivaramakrishnan (187, 1989), Selvakumar et al. (2012-2016), Kluge (2014), Kluge and Novikova (2014) and Kubendran *et al.* (2014, 2015) contributed substantially to the knowledge on Ephemeroptera of India. Significant discovery of new genera during this period was *Petersula* Sivaramakrishnan 1984, *Edmundsula* Sivaramakrishnan 1985, *Indoganodes* Selvakumar, Sivaramakrishnan & Jacobus, 2014 and *Klugephlebia* Selvakumar, Subramanian & Sivaramakrishnan, 2016 from southern Western Ghats which are Gondwanian relict.

Recently many species were described and catalogued from the Western Ghats (Sivaramakrishnan *et al.,* 2009; Subramanian & Sivaramakrishnan, 2009; Sivruban *et al.*, 2013; Anbalagan *et al.*, 2014; Blachandra *et al.*, 2016; Barber-James *et al.,* 2013; Kluge & Novikova, 2014; Kulge, 2014; Kluge *et al.*, 2014 & 2015; Kubendran *et al.*, 2014 & 2015).

Diversity

Globally, about 3000 species in 400 genera and 42 families are currently known (Barber-James *et al.,* 2008). Of these, 390 species in 84 genera and 20 families occur in the Oriental region. About 49% of the genera (41 genera) is endemic to the region. The fauna of the Indian subregion (India, Sri Lanka, Pakistan, Nepal, Bhutan and Bangladesh) is represented by four suborders, fifteen families, sixty genera and 204 species (Sivaramakrishnan *et al.,* 2009). Current status of Ephemeroptera fauna of India is represented by four suborders, thirteen families, fifty eight genera and 146 species. Species rich families are Leptophlebiidae (12 genera, 23 species), Ephemeriidae (4 genera, 18 species), Heptageniidae (10 genera, 25 species) and Baetidae (12 genera, 45 species). Four families (Leptophlebiidae, Ephemeriidae, Heptageniidae and Baetidae) are with more than 10 species. Species rich genera with more than ten species each are *Ephemera* (Ephemeriidae), *Baetis* and *Cloeon* (Baetidae). Family wise diversity is summarized table-1.

Table-1. Ephemeroptera diversity across family and genera in India

Sl. No.	Suborder	Family	No. Genera	No. Species
I	CARAPACEA			
1		PROSOPISTOMATIDAE	1	2
I	RECTRACHEATA			
2		LEPTOPHLEBIIDAE	12	23
3		EPHEMERIDAE	4	18
4		POLYMITARCYIDAE	4	5
5		POTAMANTHIDAE	2	2
6		CAENIDAE	2	9
7		NEOEPHEMERIDAE	1	2
8		EPHEMERELLIDAE	3	5
9		TELOGANODIDAE	5	8
10		TRICORYTHIDAE	1	1
III	SETISURA			
11		HEPTAGENIIDAE	10	25
IV	PISCIFORMA			
12		AMELETIDAE	1	1
13		BAETIDAE	12	45
		Total	58	146

Distribution

Mayflies are distributed in diverse inland freshwater habitats. High diversity is found in pristine hill streams. High diversity of mayflies are found in the Western Ghats region (76), Central Himalayas region (29) and the Gangetic plain (21) are reasonably well explored with regard to species diversity and distribution of the Ephemeroptera. To date, the Deccan peninsula (18), North East (10), Trans Himalaya (9) and Andaman and Nicobar Islands (3) are under-explored. The remaining biogeographical regions (Coast, Desert, Sem- Arid and Eastern Himalaya) are practically unexplored and intensive survey is urgently needed to generate data on spatio-temporal distribution dynamics. The documentation of species diversity is far from complete and many new species remain to be described.

Endemism

Mayfly fauna of India, a country endowed with two mega diversity hotspots, appears to be an assemblage of ancient Gondwanan derivatives, with a high percentage of endemism, a few Laurasian spillovers, along with some younger faunal elements that might have diversified in several spells at different periods in geological history by vicariant and dispersal events, through "out of India and towards India" exchanges between Indian Subcontinent on the one hand and Afrotropics including Madagascar, Oriental Southeast Asia and Palearctic North on the other. Due to poor dispersal ability of adults, most of the mayfly species have restricted distribution. Generally, species of lakes, ponds and other lentic habitats have wide distribution when compared to the species of lotic habitats.

Biology

Habitat: Mayflies inhabit all aquatic habitats except for marine environment, polluted and underground waters. Some species are found in brackish waters also. Lotic-erosional habitats are species rich than lotic-depositional and lentic-depositional habitats. In the higher altitudes (>3000m) species diversity is poor. Species of lentic habitats are found in ponds, lakes, water tanks, paddy fields etc. In lotic habitats, runs and riffles with bottom substrate as boulders and cobbles have higher diversity than cascades or waterfalls. Species diversity is also reduced in habitats with bottom substrate as sand or mud.

Life cycle

Emergence: In the last larval instar (nymph) food uptake stops, alimentary canal and Malpighian tubules degenerate, the former fills up with water and later with air to develop into an aerostatic organ. Spermatogenesis and oogenesis is already completed before moulting. Haemolymph, mouthparts, visceral muscles and gonads undergo considerable changes. During this period, oxygen uptake and drift activity increases. Subimago, leave the nymphal skin by rupturing the mesonotal cuticle along the midline, which is completed in 10-15 minutes. The subimago, depending upon the species emerge either from the water surface, above water or underwater. In some species more than one type of emergence is observed. Temperature and light intensity influence the metamorphosis. In tropical region, most of the species emerge within two hours after sunset.

Swarming: Conspicuous mating swarms of males are typical of mayflies. The mating swarm typically consist of several specimens to thousands of individuals. They swarm over land marks such as vegetation, rock, bush, tree, shore line, bridge, road etc. The size, timing, height and time of swarm depends on many factors such as weather, temperature, etc. Typically tropical species swarm during night. However, in the high altitudes of Western Ghats and Himalaya, swarming is also observed in the afternoon.

Mating: Mating usually takes place in flight which lasts from a few seconds to several minutes. Males grab the females from below using its fore legs curved around the wing roots. The male abdomen is turned up and the forceps grasps the apex of female abdomen and penis is inserted into oviduct opening or copulatory pouches.

Oviposition: Eggs are always deposited in water. However sometimes females are attracted to oviposit in manmade objects such as car roof tops or smooth roads. Depending on species several types of oviposition are observed: (i) females release few eggs at a time by dipping the tip of abdomen on water surface; (ii) releasing all eggs at a time on water surface; (iii) female fall on water surface and release the eggs by rupturing the abdominal wall; (iv) female approach the waterline from shore and release eggs; (v) female crawl beneath the water surface to deposit eggs on stones or logs. Females typically lay 500 to 3000 eggs which is influenced by environmental variables.

Larval stages: Species are morphologically adapted to current velocity which include hydrodynamic body shape (eg. *Prosopistoma*), stabilizing and retention structures (Eg. *Epeorus*), friction discs, sclerotized gill margins with microtrichia or suckers formed by gills. The mayfly larvae require high oxygen content in the water which is generally 3-4 times higher than in other aquatic insect groups such as Diptera. Apart from gills, cutaneous breathing is also important for mayfly larvae.

The larvae are considered "trophically generalized" or "selectively omnivorous". The feeding types are classified as (i) grazers-scrappers feed on attached algae and mouth parts (maxillae) are scrape-like (ii) shredders feed on coarse particulate organic matter (CPOM) and mouth parts are not particularly specialized (iii) gatherers-collectors feed on fine particulate organic matter (FPOM) without specialized on mouth parts (iv) filter feeders use FPOM and seston (plankton, nekton and detritus) (v) predators feed on small benthic animals such as nematodes, oligochaetes etc. Feeding is opportunistic and depends upon availability, substrate composition and seasonality.

Adult stage: Adult mayflies do not feed and reproduction and dispersal are the sole functions of adults. Adults do not move away from water but some species are found far away from their emergence site. Females of most species exhibit "upstream compensatory flight" to minimize downstream drift of eggs and larvae. This flight may vary from several meters to kilometers.

Longevity: The lifespan of typical adult mayflies usually lasts for 24 hours. However, depending on species, it varies from few hours to days.

Threats: Recent studies conducted in Eastern Himalaya and Peninsular India demonstrate that the habitat of mayflies especially the hill streams of the subcontinent is threatened due to anthropogenic activities such as habitat destruction, agricultural expansion, pesticide and industrial pollution.

Conservation and Significance

Mayflies are an important group of aquatic insects, especially in lotic habitats. They have a significant role in the wetland food chain. The larvae and adults are prey for many species of invertebrate and vertebrate predators. In addition to the role in wetland ecosystem function, their value as indicators of quality of the biotope is very well recognized. Studies across the globe have shown that mayflies are very sensitive indicators of wetland pollution and how species assemblages change with levels of human disturbance. Mayflies found at undisturbed habitats with less pollution and good riparian vegetation were specialists with narrow distribution. On the other hand, species recorded at industrial or urban areas with polluted wetlands and disturbed riparian vegetation were generalists with wide habitat preference and distribution. These studies also show that mayflies are sensitive not only to the quality of the wetland but also to the major landscape changes, especially changes in the riparian zone. They are ideal objects for integrated phylogenetic, biogeographic and phylogeographic studies, being endowed with several archaic traits in all life stages along with rather weak dispersal powers. Many of the montane mayflies, both larvae and adult are equally charismatic.

Gaps in research

Larval and adult stages of several species of mayflies are unknown. Moreover many regions of India especially the rivers, streams and other wetlands of eastern and western Himalaya, central India are under explored. Future research should focus on correlating adult and larval stages and exploring under and unexplored regions. To our knowledge, DNA barcodes were generated for 40 species belonging to 32 genera under 10 families of Ephemeroptera from South India by Selvakumar et al. (2016), no other aspects of molecular work was undertaken on mayflies in India so far.

Future dimensions

Sivaramakrishnan (2016) suggested following aspects for future studies on mayfly systematics in India should focus on: 1. Intensive explorations in unexplored and under-explored areas, primarily to avoid bias in understanding patterns of mayfly species diversity and distribution; 2. Larval-adult associations employing modern molecular techniques; 3. Species delimitation fine-tuning and unraveling the mysteries of intra specific genetic diversity; 4. Combined molecular and morphological systematic and phylogenetic studies; 5. Molecular phylogeography of genera representing ancient evolutionary lineages; 6. Study of cryptic variation in species inhabiting evolutionary refugia, ecological refuges and in crucial ecological indicator taxa; and 7. Study of impacts of habitat fragmentation, climate changes and anthropogenic pollution on present mayfly genus and species composition; range contractions and range extensions of imperiled species and those vulnerable to extinction especially due to genetic erosion in lotic and lentic aquatics in different biogeographic regions of India.

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PLATE I

1. *Prosopistoma indicum*

2. *Choroterpes* (*C*) *petersi*

3. *Choroterpes* (*E*) *nambiyarensis*

4. *Indialis badia*

5. *Nathanella saraswathiae*

6. *Notophlebia ganeshi*

7. *Notophlebia jobi*

8. *Petersula courtallensis*

PLATE II

9. *Potamanthellus caenoides*

10. *Derlethina tamiraparaniae*

11. *Dudgeodes palnius*

12. *Indoganodes jobini*

13. *Afronurus kumbakkariensis*

14. *Epeorus petersi*

15. *Thalerosphyrus flowersi*

PLATE III

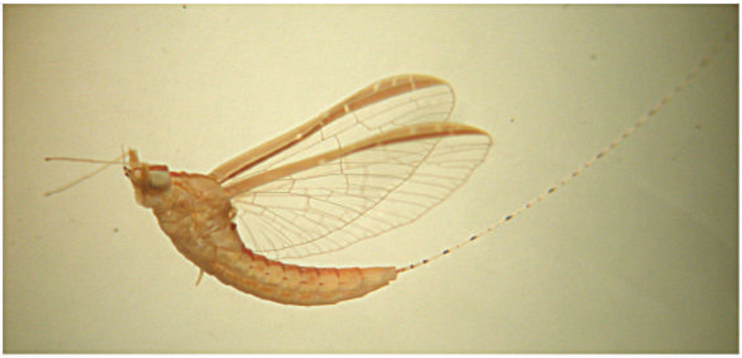
16. *Acentrella (Liebebiella) vera*

17. *Baetis michaelohubbardi*

18. *Bungona (Chopralla) pusilla*

19. *Labiobaetis jacobusi*

20. *Cloeon bicolor*



21. Adult of *Cloeon bicolor*

Chapter 29

INSECTA : LEPIDOPTERA

NAVNEET SINGH

ABSTRACT

The order Lepidoptera comprise primarily terrestrial insects with scale covered wings. Out of about 1,57,424 described species known from the world, only 740 species are reported to be aquatic. Lepidopteran caterpillars adopt to aquatic habit in the process of co-evolution and radiation. Only 80 species belonging to the subfamily Acentropinae which forms 0.53% of total lepidopteran species from India, are known to be aquatic inhabitants in India. However, very scarce information is available about the lepidopterans that posses aquatic life stages.

Key words:

INTRODUCTION

Lepidoptera is an attractive and fascinating group of Insects in terms of species diversity and economic importance. It is one of the most widespread and widely recognizable insect orders in the world, encompassing butterflies (including skippers) and moths. Lepidopteran species are mainly recognized due to the body and wings covered with scales (modified and flattened hairs which give the butterflies and the moths their extraordinary variety of colour patterns). However, the definition of Lepidoptera given before the advent of cladistics, for example by Imms, 1957, included many of the attributes which were not diagnostic for the Order Lepidoptera. Kristensen & Skalski (1998) recognized 27 Lepidopteran apomorphies out of which, Holloway *et al.* (2001) listed 10 easily observed attributes. Phylogenetically, order Lepidoptera is the sister group of order Trichoptera. Kristensen & Skalski (1998) suggested that the common ancestor of the Lepidoptera and the Trichoptera had larvae that lived in wet soil conditions. From where the Trichopterans developed the aquatic larval mode of life and majority of the Lepidopterans moved out of water and developed the terrestrial mode of life.

Predominantly, Lepidopterans are the terrestrial insects with about 1, 57, 424 described species from the world (Nieukerken *et al.*, 2011), out of which only 740 species are reported to be aquatic (Mey & Speidel, 2008). The Lepidopteran species with larvae feeding above the water surface on aquatic vegetation, mining the aquatic vegetation or feeding externally on the submerged vegetation are actually consider to be the aquatic. The adoption of aquatic habit by the Lepidopteran caterpillars is an example of co-evolution and radiations with the evolution of aquatic vegetation. The larvae of Lepidoptera have an enormous adaptive potential

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(Scoble, 1992), so with no exception, the semi-aquatic or fully aquatic Lepidopteran caterpillars have developed various modes of respiration like plastron respiration, open tracheal system, tracheal gills, or closed spiracles to support their aquatic life style. The aquatic caterpillars can be identified by the presence of filamentous gills on the body or by the presence of a portable case. Aquatic pupae of Lepidoptera can be identified from the protruded abdominal spiracles (Yen, 2004).

Review of Literature

Review of literature revealed that majority (about 99 %) of aquatic Lepidopterans belong to the single moth subfamily Acentropinae (= Nymphulinae) of family Crambidae. In addition to Acentropinae, very few species of different moth families like Arctiidae, Pyraustinae, Tortricidae, Noctuidae and Cosmopterygidae have the semi-aquatic/aquatic larvae. As far as the world fauna is concerned, the diversity of different moth families with aquatic larvae are mainly dealt by: Munroe (1983, 1995), Heppner (1991), Shaffer *et al.* (1996), Speidel & Mey (1999), You *et al.* (2002), Henning (2003), Li *et al.* (2003), Speidel (2003, 2005), Yen (2004), Mey & Speidel, (2005, 2008), You & Li (2005), Mey (2006). The Indian Lepidoptera with aquatic larvae is mainly represented by subfamily Acentropinae. The diversity of this subfamily is dealt by: Hampson (1896), Rose & Pajni (1985), Mandal (1991), Arora (2000), Bhattacharya (1997, 2000) and Mathew (2006).

Methodology

The Lepidopteran taxonomy is mainly based on the adult morphology, rather than larval characters. So, the standard methodology used for the taxonomic procedures of the terrestrial Lepidoptera is also followed for the study of aquatic Lepidopteran diversity. The collection of adult moths is done with the help of vertical sheet light trap equipped with mercury bulb (125 W) at night hours. The collected moths then killed with the ethyl acetate vapors in the killing bottles. Freshly killed specimens are pinned and stretched on stretching boards. The dry preservation of moths is done in ento boxes fumigated with naphthalene balls. Identification is done with the help of available literature.

Diversity

The available information on the diversity, distributional patterns and taxonomy of aquatic Lepidoptera is very scarce and incomplete to find the proper status of its diversity from any region, particularly from a country like India with vast geographic range, varied type of climatic conditions, and different topographic patterns. However, a summary on the current status of aquatic Lepidoptera is provided on the basis of published data. Balian *et al.* (2008) calculated a total number of about 1, 26, 000 fresh water animal species, which represented about 9.5 % of the total described animal species. Where, the aquatic Lepidoptera is represented by 740 species under three subfamilies, Acentropinae, Pyraustinae (Crambidae) and Arctiinae (Arctiidae), which makes only about 0.44% of the total described species (Mey & Speidel, 2008) (Table-1). However, very few species of Noctuidae, Cosmopterigidae, Tortricidae, Nepticulidae, Cossidae, Sphingidae and Crambidae (subfamilies: Schoenobiinae and Crambinae) do have semi-aquatic or fully aquatic larvae (Munroe, 1977; Lange, 1978; Williams and Feltmate, 1992; Habeck, 1994; Merritt & Cummins, (1996); Solis, 1999; Wagner, *et al.,* 2002).

As far as Indian fauna is concerned, 80 species of the aquatic Lepidoptera belonging to subfamily Acentropinae (Crambidae: Pyraloidea) are known. This represents about 0.53% of the total described species of Indian Lepidoptera. The adults of Acentropinae can be separated from other Pyralids from the following set of characters: Hindwing with median nervure simple (not pectinated), Forewing with vein R5 from cell (not stalked with R3 & R4) and vein R2 stalked with R3 & R4. The subfamily can also be identified reliably from the protruded abdominal spiracles of pupa (Yen, 2004). We can find two important checklists summarizing the diversity of Acentropinae from India. Speidel & Mey (1999) catalogued 49 species of Acentropinae having the type localities from India. Mathew (2006) listed 80 species of Acentropinae (=Nymphulinae) from India (Table-2)

Table 1. (Based on Mey & Speidel, 2008)

Superfamily	Family	Subfamily	Species in World	Species in Oriental Region	Species in India
Pyraloidea	Crambidae	Acentropinae (=Nymphulinae)	737	169	80
Pyraloidea	Crambidae	Pyraustinae	02	Nil	Nil
Noctuoidea	Arctiidae	Arctiinae	01	Nil	Nil

Table 2. (Based on Mathew, 2006)

Superfamily PYRALOIDEA

Family CRAMBIDAE

Subfamily ACENTROPINAE

(Mathew, 2006 used the family name NYMPHULINAE)

Genus	Species
Agassiziella Yoshiyasu, 1989	*Agassiziella albidivisa* (Warren, 1896)
	Agassiziella angulipennis (Hampson, 1891)
	Agassiziella fuscifusalle (Hampson, 1893)
	Agassiziella picalis (Guenee, 1854)
Ambia Walker, 1859	*Ambia albipunctalis* Warren, 1896
	Ambia caeruleata Hampson, 1893
	Ambia complicata Warren
	Ambia conspurcatalis Warren, 1896
	Ambia iambesalis Walker, 1859
	Ambia lobophoralis Hampson, 1896
	Ambia marginalis Moore
	Ambia poritialis Walker, 1859
	Ambia semifascialis Warren, 1896
	Ambia tenebrosalis Hampson, 1896
	Ambia xantholcuca Hampson, 1896

Genus	Species
Aulacodes Guenee, 1854	*Aulacodes colonialis* Guenee
	Aulacodes dominalis Walker, 1865
	Aulacodes hamalis Snellen
	Aulacodes saturatalis (Snellen, 1890)
Camptomastix Warren, 1892	*Camptomastix exuvialis* (Snellen, 1890)
	Camptomastix hisbonalis (Walker, 1859)
Cataclysta Hubner, 1827	*Cataclysta angulata* Moore
	Cataclysta trimacula Hampson
Clupeosoma Snellen, 1880	*Clupeosoma sericialis* (Hampson, 1896)
Elophila Hubner, 1822	*Elophila melagynalis* (Agassiz, 1978)
Eoophyla Swinhoe, 1900	*Eoophyla melanops* (Hampson, 1896)
	Eoophyla peribocalis (Walker, 1859)
	Eoophyla sejunctalis (Snellen, 1876)
Eristena Warren, 1896	*Eristena bifurcalis* (Pryer, 1877)
	Eristena murinalis (Warren, 1896)
	Eristena oligostigmalis Hampson, 1906
	Eristena postalbalis Hampson
	Eristena pulchellalis (Hampson)
	Eristena straminealis Hampson, 1903
Goniopalpia Hampson, 1903	*Goniopalpia* deIicataIis Hampson, 1903
Nymphicola Snellen, 1880	*Nymphicola blandialis* (Walker, 1859)
Nymphula Schrank, 1802	*Nymphula affinialis* (Guenee, 1854)
	Nymphula falliolatalis Swinhoe, 1890
	Nymphula fusalis Hampson, 1896
	Nymphula fuscicostalis Hampson, 1896
	Nymphula grisialis Hampson, 1912
	Nymphula leucostola Hampson, 1896
	Nymphula pygmaealis Warren, 1896
	Nymphula responsalis (Walker, 1865)
	Nymphula votalis (Walker, 1854)
Oligostigma Guenee, 1854	*Oligostigma albifurcalis* Hampson, 1906
	Oligostigma alicialis Hampson, 1906
	Oligostigma andreusialis Hampson, 1912
	Oligostigma araealis Hampson, 1897
	Oligostigma auropunctalis Hampson, 1903

Genus	Species
Oligostigma Guenee, 1854	*Oligostigma chrysozonalis* Hampson, 1912 *Oligostigma dianalis* Hampson *Oligostigma excisa* (Swinhoe, 1901) *Oligostigma fumibasalis* Hampson, 1896 *Oligostigma hapilista* Swinhoe, 1892 *Oligostigma melanotalis* Hampson, 1906 *Oligostigma niveinotatumt* Hampson *Oligostigma ornatum* Moore *Oligostigma parvalis* Moore, 1877
Paracataclysta Yoshiyasu, 1983	*Paracataclysta fuscalis* (Hampson, 1893)
Paracymoriza Warren, 1890	*Paracymoriza albifascialis* (Hampson) *Paracymoriza aurantialis* (Swinhoe) *Paracymoriza exsolvalis* (Snellen, 1882) *Paracymoriza inextricata* (Moore, 1888) *Paracymoriza vagalis* (Walker, 1865)
Parapoynx Huebner, 1825	*Parapoynx bilinealis* (Snellen, 1876) *Parapoynx crisonalis* (Walker, 1859) *Parapoynx diminutalis* Snellen, 1880 *Parapoynx fluctuosalis* (Zeller, 1852) *Parapoynx stagnalis* (Zeller, 1852)
Parthenodes Guenee, 1854	*Parthenodes aequivocalis* Warren, 1896 *Parthenodes bisangulata* (Hampson, 1895) *Parthenodes gangeticalis* (Lederer, 1863) *Parthenodes latifascialis* Warren, 1896 *Parthenodes nigra* (Warren, 1896) *Parthenodes nigriplaga* Swinhoe *Parthenodes olivalis* Hampson *Parthenodes stellata* (Warren, 1896)
Strepsinoma Meyrick, 1897	*Strepsinoma* croesusalis (Walker, 1859)
Teratausta Hampson, 1903	*Teratausta* odontalis Hampson, 1903

Aquatic Lepidoptera and Humanity

The aquatic Lepidopterans do have direct or indirect effects on human and its activities and furthermore on the functioning of our ecosystems. The immature stages of aquatic Lepidoptera are important constituents of different type of aquatic food chains. Though not as a serious pest, but some species like *Parapoynx fluctuosalis*, *P. vittalis* and *P. stagnalis* are known to damage rice in Asia. The phytophagous larvae of some aquatic Lepidoptera have been used in control of *Hydrillia* and *Elodea* in Florida (Buckingham, 1994). The species of subfamily Acentropinae are very sensitive to the quality of water. They are among the first animals to evade from the polluted waters. So, members of this subfamily are very important to get the information of water health.

Gap in Research Area

The indication about the aquatic Lepidoptera is a surprise to many, as very scarce information is available about the Lepidopterans that passes their life stages in water. Even the taxonomists working on the aquatic fauna or particularly the aquatic entomologists have little knowledge about the aquatic Lepidoptera. As discussed under heading 'Diversity', only 0.44% of the Lepidopterous fauna is known to be aquatic whereas, other aquatic animals are 9.5% of their total discoveries. Probably, the primary reason behind it is not the low diversity of aquatic Lepidoptera, but lack of expertise, and may be the lack of awareness. Generally, the techniques for sampling and handling of aquatic Lepidoptera are

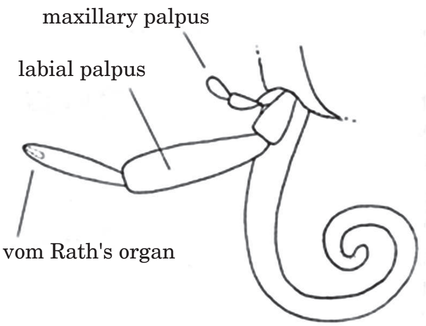

Fig. 1

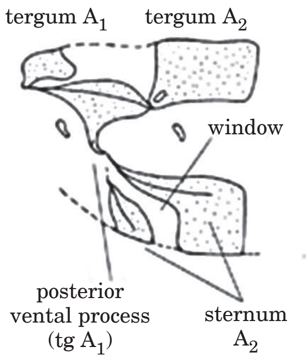

Fig. 2

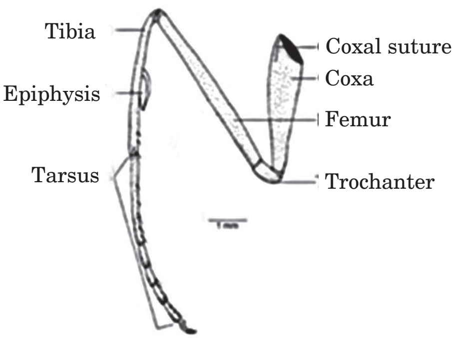

Fig. 3

Fig. 4

Fig. 1&2 from Holloway *et. al.,* 2001; Fig. 3&4 from https://www.google.co.in/search?q=epiphysis+lepidoptera

totally different from that of the other aquatic Insects. The Lepidopterans need careful killing in euthanized jars followed by pinning, stretching on boards, then dry storage in ento boxes fixed in drawers. Normally, these equipments are not available with the aquatic entomologists or general limnologists and also, the entomologist with expertise of Lepidoptera taxonomy usually lacks the Limnology background. Furthermore, the taxonomy of Lepidoptera is mainly based on the adults, and the studies on larval attributes are very limited. These are some of the issues responsible for recording of very few species of aquatic Lepidoptera. This chapter represents the present knowledge on the topic but is significantly underestimate of the real diversity of aquatic Lepidoptera. There are probably more Lepidopteran families, genera and species with aquatic representatives. The poor exploration and knowledge of tropical Lepidoptera, especially of hot bio-diverse regions coupled with their huge variety of aquatic habitats suggest about the vast opportunities in the field of the taxonomic research of aquatic Lepidoptera.
Note: The plate below is reg. the characters of lepidoptera. But I think during review, list of characters given in Introduction is deleted. So Now this plate becomes irrelevant and should be removed.

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Chapter 30

INSECTA : DIPTERA

DHRITI BANERJEE, ATANU NASKAR, JAYITA SENGUPTA, SURAJIT HAZRA, RADHEYSHYAM MRIDHA AND PANCHANAN PARUI.

ABSTRACT

Diptera (true flies), a group of two winged insects, exhibit a great diversity of habits which can broadly be classified as terrestrial, semi-aquatic and aquatic. Adult dipterans are usually terrestrial in habit while their larvae and pupae are aquatic and dependant on water. The fly larvae can survive in any plausible aquatic habitat, from the pitchers of the pitcher plant, tree holes, saturated soil and mud puddles, to flowing streams, ponds, large lakes, rivers and even the marine, rocky intertidal zone. They are very important in the aquatic food web and are the most diverse and abundant macro-invertebrates collected from fresh water habitats.40 families of Diptera are known to be aquatic worldwide, of which 36 families, 151 genera and 1,588 species known from India are aquatic or semi-aquatic in nature.

Key words: Diptera, Diversity, Aquatic, India.

INTRODUCTION

Diptera (true flies), a group of two winged insects, occur almost everywhere from high mountains to the saline sea and from the hot scorching deserts to the Arctic and Antarctic cold deserts. They exhibit a great diversity of habits which can broadly be classified as terrestrial, semi-aquatic and aquatic. Adult dipterans are usually terrestrial in habit while their larvae and pupae are aquatic and dependant on water. The flies are tolerant to extreme climatic conditions, some of them inhabiting polluted water bodies. They are very important in the aquatic food web and are the most diverse and abundant macro-invertebrates collected from fresh water habitats. The fly larvae can survive in any plausible aquatic habitat, from the pitchers of the pitcher plant, tree holes, saturated soil and mud puddles, to flowing streams, ponds, large lakes, rivers and even the marine, rocky intertidal zone.

7220 extant species of Diptera belonging to 1323 genera and 92 families, have been documented from India [Banerjee, (*in press*); Pape and Evenhuis, 2013; Pape and Thomson, 2016]. 40 families of Diptera are known to be aquatic worldwide, of which 36 families, 151 genera and 1,588 speciesknown from India are aquatic or semi-aquatic in nature.

The present overview represents these 36 families of 151 genera and 1,588 species of aquatic and water dependant Indian Diptera. The status of the their diversity, distribution pattern of the aquatic fauna, their habitat and bio-ecology

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has been enumerated along with threats to the diversity and conservation of this mega diverse insect fauna.

Origin and Evolution and Fossil History of the Aquatic Diptera

Diptera originated from some extinct group of scorpion flies (Blagoderov *et al.*, 2002), sometime in the Middle Triassic. The Nematocerans (most of the aquatic and semi-aquatic forms) dominated during this period with the advent of Psychodomorpha and Culicomorpha (Kremzinski and Evenhuis, 2000). The Jurassic saw a significant differentiation of Diptera fauna with rapid morphological changes with some of the Jurassic families persisting till the present. (Kremzinski and Evenhuis, 2000). However it was during the Cretaceous, that the present day Lower Diptera (nematoceran) families diversified, the blood sucking adults with aquatic larval stages (both nematoceran and orthorraphous brachycerans) appeared and gradually established themselves.

A brief review of literature

Though the first Nematoceran Diptera from India, with aquatic life cycle stages was discovered by Fabricius, way back in 1775, the discovery of the causation of the malaria vector by Ronald Ross in 1903, led to the actual spurt in research activities on the mosquitoes. Other studies on mosquito-borne diseases in India and abroad followed through, thus initiating research on the dipteran aquatic larval stages mostly aiming at vector control. Since then, India became a hotbed of Diptera research with Calcutta School of Tropical Medicine being the nodal centre. Several national institutions, started working on the different Dipteran groups gradually over time, thus enriching the aquatic fauna in general. The founder Director of ZSI, T.N. Annandale in 1911 initiated the work on the aquatic dipteran fauna collected from Shimla hills and Darjeeling district, and later the first Indian Director of Zoological Survey of India, Baini Prasad worked on the larval architecture of aquatic Diptera. The main focus of his research was on the anatomy of Chironomidae, Dixidae and Chaoboridae larvae.

As compared to study of the adult dipteran fauna, the larval stages of mostly the vector groups were given importance. Dipteran larvae were studied worldwide with keys to the larval stages were often referred for identification of the Indian fauna. The major workers who had worked on the different Lower Dipteran groups related to the aquatic fauna has been mentioned in the history of aquatic Diptera research. Larval dipterans worldwide have been studied by McAlpine (1981), Darvas *et al.* (1984, 1998) and Mackey and Brown (1980), Brown *et al.* (2010). Datta (1997, 1998) had elaborated on the different diverse habits of flies in general. However, the only consolidated information on the aquatic Diptera diversity from India reports 25 families, with around 136 genera from India (Parui *et al.,* 2003).

Collection and preservation techniques of aquatic insects

Collection: The most common techniques used for collection of aquatic insects are the D-frame and O-frame aquatic nets, which are quite sturdy to accommodate the resistance of the water. Both can be used in still water but the D-frame net is best for sampling in flowing water. The size of the mesh or sieve (pore size of the net) varies and depends upon the size of the specimens one wants to collect, usually ranging from 20-500 µm.

Collection from lentic habitats is usually done by sweeping the net vigorously through the water to make sure it gets into vegetation and along the banks and is carefully lifted with the entire mass of macrophytes or sediments that comes along. For lotic habitats, 'Kick sampling method' is usually followed. As mentioned earlier, the D-frame net is more effective here. The flat side of the D-frame net is placed on the bottom of the stream and, upstream from the net, the vegetation is disturbed by vigorous dragging of the net, which facilitates the insects to be swept into the net. Same is the technique for collection along the banks of streams, by always sweeping the net upstream, letting the current carry the animals into the net.

Preservation: The collected insects are immediately preserved in 70% ethyl alcohol with few drops of glycerine and later carefully sorted, counted and placed in separate vials. The vials are then labelled with all relevant information and kept for identification.

Status of Global vis-a vis Indian Aquatic Diptera Diversity

Present study revealed that the Indian aquatic fly fauna comprises of 90% (36 families out of 40) of the aquatic fly fauna reported worldwide (Table 1, Fig. 1) and 39.13% (36 families out of 92) of the known dipteran families from India are aquatic or water dependant (Fig. 2). 72% (18 families) of the families of the total known Indian Nematoceran (Lower Diptera) familiesare aquatic (Table. 2 Fig. 4), and only 26.7% (Table 2 Fig. 5) of the known Indian Brachycerans are water reliant (18 families).

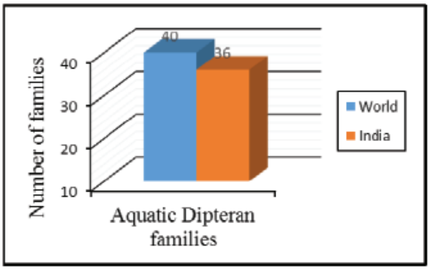

Fig. 1. The graph represents the comparison between World and Indian Aquatic Dipteran families.

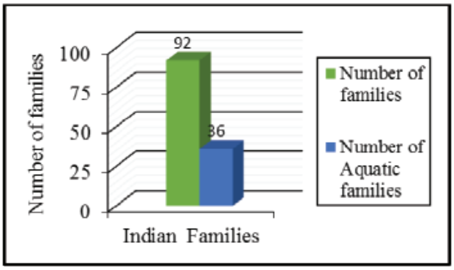

Fig. 2. The graph represent the comparison between Indian families and Indian Aquatic dipteran families.

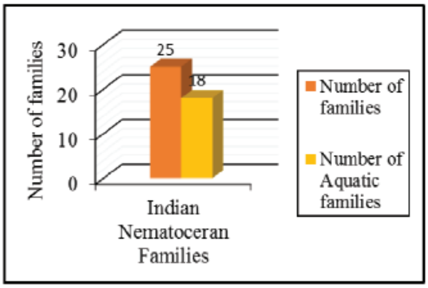

Fig. 3. The graph represents the comparison between Indian Nematoceran families and Indian Aquatic Nematoceran families.

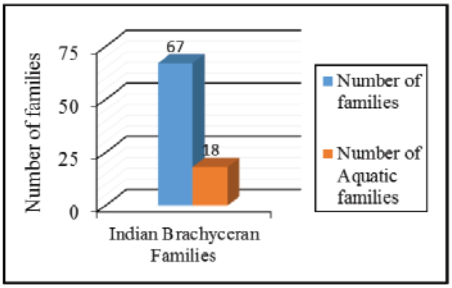

Fig. 4. The graph represents the comparison between Indian Brachyceran families and Indian Aquatic Brachyceran families.

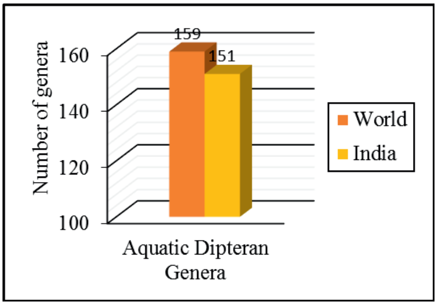

Fig. 5. The graph represents the comparison between World and Indian Aquatic Dipteran genera.

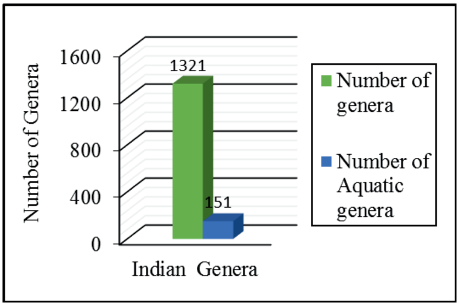

Fig. 6. The graph represents the comparison between Indian dipteran genera and Indian aquatic genera.

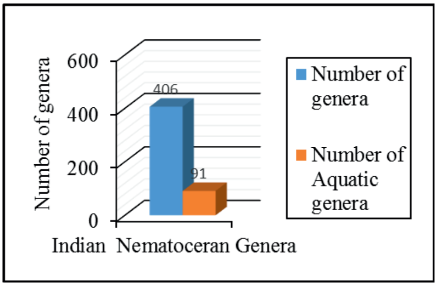

Fig. 7. The graph represents the comparison between Indian Nematoceran dipteran genera and Indian Nematoceran aquatic genera.

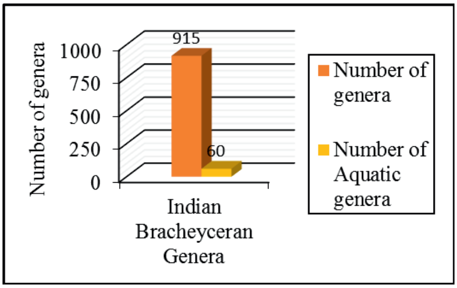

Fig. 8. The graph represents the comparison between Indian Brachyceran dipteran genera and Indian Brachyceran aquatic genera.

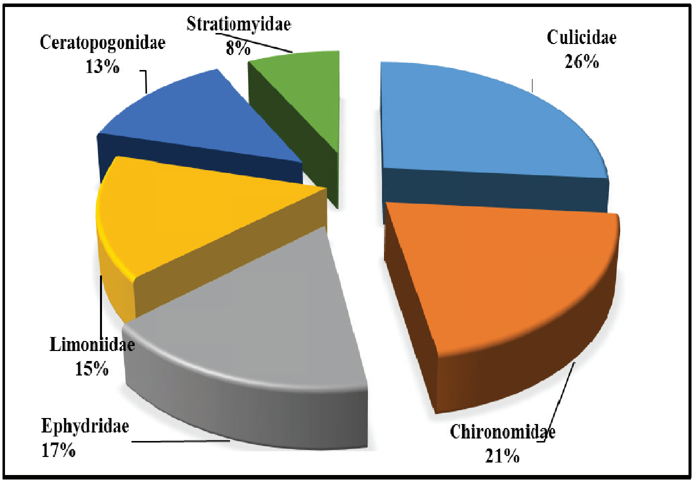

Fig. 9. Pie diagram representing generic diversity from the major aquatic dipteran family

Generic diversity also reveals similar status. Of the aquatic genera known worldwide (159), 94.7% (151) are reported from India (Table. 3 Fig. 5), while of the total Indian genera only 11.4% are water dependant (Fig. 6). Further 22.41% of the total nematoceran genera of India are aquatic (Fig. 7) and only 6.55% of the total brachyceran genera are aquatic (Fig. 8). The Indian Nematocera show a predominance in the aquatic habitats occupying almost 72% of the niches occupied by the flies.

Table 1. Diversity of Aquatic dipteran fauna worldwide vis-à-vis India

	Aquatic Dipteran families	**Aquatic Dipteran Genera**	**Aquatic Dipteran Species**
World	40*	159	43271*
India	36	151	1,588

*Source : Balian *et al.*, 2010, Wagner *et al.,* 2008.

The Family Culicidae is the most represented group showing maximum of the aquatic generic abundance (22 genera) followed by Chironomidae (21 genera), Ephydridae (15 genera), Limoniidae (14 genera) and Ceratopogonidae (12 genera) (Table: 2 & 3 Fig. 9). Table 3 shows family wise representative genera known to be aquatic in nature. Our diversity studies reveal that of the Lower Dipteran (Nematocera), the families Culicidae, Chironomidae, Limoniidae, Tipulidae, Ceratopogonidae, Psychodidae and Simuliidae are highly diverse (Fig. 10). Among the Brachycera (higher Diptera) the families Ephydridae, Tabanidae, Syrphidae, Dolichopodidae, Muscidae, Stratiomyiidae and Sarcophagidae are both high diverse and well distributed.

Classification of Aquatic Diptera

The Diptera as an order is monophyletic with two major suborders (i) Lower Diptera or the erstwhile Nematocera and (ii) Brachycera. The entire fly order is traditionally divided into two major groups: the Lower Diptera ("Nematocera"), mosquito-like flies with long antennae, and the Brachycera, stout and fast moving flies with short antennae. The majority species of Brachycera, belong to the clade Cyclorrapha, characterized by their adaptable larval stage (maggot) and their means of metamorphosis (puparium). The Lower Diptera is composed of Tipulomorpha (crane flies), Culicomorpha (mosquitoes), Psychodomorpha (sand flies)and Bibinomorpha (march flies and gall midges) and are the most common aquatic forms. The Brachycera is composed of Eremoneura (flies with three larval instars), Cyclorrapha (flies that pupate in a puparium), Schizophora (flies that escape from the puparium using a eversible frontal pouch: *Drosophila*) and Calyptratae (larger flies with wings having an enlarged basal lobe called calypter: houseflies) (Weigmann *et al.,* 2011). A few of the brachyceran families have larval stages which are aquatic in nature.

Table 2. 'Water - Dependent' Dipteran families and genera of India

Family Name	Nos. of Aquatic Indian Genera	Family Name	Nos. of Aquatic Indian Genera
Suborder Lower Diptera		Infraorder Tabanomorpha	
Nematocera		19. Family Rhagionidae	1
Infraorder Blephariceromorpha		20. Family Tabanidae	2
Superfamily Blephariceroide			
1. Family Deuterophlebiidae	1	21. Family Athericidae	1
2. Family Blephariceridae	2	Infraorder Stratiomyomorpha	
Infraorder Nymphomyiomorpha		Superfamily Stratiomyoidea	
Superfamily Nymphomyioidea		22. Family Stratiomyidae	7
3. Family Nymphomyioidea	1	Infraorder: Asilomorpha	
Infraorder Tipulomorpha		Superfamily: Empidoidea	
Superfamily Trichoceroidea		23. Family Empididae	3
4. Family Trichoceridae	2	24. Family Dolichopodidae	2
Superfamily Tipuloidea		Infraorder Muscomorpha	
5. Family Cylindrotomidae	1	Section Aschiza	
6. Family Limoniidae	14	Superfamily Phoroidea	
7. Family Pediciidae	2	25. Family Phoridae	2
8. Family Tipulidae	5	Superfamily Syrphoidea	
Infraorder Ptychopteromorpha		26. Family Syrphidae	4
Superfamily Ptychopteroidea		Section Schizophora	
9. Family Ptychopteridae	1	Subsection Acalyptratae	
10. Family Tanyderidae	1	27. Family Sepsidae	3
Infraorder Psychodomorpha		28. Family Sciomyzidae	3
Superfamily Psychodoidea		29. Family Dryomyzidae	1
11. Family Psychodidae	2	Superfamily Carnoidea	
Infraorder Culicomorpha		30. Family Canacidae	1
Superfamily Chironomoidea		Superfamily Sphaeroceroidea	
12. Family Ceratopogonidae	12	31. Family Sphaeroceridae	1
13. Family Chironomidae	19	Superfamily Ephydroidea	
Superfamily Simulioidea		32. Family Ephydridae	15
14. Family Thaumaleidae	1	Subsection Calyptratae	
15. Family Similudae	1	Superfamily Muscoidea	
Superfamily Culicoidea		33. Family Muscidae	8
16. Family Dixidae	1	34. Family Anthomyiidae	1
17. Family Culicidae	24	35. Family Scathophagidae	1
18. Family Chaoboridae	1	Superfamily Oestroidea	
Sub Order Brachycera		36. Family Sarcophagidae	3

Table 3. Aquatic Diptera Genera from India

Sl. No.	Family Name (Sub order Nematocera)	Aquatic Genera from India
1	Deuterophlebiidae	*Deuterophlebia* Edwards, 1922
2	Nymphomyiidae	*Nymphomyia* Tokunaga, 1932
3	Trichoceridae	*Paracladura* Brunetti 1911, *Trichocera* Meigen 1803
4	Cylindrotomidae	*Phalacrocera* Schiner, 1863
5	Limoniidae	*Erioptera* Meigen, 1800, *Gonomyia* Meigen, 1818, *Molophilus* Curtis, 1833, *Ormosia* Rondani, 1856, *Rhabdomastix* Skuse, 1890, *Styringomyia* Loew, 1845, *Conosia* Van der Wulp, 1880, *Hexatoma* latreille, 1809, *Paradelphomyia* Alexander, 1936, *Pilaria* Sintenis, 1889, *Polymera* Wiedemann, 1820, *Pseudolimnophila* Alexander, 1919, *Antocha* Osten Sacken, 1859, *Helius* Lepeletier and servile, 1828
6	Pediciidae	*Dicranota* Zetterstedt, 1838, *Pedicia* Latreille, 1809
7	Tipulidae	*Holorusia* Loew, 1863, *Leptotarsus* Guérin-Méneville, 1831, *Tipula* Linnaeus, 1758, *Dolichopeza* Curtis, 1825, *Leptotarsus* Guérin-Méneville, 1831
8	Ptychopteridae	*Ptychoptera* Meigen, 1803
9	Blephariceridae	*Philorus* Kellogg, 1903, *Blepharicera* Macquart, 1843
10	Tanyderidae	*Protanyderus* Handlirsch, 1909
11	Psychodidae	*Psychoda* Latreille, 1797, *Telmatoscopus* Eaton, 1904
12	Ceratopogonidae	*Atrichopogon* Kieffer, 1906, *Bezzia* Kieffer, 1899, *Culicoides* Latreille, 1809, *Dasyhelea* Kieffer, 1911, *Forcipomyia* Meigen, 1818, *Alluaudomyia* Kieffer, 1913, *Johannsenomyia* Malloch, 1915, *Palpomyia* Meigen, 1818, *Sphaeromias* Curtis, 1829, *Stilobezzia* Kieffer, 1911, *Leptoconops* Skuse, 1889, *Nilobezzia* Kieffer, 1921
13	Chironomidae	*Clinotanypus* Kieffer, 1913, *Endochironomus* Kieffer 1918, *Tanypus* Meigen, 1803, *Diamesa* Meigen, 1835, *Einfeldia* Kieffer 1924, *Harnischia* Kieffer 1921, *Kiefferulus* Goetghebuer 1922, *Sympotthastia* Pagast, 1947, *Brillia* Kieffer, 1913, *Cricotopus* Wulp, 1874, *Heterotrissocladius* Sparck, 1923, *Glyptotendipes* Kieffer 1913, *Microchironomus* Kieffer 1918, *Parametriocnemus* Goetghebuer, 1932, *Chironomus* Meigen, 1803, *Orthocladius* Wulp 1874, *Cryptochironomus* Kieffer, 1918, *Dicrotendipes* Kieffer, 1913, *Paracladopelma* Harnisch 1923, *Tripelma* Kieffer 1913, *Rheocricotopus* Thienemann & Harnisch 1932.
14	Thaumaleidae	*Thaumalea* Ruthe, 1831
15	Similudae	*Simulium* Latreille, 1802
16	Dixidae	*Dixa* Meigen, 1818

Sl. No.	Family Name (Sub order Nematocera)	Aquatic Genera from India
17	Culicidae	*Aedes* Meigen, 1818, *Anopheles* Meigen, 1818, *Aedomyia* Edwards 1912, *Armigeres* Theobald 1901, *Culex* Linnaeus, 1758, *Culiseta* Felt, 1904, *Ficalbia* Theobald 1903, *Coquillettidia* Dyar 1905, *Hodgesia* Theobald 1904, *Heizmannia* Ludlow 1905, *Lutzia* Theobald 1903, *Malaya* Leicester 1908, *Mansonia* Blanchard, 1901, *Mimomyia* Theobald 1903, *Orthopodomyia* Theobald, 1904, *Stegomyia* Theobald 1901, *Topomyia* Leicester 1908, *Toxorhynchites* Theobald, 1901, *Tripteroides* Giles 1904, *Udaya* Thurmann 1954, *Uranotaenia* Lynch Arribalzaga, 1891, *Verrallina* Theobald 1903, *Psorophora* Robineau-Desvoidy 1827.
18	Chaoboridae	*Chaoborus* Lichtenstein, 1800
19	Rhagionidae	*Chrysopilus* Macquart 1826
20	Athericidae	*Atherix* Meigen, 1803
21	Tabanidae	*Chrysops* Meigen, 1803,*Tabanus* Linnaeus, 1758
22	Stratiomyidae	*Stratiomys* Geoffroy, 1762, *Odontomyia* Meigen 1803, *Allognosta* Osten Sacken, 1883, *Beris* Latreille 1802, *Oxycera* Meigen, 1803, *Sargus* Fabricius 1798, *Adoxomyia* Kertesz, 1907
23	Dolichopodidae	*Argyra* Macquart, 1834, *Asyndetus* Loew, 1869
24	Empididae	*Hemerodromia* Meigen, 1822, *Rhamphomyia* Meigen, 1822, *Chelipoda* Macquart, 1823
25	Phoridae	*Diplonevra* Lioy, 1864, *Megaselia* Rondani, 1856
26	Syrphidae	*Eristalis* Latreille, 1804, *Mallota* Meigen, 1822, *Myolepta* Newman, 1838, *Syritta* Lepeletier & Serville, 1828
27	Sepsidae	*Parapalaeosepsis* Duda 1926, *Themira* Robineau-Desvoidy, 1830, *Sepsis* Fallen, 1810
28	Canacidae	*Xanthocanace* Hendel, 1914
29	Dryomyzidae	*Dryomyza* Fallen, 1820
30	Sciomyzidae	*Sepedon* Latreille, 1804, *Dichetophora* Rondani 1868, *Pherbellia* Robineau-Desvoidy, 1830
31	Sphaeroceridae	*Leptocera* Olivier 1813
32	Ephydridae	*Chlorichaeta* Becker, 1923, *Chaetomosillus* Hendel, 1934, *Placopsidella* Kertesz, 1901, *Trimerogastra* Hendel 1914, *Allotrichoma* Becker, 1896, *Elephantinosoma* Becker 1903, *Discocerina* Macquart 1835, *Ditrichophora* Cresson, 1924, *Hecamedoides* Hendel, 1917, *Polytrichophora* Cresson 1924, *Actocetor* Becker, 1903, *Ceropsilopa* Cresson, 1917, *Psilopa* Fallen, 1823, *Discomyza* Meigen, 1830, *Typopsilopa* Cresson, 1916
33	Muscidae	*Atherigona* Rondani 1856, *Coenosia* Meigen 1826, *Dichaetomyia* Malloch 1921, *Graphomya* Robineau-Desvoidy, 1830, *Limnophora* Robineau-Desvoidy, 1830, *Lispe* Latreille, 1797, *Lispocephala* Pokorny, 1893, *Phaonia* Robineau-Desvoidy, 1830.

Sl. No.	Family Name (Sub order Nematocera)	Aquatic Genera from India
34	Anthomyiidae	*Anthomyia* Meigen, 1803
35	Scathophagidae	*Scathophaga* Meigen, 1803
36	Sarcophagidae	*Sarcophaga* Meigen,1826, *Blaesoxipha* Loew, 1861, *Sphenometopa* Townsend, 1908.

Distribution of the Aquatic Diptera over the States and Union territories

The aquatic or water dependant Diptera fauna comprises of 36 families and 151 genera of among the 40 families and 159 genera of aquatic Diptera distributed worldwide (Table 2). Amongst all the Indian states West Bengal ranks the highest in aquatic Dipteran diversity, considering the positioning of the state on the tropics, with abundant rainfall and high humidity as well as the extensive surveys conducted in the state (Table 4). The high diversity pattern is also manifested by the states of Assam, Himachal Pradesh, Uttarakhand, Sikkim, Tamil Nadu, Kerala, Arunachal Pradesh, Meghalaya and Maharashtra. Diversity is minimum in the UT of Dadra and Nagar Haveli which has the lowest diversity probably because of deficient data.

Endemicity

The Indian dipteran fauna is an interesting congregation of endemic and exotic elements. Of the known number of dipteran species of India, 110 genera and 2183 species, i.e. roughly 30-35% of species, are endemic (Datta, 1991, Ramakrishna and Alfred, 2007). It is estimated that 25% of the known aquatic Diptera from India are endemic to India. Since, the true aquatic nature of the flies is possible to discern only after studying their life cycle, behaviour, ecology and habitat. It may be presumed that the actual endemicity may be a lot more considering the range of aquatic dipterans known from India.

Threats and Conservation

The availability and amount of food and oxygen are the most important factors determining the distribution of Diptera in the aquatic bodies. They have equally diverse responses to pollution, with some being exceptionally sensitive, while others tolerate the worst imaginable water quality (Voshell, 2009). The use of aquatic insects is a standard method and an efficient, fast, and inexpensive technique of management of freshwater resources, monitoring of aquatic biota in water recourses by trained health personnel and can be a critical step to describe water quality in developing countries (Malekei-Ravasan *et al.,* 2013). At its simplest form, changes in water quality are equated to changes in diversity or biotic indices (Washington, 1984; Metcalfe, 1989).

Hardly any species of aquatic dipteran insects have been listed as endangered or threatened. However, the reason for this is that studying the distribution and population numbers of such a diverse group of organisms is an overwhelming task. The importance of the study of aquatic organisms in environmental impact studies and biomonitoring of freshwater habitats calls for an urgent need for comprehensive studies (Stein *et al.,* 2008).

Table 4. Distribution of Aquatic dipteran fauna across the Indian States and Union Territories

State	Deuterophlebiidae	Nymphomyiidae	Trichoceridae	Cylindrotomidae	Limoniidae	Pediciidae	Tipulidae	Ptychopteridae	Blephariceridae	Tanyderidae	Psychodidae	Ceratopogonidae	Chironomidae	Thaumaleidae	Simuliidae	Dixidae	Culicidae	Chaoboridae	Rhagionidae	Athericidae	Tabanidae	Stratiomyidae	Dolichopodidae	Empididae	Phoridae	Syrphidae	Sepsidae	Canacidae	Dryomyzidae	Sciomyzidae	Sphaeroceridae	Ephydridae	Muscidae	Anthomyiidae	Scathophagidae	Sarcophagidae	Total
West Bengal	0	1	1	1	3	3	4	1	3	0	4	5	5	1	1	1	3	0	1	1	11	6	5	4	1	6	2	2	0	3	1	8	4	2	1	2	[illegible]
Assam	0	0	0	1	5	2	1	0	0	0	2	8	1	1	0	1	2	0	1	1	8	4	2	0	1	3	0	0	0	1	1	1	3	1	0	0	[illegible]
Himachal Pradesh	0	0	0	0	0	0	3	0	2	0	2	0	7	0	1	1	3	0	0	0	5	0	6	3	0	2	1	0	1	1	0	0	4	1	1	2	46
Uttarakhand	2	0	1	0	1	0	3	1	0	1	3	1	2	1	1	1	5	1	0	0	5	2	2	1	1	1	1	0	1	0	0	0	2	1	0	1	42
Sikkim	1	1	1	3	2	2	1	1	1	1	0	2	0	1	0	0	3	0	0	0	3	0	1	0	0	6	1	0	0	1	1	0	3	1	1	1	39
Tamil Nadu	0	0	0	0	5	0	4	0	0	0	1	2	0	0	1	0	3	0	1	0	6	2	1	0	0	4	1	0	0	1	0	1	2	1	0	2	38
Kerala	0	0	0	0	3	0	0	0	0	0	1	0	1	0	0	0	6	0	1	0	7	2	2	0	2	2	1	0	1	0	0	0	3	0	0	2	34
Arunachal Pradesh	0	0	0	0	6	0	2	0	0	0	0	0	0	0	1	0	8	0	0	0	3	1	1	1	0	2	1	0	0	1	0	0	1	0	0	1	29
Andaman Is land	0	0	0	0	3	0	5	0	0	1	3	0	3	0	0	0	0	0	1	0	1	2	1	0	1	2	1	0	0	0	0	0	3	0	0	1	28
Meghalaya	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	4	2	0	0	0	4	1	0	0	0	0	0	3	0	0	0	27
Maharastra	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	3	0	1	0	5	0	0	0	1	2	0	0	0	0	1	7	2	0	0	1	25
Madhya Pradesh	0	0	0	0	1	0	1	0	0	0	1	0	2	0	0	0	8	0	0	0	3	1	1	0	0	2	1	0	0	0	0	2	1	0	0	0	24
Chattishgarh	0	0	0	0	2	0	1	0	0	0	1	0	1	0	0	0	5	0	0	0	2	1	2	0	0	1	1	0	0	0	0	1	1	0	0	1	20
Bihar	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	1	0	0	0	1	1	0	0	2	0	2	0	0	1	1	0	2	0	0	4	20
Uttar Pradesh	0	0	1	0	0	0	3	1	0	1	0	1	1	1	0	0	1	1	0	0	1	0	1	1	1	1	1	0	0	1	0	0	0	1	1	0	20
Gujrat	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	5	0	0	0	2	1	1	0	0	2	1	0	0	0	0	1	0	0	0	3	18
Manipur	0	0	0	0	0	5	2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1	1	0	0	0	0	0	2	0	0	3	16
Rajasthan	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	3	0	0	1	14
Jammu And Kashmir	0	0	1	0	0	0	0	0	0	0	0	0	3	0	1	0	0	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	2	1	0	11
Karnataka	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	2	0	2	0	0	0	0	2	1	0	0	0	10
Mizoram	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1	1	0	0	0	0	1	2	0	0	0	10
Tripura	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	1	0	0	0	1	1	0	0	1	0	0	0	0	0	2	9
Delhi	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	3	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0	1	0	0	0	8
Andhra Pradesh	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	2	1	0	0	1	0	0	0	0	0	1	8
Odisha	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1	0	0	2	1	0	0	0	1	1	0	0	0	0	8
Chandigarh	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	5
Nagaland	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	2	0	0	0	1	0	0	0	0	0	0	4
Goa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	2	0	0	0	4
Punjub	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0	0	1	1	1	0	0	1	1	0	0	1	0	0	0	0	0	2	3
Jharkhand	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
Harjana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2
Puducherry	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Lakshadweep	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Dadra & Nagar Have	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Gaps in research

The diversity and distribution pattern of aquatic and water dependant Diptera familiesare not a very rigorously studied subject, because of the complicacy of identifying the life cycle stages and the emerging adult forms. In India, a few of the families have been well studied but most of the aquatic families are not dealt deeply enough. The dearth of trained taxonomist on aquatic or water dependant Diptera specifically the eggs, larvae and pupal stages does not permit proper identification of aquatic Diptera fauna beyond the family level in several instances.Further, the lack of information on the aquatic Diptera fauna stems from the fact that adults being terrestrial, are more easily available for study, compared to the unseen or hidden life cycle stages.

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PLATE I

Showing the different habitats of Indian Aquatic Diptera.

Dried up riverbed

River side

Hillstream

PLATE II

Showing the different habitats of Indian Aquatic Diptera.

Lake

Bog

Slow moving stream

PLATE III

Some photographs and drawing of Larvae, Pupae and adult of Culicidae family

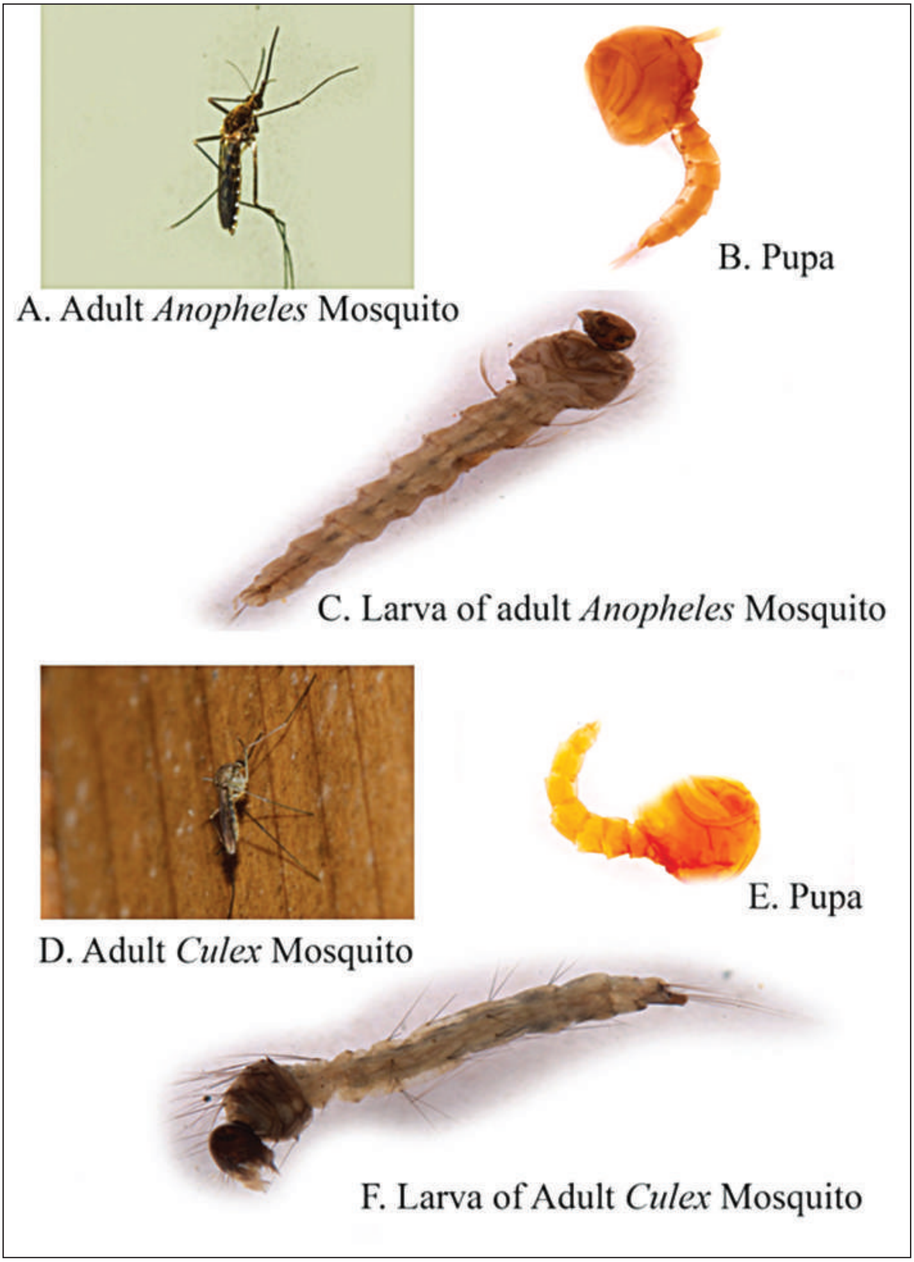


PLATE IV

Some photographs and drawing of Larvae, Pupae and adult of Chironomidae family

A. Adult Chironomidae

B. Pupa

C Larva of Adult Chironomidae

D Adult Ceratopogonidae

E. Pupa

F Larva of Adult Ceratopogonidae

PLATE V

Some photographs and drawing of Larvae, Pupae and adult of Stratiomyidae family

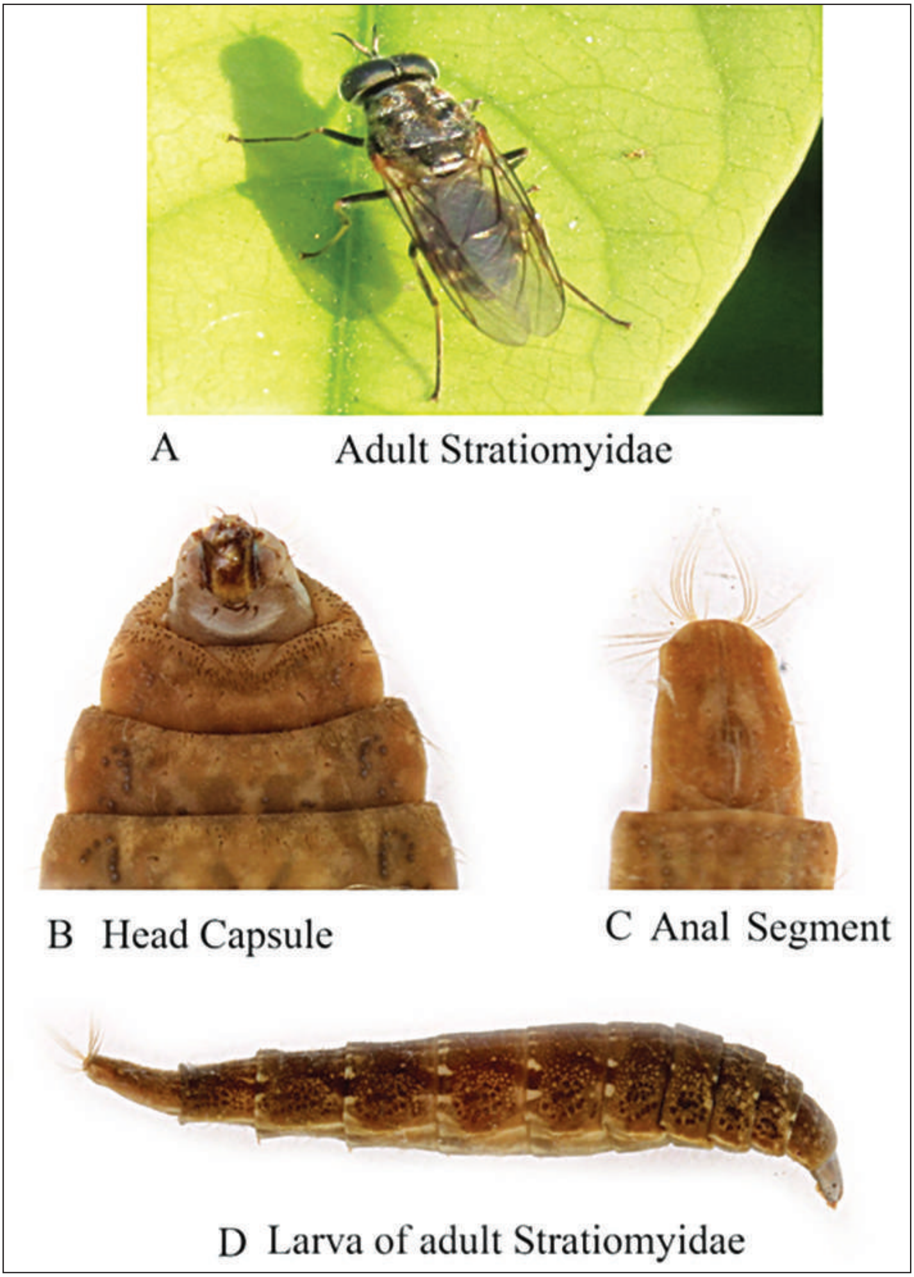
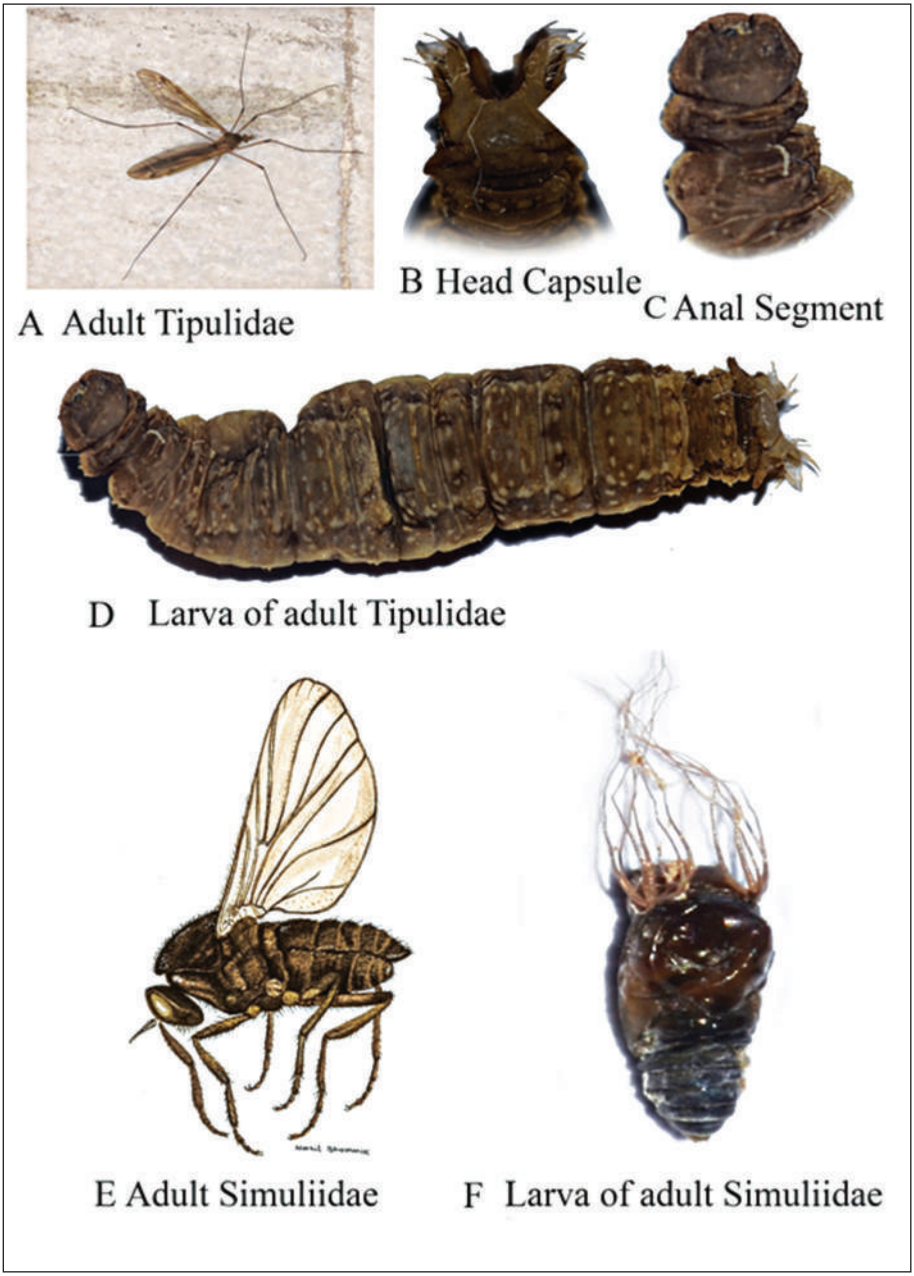


PLATE VI

Some photographs and drawing of Larvae, Pupae and adult of Tipulidae familyfamily



Chapter 31

INSECTA : HYMENOPTERA (AQUATIC)

RAJMOHANA K.

ABSTRACT

Hymenoptera are generally terrestrial. However, a few hymenopteran parasitoids have as their hosts, the egg, larvae and pupal stages of several aquatic insects coming under Heteroptera, Odonata, a few Lepidoptera, Coleoptera and even Diptera. As per earlier reports, globally 150 species of Hymenoptera from 11 families are recognized as aquatic. Aquatic Hymenoptera in India mostly belong to 8 families-Braconidae and Ichneumonidae (Superfamily Ichneumonoidea), Mymaridae, Eulophidae and Trichogrammatidae (Superfamily Chalcidoidea), Platygastridae (Superfamily Platygastroidea), Figitidae (Superfamily Cynipoidea) and Diapriidae (Superfamily Diaprioidea). Parasitism by Hymenoptera under water has never been studied in detail in India, that confirmed records exist for only 10 species in 7 genera under 3 families from or near water bodies. Species level data on aquatic Hymenoptera in India is extremely scanty. Information on several genera having their distribution in India, that are recorded as parasitoids of aquatic insects elsewhere, are compiled herewith inorder to focus upon the necessity and scope of future work in this line.

Key words: Aquatic Hymenoptera, India, Ichneumonidae, Mymaridae, Platygastridae.

INTRODUCTION

Hymenoptera is one of the most numerous groups and also one of the four great orders of insects, the other three being Coleoptera, Lepidoptera, and Diptera (Mason and Huber 1993). The order is divided into suborders Symphyta (sawflies), and Apocrita, the latter is again subdivided into Aculeata (bees, wasps and ants) and Parasitica (= Terebrantia). More than 80% of Hymenoptera are parasitic (Lawrence, 2008). The Parasitica are a paraphyletic assemblage of taxa, and share a similarity in basal biology and fill important ecological niches that are of great economic importance (Zuparko, 2008). Although as adults they are free living, during their larval stage they live as parasitoids of other insects or spiders. Hence parasitic Hymenoptera are highly significant in influencing population dynamics of other insects.

Hymenopterans are generally terrestrial, but quite a few of them have adapted for an aquatic mode of life too. Hagen (1996) defined aquatic Hymenoptera as a group which includes all hymenopteran species that parasitize any life stage

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of aquatic insects. The female wasps of a few parasitoid families swim beneath the water to lay eggs into the various life stages like eggs, larvae and/or pupae of their aquatic insect hosts, principally Heteroptera, Odonata and also holometabolous orders like Lepidoptera and Coleoptera. Globally 150 species from 11 families are recognized as aquatic (Bennet, 2008). Species level data on aquatic Hymenoptera in India is extremely scanty, that confirmed records exist for only 10 species in 7 genera under 3 families from or near water bodies in India (Table 1). Information on several genera having their distribution in India, that are recorded as parasitoids of aquatic insects elsewhere, are compiled herewith.

Historical resume

Hymenoptera was first observed frequenting an aquatic body by Walker (1836), when he observed the ichneumonid wasp *Agriotypes armatus* descending into water. Later Siebold (1858) and Muller (1888) found that the above mentioned wasp was a parasitoid of the Trichopteran larvae. Interestingly Lubbock (1863) observed the mymarid wasp *Caraphractus cinctus* Walker (= *Polynema natans*, Lubbock) and the trichogrammatid wasp *Prestwichia aquatica* Lubbock, swimming in water, which he later described as new to science. The mymarid was using its wings for swimming, while the trichogrammatid, its legs. Another wasp, *Anagrus subfuscus* Förster, (Mymaridae) was reported from dragonfly eggs in (1903) by Heymons. He also observed the braconid wasp *Chorebus stagnalis* (Heymons) (=*Gyrocampa stagnalis*) swimming with their legs. Needham (1908) documented several Trichogrammitid wasps, in a water body containing *Ishnura* (Odonata) eggs. Later Matheson and Crosby in 1912, identified the wasps as *Hydrophylita aquivolans* (Matheson and Crosby) (=*Hydophylax aquivolans,* 1912). Marchal in (1900) recorded *Tiphodytes* Bradley (= *Limnodytes* Marchal), the Platygastrid wasp from Gerrid eggs. In 1911, Mathesin and Crosby reared them from the eggs of *Gerris remigis*. In 1912, the same authors described, reported the behavior and copulation of the mymarid *Caraphractus cinctus* Walker (= *Polynema natans*, Lubbock) underwater, reared a few of them from the eggs of the backswimmer *Notonecta*, which were inserted into the aquatic plant *Ludwigia palustris*. Hoffmann (1932) compiled a list of Hymenopteran parasites from the eggs of aquatic and semi-aquatic insects. Frohne (1939) published on the semi-aquatic Hymenoptera in north Michigan lakes.

Lathromeroidea sp. (Trichogramatidae) was recorded as a parasitoid of gerrid eggs by Henriquez & Spence (1993). *Trichogramma* species parasitizing the eggs of Sialidae (Megaloptera) was reported by (Azan & Anderson 1969, Barnard 1977). Hagen (1996) compiled the records of aquatic hymenoptera for North America and Fursov (1985) elaborated a review of European Chalcidoidea (Hymenoptera) parasitizing the eggs of aquatic insects. Bennet (2001), discussed the evolution of aquatic behaviour in Ichneumonidae. Bennet *et al* (2008) compiled the global diversity of hymenopteran wasps in freshwaters. Johnson *et al*, 2012, published on the aquatic Platygastroidea. *Hydrophylita lestesi* (Costa Lima 1960) (Trichogrammatidae), was observed parasitizing the eggs of *Lestes* sp. (Lestidae) on leaves of *Hedychium coronarium* in Querino and Hamada, (2009). The same paper reported the parasitisation by the trichogrammitd *Pseudoligosita longifringiata*

(Viggiani) on the Odonata *Argia insipida* Hagen. *Feitosa et al.*, 2016 reviewed the association of *Anagrus amazonensis* Triapitsyn, Querino & Feitosa (Hymenoptera, Mymaridae) with aquatic insects in upland streams and floodplain lakes in central Amazonia, Brazil.

Except for some instances, authentic studies on the habits and life histories of aquatic Hymenoptera in India are extremely rare. *Agriotypus himalensis* Mason (Ichneumonidae) was described from Assam, from the aquatic cocoons of *Neophylax* sp. (Trichoptera: Odontoceridae). Later Sinu *et al.,* 2007, reported the host searching behavior and potential of an aquatic ichneumonid pupal parasitoid of rice caseworm (*Parapoynx stagnalis*), in an upland rice paddy agro-ecosystem of the Western Ghats.

Methodology

Yellow pan traps, are found to be extremely effective in collecting aquatic wasps. Small yellow commercial rectangular or circular plastic bowls approximately 5cm high, serve as individual pans. They are deployed in large numbers, > 50 traps at a time. Each pan is filled with water along with a few drops liquid dish soap, so as to break the surface tension of the water film at the surface. The pans are set out at the day break, not obscured by vegetation, near permanent water bodies and are emptied in the late evening the same day. Adding salt can help in retaining the specimens in water intact, minimizing decomposition. The water in pans are filtered through, fine-meshed net, washed thoroughly under a fine stream of running water and then preserved in 70-90% ethanol.

DIVERSITY OF AQUATIC HYMENOPTERA IN INDIA

A few species of parasitic Hymenoptera belonging to Braconidae and Ichneumonidae (Superfamily Ichneumonoidea), Mymaridae, Eulophidae and Trichogrammatidae (Superfamily Chalcidoidea), Platygastridae (Superfamily Platygastroidea), Figitidae (Superfamily Cynipoidea) and Diapriidae (Superfamily Diaprioidea), in India are aquatic.

Other than the egg parasitoids, in Hymenoptera, some spider wasps under family Pompildae (Superfamily Vespoidea) are aquatic.

Superfamily ICHNEUMONOIDEA

Family ICHNEUMONIDAE

Subfamily Agriotypinae includes aquatic ectoparasitoid wasps that parasitize caddisfly pupae and prepupae (order Trichoptera) inhabiting fast-running streams (Townes, 1969). *Agriotypus himalensis* Mason, 1971, (Agriotypinae) was described from Assam, at about 7200ft in the Himalayas, from the aquatic cocoons of *Neophylax* sp. (Trichoptera: Odontoceridae). The pupa of the parasitoids bears ribbon-like respiratory filaments.

Aquatic host searching behaviour is known in the Ichneumonid subfamilies Cryptinae and Cremastinae as well. The former contains species that are semi-aquatic and they search for hosts at the water surface. A few species are known to attack nymphalids too (Bennet, 2001). Sinu *et al.,* 2007, reported the host searching behavior and potential of an aquatic ichneumonid, possibly an undescribed species of genus *Apsilops* in subfamily Cryptinae, which is a pupal parasitoid of the rice caseworm, *Parapoynx stagnalis* (Lepidoptera) in an upland rice paddy agro-ecosystem of the Western Ghats, India. They also observed the non-emergence of these wasps from parasitized rice caseworms kept in a dry terrarium, corroborating aquatic mode of life of the wasps and also stated that the semi-aquatic behavior of the wasp could have evolved in response to the underwater pupation adopted by the rice caseworm.

Family BRACONIDAE

Several braconid genera like *Asobara* Förster, *Chaenusa* Haliday, *Chorebus* Haliday *Dacnusa* Haliday *Opius* (*Opius*) Wesmael were recorded as parasitoids of aquatic larvae-pupae of dipteran ephydrids (*Parydra*) else where. All the above genera and also *Phaenocarpa* (*Phaenocarpa*) Förster parasitizing the sciomyzids (*Antichaeta*) pupae, have their distribution in India (Taxapad, 2012).

Superfamily CHALCIDOIDEA

Family EULOPHIDAE

Several species in genus *Aprostocetus* Westwood, (subgenus *Ootetrastichus*) are known to attack the eggs of Odonates and the coleopteran Dytiscid beetle, in plant stems under water, though such reports are yet to be made from India. Triapitsyn *et al.*, (2011) reported a species of the above genus from petioles of water hyacinth from eggs of *Megamelus* sp. (Delphacidae) and the dictyopharid plant hopper *Taosa* sp., associated with *Eichornia crassipes*, the invasive aquatic weed. *Aprostocetus* in India is species rich, with about 80 species (Noyes, 2016).

Family MYMARIDAE

Mymaridae is one of the families of parasitic Hymenoptera that have accurate species that are aquatic and attacking the eggs of aquatic insects groups like Odonata, Heteroptera and Coleoptera. Genus *Anagrus* Haliday, whose members are reported as parasitoids of *Lestes* (Odonata) and Dytiscid eggs elsewhere, has about 10 species in India. A new mymarid species- *Ptilomymar heptafuniculata,* described by Manickavasagam and Palanivel in 2014, was collected during explorations around aquatic ecosystems in Yercaud hills.

Family TRICHOGRAMMATIDAE

This family includes species that are parasitoids of eggs of several insects orders. *Trichogramma semblidis* attack the Sciomyzid marsh flies of *Sepedon*. *T. japonicum* are associated with aquatic habitats (Consoli *et al*, 2010). Both the above mentioned parasitoid species are present in India (Noyes, 2016). Some members of genus *Paracentrobia*, attack the eggs of Odonata. Their aquatic host associations are not yet reported in India, though several species of the genus are present here (Noyes, 2016). A few members in genus *Pseudoligosita* are also aquatic.

Superfamily CYNIPOIDEA

Family FIGITIDAE

A few genera in subfamily Eucoilinae under family Figitidae are parasitoids of the pupae of stream inhabiting cyclorraphous dipteran families like Ephydridae and Canacaeidae. Genus *Kleidotoma* Westwood are known to parasitise the flies Canacaeidae, Drosophilidae, Ephydridae, Sepsidae, Sphaeroceridae, Phoridae, Chloropidae, Anthomyiidae and Muscidae (Beardsley, 1990; Forshage and Nordlander, 2008) and those living in concealed and decomposing habitats (Noort, 2017). The Indian fauna of Cynipoidea remain largely unexplored. Akthar *et al.*, 2013, reported the genus *Kleidotoma* for the first time from India, host remains unknown. Several specimens of *Kleidotoma* were collected from the irrigated paddy fields, in the Kerala part of South western Ghats (personal observation).

Superfamily DIAPRIIOIDEA

Family DIAPRIIDAE

Diapriidae are pupal parasitoids of a wide group of dipteran families like Sciomyzidae Stratiomyidae, Syrphidae, Muscidae, Tephritidae, Calliphoridae, Sarcophagidae and Ephydridae, of which, the adult flies abound near marshes, swamps and pond margins, the main breeding sites of their larva. *Trichopria* Ashmead, the genus which have been reported several times in aquatic environments elsewhere, are very common, widely distributed and much speciose in India.

Superfamily PLATYGASTROIDEA

Family PLATYGASTRIDAE

All members of tribe Thoronini (subfamily Scelioninae, family Platygastridae) are known to attack the eggs of aquatic heteropetrans and odonates (Austin *et al.,* 2004). Under the tribe Thoronini, a total of 7 species are known from India (Table 1). Those in the table marked with asterix, are endemic to India. Genera belonging to Thoronini having several species (Fig. 1 to 6), namely *Tiphodytes* Bradley, *Tanaodytes*, *Microthoron* Masner and *Narendraniola* Rajmohana, have been collected in yellow pan traps deployed near water bodies (unpublished data). *Tiphodytes* is a well known egg parasitoid of the heteropteran water striders- *Gerris* and *Trepobates* spp. These wasps are found exclusively in aquatic habitats and have been recorded walking on the upper and lower surfaces on the leaves of water lilies (Masner, 1972). Rajmohana (2014) collected *Tiphodytes* spp. from irrigated rice ecosystems, in Kerala.

Some species under genus *Telenomus* Haliday (subfamily Telenominae) and genus *Trimorus* Förster (subfamily Teleasine) are also known to parasitise the eggs of Diptera and Lepidoptera in water. Though not directly documented in aquatic habitats, several species of the above genera with similar morphological adaptations for an aquatic mode of life are quite common in India. Members of *Trimorus* are parasitic on the eggs of the carabid ground beetles. A few species like *Trimorus sringatus* Rajmohana and *T. microstriae* Rajmohana collected in irrigated rice ecosystems (Rajmohana, 2014) have their wings modified for swimming. The anal margin of their forewings is attenuated and scalloped, so as to function as an oar when under water.

Several species of *Telenomus tabanivorus* group, parasitizing the eggs of horse flies and Lepidopteran stem borers are documented in India, but without host associations. Since their host eggs are seen in aquatic environments, these wasps too have derived aquatic adaptations, to enable their survival in water, atleast for a short period.

Superfamily VESPOIDEA

Family POMPILIDAE

Other than the parasitoids, the only Hymenoptera frequenting waters, are one or two species of *Anoplius* Dufour, the pompilid spider wasps. They are known to enter water to predate upon the fishing araenid water spider, *Dolomedes* sp. Though the groups are recorded in India, the instances of such predation in water, are yet to be documented from the region.

Table 1. Species of aquatic Hymenoptera collected from or near water bodies in India

No.	Species	Ref.
1.	*Tiphodytes crassus* Rajmohana*	Rajmohana (2012)
2.	*Tiphodytes gracilis* Rajmohana*	Rajmohana (2012)
3.	*Tiphodytes minutus* Rajmohana*	Rajmohana (2012)
4.	*Tanaodytes elongatus* Rajmohana*	Rajmohana (2012)
5.	*Narendraniola flagellata* Rajmohana*	Rajmohana (2012)
6.	*Microthoron baeiodes* Masner	Masner (1972) Mukerjee (1978)
7.	*Microthoron dunensis* Mukerjee*	Mukerjee (1994)
8.	*Apsilops sp.*	Sinu *et al* (2007)
9.	*Agriotypus himalensis*	Mason, 1971
10.	*Ptilomymar heptafuniculata*	Manickavasagam and Palanivel (2014)

Morphological features and aquatic adaptations

Aquatic Hymenoptera share a number of morphological features, facilitating them to submerge, breathe as well as swim in water. Most of them have stiff hairs or setae on their body, acting as a plastron for trapping air bubbles. The aquatic Platygastroidea have a smooth and shiny body, with very little microsculpture. The attenuate and scalloped anal margin in forewings helps in swimming (Johnson *et al.,* 2012). With the long marginal fringes, the effective width of wings in most cases is large and functions as a swimming aid.

Threats

The drastic alteration of the hydrological regime of the Earth to meet the needs of rapidly expanding societies or in response to alterations of the land and the atmosphere has critically affected the freshwater biodiversity globally (Vorosmarty *et al.*, 2004). The threats to aquatic insect community arise mainly due to the chemical pollution from industries, agriculture runoff, physical alteration of water bodies due to construction works and drainage and also because of the alien invasives.

Conservation and human significance

Parasitic hymenopterans are known to impact and regulate the populations of their host insects. Hence their presence as natural enemies, prevent the proliferation of their host groups, thus promoting alpha level community diversity in aquatic ecosystems as well. Several groups of parasitic Hymenoptera are known to attack a wide range of dipterans, whose immature stages are aquatic. Many of the predatory aquatic heteroptera like Nepid and gerrrid bugs feeding on small aquatic larvae are efficient natural mosquito regulators. Theoretically speaking, the presence of the parasitoid wasps in large numbers can negatively impact the control of mosquito larvae.

Gaps in research

Information regarding the diversity of aquatic parasitic hymenoptera in India are far from complete, while the natural history of the group largely remain totally unknown. Parasitism by Hymenoptera under water has never been studied in detail in India. Specific and focused investigations are needed to generate indepth knowledge on highly specialized biotic interactions of this kind.

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PLATE I

Fig. 1. *Microthoron Baeiodes* Masner

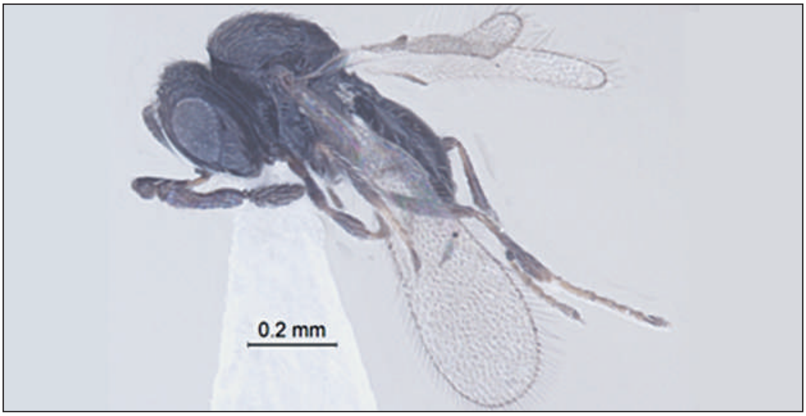

Fig. 2. *Narendraniola flagellata* Rajmohana Male

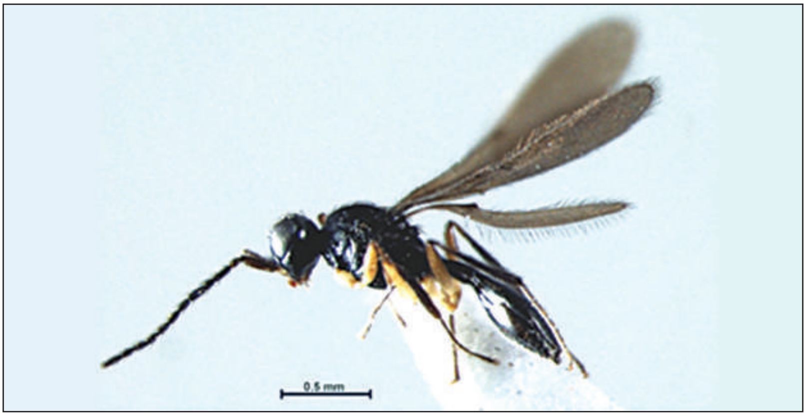

Fig. 3. *Tanaodytes elongatus* Rajmohana Male

PLATE II

Fig. 4. *Tiphodytes gracilis* Rajmohana

Fig. 5. *Tiphodytes minutus* Rajmohana

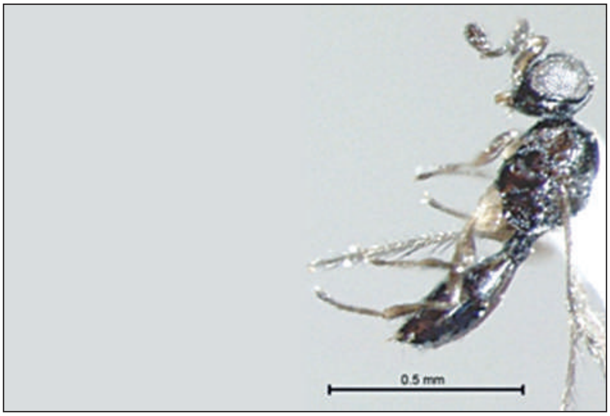

Fig. 6. *Tiphodytes crassus* Rajmohana

Chapter 32

MOLLUSCA

AMIT MUKHOPADHYAY*, BASUDEV TRIPATHY AND ABHIJNA GHOSH

ABSTRACT

Freshwater molluscs play a pivotal role in the freshwater ecosystem. Globally, there are estimated 5,000 species of fresh water molluscs, of which 217 have been reported from India. This paper gives an updated nomenclature with a checklist of 150 species of gastropods and 67 species of bivalves reported from freshwater environment of various ecosystems of India. In terms of biogeographical distributions of freshwater mollusc in India, 15 species of gastropods and 18 species of bivalves have discontinuous distribution. Western Ghats is considered to be a unique biodiversity hotspot for molluscs with a record of 77 species of freshwater molluscs alone in this area. This paper along with an updated nomenclature of freshwater molluscs of India also highlights their diversity, distribution and conservation in India.

Key Words: Mollusca, Bivalves, Gastropods, Freshwater, India.

INTRODUCTION

In the freshwater environment, molluscs are an important group and their abundance plays pivotal role in freshwater ecosystem functioning (Vaughn *et al.,* 2004). Fresh water molluscs are common in ponds, lakes, paddy fields, quiet water pools, and flowing waters like lower section of perennial rivers, irrigation canals etc. Freshwater gastropods are generally found attached to submerged vegetation, rocks, sticks, bricks etc, but bivalves live partly buried in the sand or mud. Similar to the gastropods the bivalves exhibit variations in shell features depending upon the ecology of the species and may produce eco-phenotypes (Subba Rao, 1989). Molluscs form an important component of biological monitoring in terms of rating the water quality and status of aquatic systems (Strong *et al.,* 2008). Based on their occurrence, freshwater molluscs are distinguished into two- primary and secondary freshwater species. The primary freshwater molluscs are confined exclusively to the freshwater habitats, whereas secondary freshwater species are distributed both in estuarine and freshwater habitats. There are estimated 5,000 freshwater molluscs in the world for which valid descriptions exist besides 10,000 undescribed species (Balian *et al.,* 2008). A perusal of literature on malacofauna suggests that the most referred work of Preston's –Fauna of British India on the Freshwater Gastropoda and Plecypoda is nearly hundred years old and 370

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species reported from undivided India, Burma, Ceylon (Preston, 1915), and last the compilation by N.V. Subba Rao who consolidated information on freshwater molluscs and published a Handbook of Freshwater Molluscs of India in 1989 with 195 species recorded from India and adjoining areas (Subba Rao, 1989). Meanwhile, substantial information has been accumulated on freshwater molluscs of India. A number of new species, new information on their biology, range distribution etc. have been added to the list of Preston and Subba Rao. This paper therefore deals with a revised list of freshwater mollusc fauna of India along with their diversity, distribution and conservation in India.

Ideal habitat for Freshwater Mollusca

Diversity

Collections of molluscs from the Indian subcontinent are scattered far and wide. Although there are several species mentioned in literature as occurring in India, authors have taken into account only those species which could be physically verified. Nevertheless, some of the species are included on the merit of the literature. However, authors have made all efforts to present an up-to-date information for all the available species in India. The classification was followed after Bouchet and Rocroi (2005) for Gastropoda and Bouchet *et al.* (2010) for Bivalvia.

In the present work, 150 species of gastropods belonging to 51 genera and of 16 families have been ascertained to occur in India.

Table 1. A complete checklist of freshwater Mollusca with Nomenclature update

Sl. No.	Species with new classification	References effecting nomenclature
	Class GASTROPODA Order CYCLONERITIMORPHA Family NERITIDAE	
01	*Neritina pulligera* (Llinnaeus, 1767)	Rosenberg (2013)
02	*Neripteron platyconcha* (Annandale and Prashad, 1919)	Eichhorst (2016)

Sl. No.	Species with new classification	References effecting nomenclature
03	*Neripteron violaceum* (Gmelin, 1791)	Bouchet, (2016)
04	*Neripteron auriculatum* (Lamarck, 1816)	Eichhorst (2016)
05	*Neritina perottetiana* (Recluz, 1841)	Köhler & Rintelen (2011)
06	*Neritina smithii* W. Wood, 1828	Boominathan *et al.* (2012)
07	*Neritina turrita* (Gmelin, 1791)	Haynes (2005)
08	*Vittina variegata* (Lesson, 1831)	Bouchet (2016)
09	*Neritodryas subsulcata* (Sowerby, 1836)	Rintelen (2011)
10	*Clithon bicolor* (Recluz, 1842)	Eichhorst (2016)
11	*Clithon corona* (Linnaeus, 1758)	Eichhorst (2016)
12	*Clithon reticularis* (Sowerby, 1836)	Eichhorst (2016)
13	*Septaria lineata* (Lamarck, 1876)	Eichhorst (2016)
14	*Septeria porcellana* (Linnaeus, 1758)	Eichhorst (2016)
	Order ARCHITAENIOGLOSSA Family VIVIPARIDAE	
15	*Taia crassicallosa* Annandale and Rao, 1925	Tripathy & Mukhopadhyay (2014)
16	*Filopaludina bengalensis* (Lamarck, 1822)	Brandt (1974), Bouchet (2017)
17	*Bellamya crassispiralis* (Annandale, 1921)	Budha & Madhyastha (2010)
18	*Mekongia crassa* (Benson, 1836)	Budha & Daniel (2010)
19	*Idiopomadissimilis* (Mueller, 1774)	Brandt (1974), Bouchet (2015)
20	*Bellamya micron* (Annandale, 1921)	Tripathy & Mukhopadhyay (2014)
21	*Angulyagra microchaetophora* (Annandale, 1921)	Tripathy & Mukhopadhyay (2014)
22	*Angulyagra oxytropis* (Benson, 1836)	Tripathy & Mukhopadhyay (2014)
23	*Cipangopaludina lecythis* (Benson, 1836)	Lu *et al.* (2014)
	Family AMPULLARIIDAE	
24	*Pila globosa* (Swainson, 1822)	Cowie (2015)
25	*Pila scutata* var. *compacta* (Reeve, 1856)	Low *et al.* (2013)
26	*Pila theobaldi* (Hanley, 1875)	Ramakrishna and Dey, 2007, Madhyastha & Daniel (2010)
27	*Pila virens* (Lamarck, 1822)	Budha & Madhyastha(2010)
28	*Pila saxea* (Reeve, 1856)	Cowie (2015).
29	*Pomacea diffusa* Blume, 1957	Pointier (ed.)(2015)
	Family VALVATIDAE	
30	*Valvata piscinalis* (Mueller,1774)	Neubauer *et al*. (2015)
	Family LITTORINIDAE	
31	*Mainwaringia leithii* (Smith, 1876)	Reid (2010)

Sl. No.	Species with new classification	References effecting nomenclature
32	*Cremnoconchus syhadrensis* (Blanford, 1863)	Reid *et al.* (2013)
33	*Cremnoconchus canaliculatus* Blanford, 1870	Reid *et al.,* 2013
34	*Cremnoconchus conicus* (Blanford,1870)	Reid *et al.,* 2013
35	*Cremnoconchus hanumani* Reid, Aravind, Madhyastha, 2013	Reid *et al.,* 2013
36	*Cremnoconchus globulus* Reid, Aravind, Madhyastha, 2013	Reid *et al.*, 2013
37	*Cremnoconchus agumbensis* Reid, Aravind, Madhyastha, 2013	Reid *et al.*, 2013
38	*Cremnoconchus dwaraki* Reid, Aravind, Madhyastha, 2013	Reid *et al.*, 2013
39	*Cremnoconchus cingulatus* Reid, Aravind, Madhyastha, 2013	Reid *et al.*, 2013
40	*Cremnoconchus castanea* Reid, Aravind, Madhyastha, 2013	Reid *et al*., 2013
	Family HYDROBIIDAE	
41	*Indopyrgus nevilli* (Thiele, 1928)	Rintelen (2011)
42	*Bithynia tentaculata kashmirensis* (Nevill, 1884)	Gloer & Bossneck (2013)
43	*Bithynia troscheli* (Paasch, 1842) *Taxon inquirendum*	Glöer, Falniowski & Szarowska (2006)
44	*Bithynia cerameopoma* (Benson, 1830)	Bouchet (2015)
45	*Neosataria evezardi* (Blanford, 1880)	Kulkarni & Khot (2015)
46	*Bithynia pulchella* (Benson, 1836)	Bouchet (2015)
47	*Bithynia textum* Annandale, 1921	Madhyastha & Daniel (2010)
48	*Bithynia (Gabbia) orcula Frauenfeld var. producta* (Nevill,1884)	Gloer & Bossneck (2013)
49	*Bithynia stenothyroides* (Dohrn, 1857)	Bouchet (2015)
50	*Gabbia travancorica* (Benson, 1860)	Madhyastha (2011)
51	*Mysorella costigera* (Kuester,1852)	Tripathy & Mukhopadhyay (2014)
	Family POMATIOPSIDAE	
52	*Tricula gravely* Prashad,1921	Tripathy & Mukhopadhyay (2014)
53	*Tricula montana* Benson,1843	Bouchet (2013)
	Family STENOTHYRIDAE	
54	*Stenothyra blanfordiana* Nevill, 1880	Tripathy & Mukhopadhyay (2014)
55	*Stenothyra deltae* (Benson, 1836)	Tripathy & Mukhopadhyay (2014)
56	*Stenothyra foveolata* Benson,1856	Tripathy & Mukhopadhyay (2014)
57	*Stenothyra hungerfordiana* Nevill,1880	Tripathy & Mukhopadhyay (2014)

Sl. No.	Species with new classification	References effecting nomenclature
58	*Stenothyra minima* (Sowerby,1837)	Tripathy & Mukhopadhyay (2014)
59	*Stenothyra nana* Annandale and Prashad, 1921	Tripathy & Mukhopadhyay (2014)
60	*Stenothyra ornata* Annandale and Prashad, 1921	Tripathy & Mukhopadhyay (2014)
61	*Stenothyra soluta* Annandale and Prashad, 1919	Tripathy & Mukhopadhyay (2014)
62	*Stenothyra woodmasoniana* Nevill, 1880	Tripathy & Mukhopadhyay (2014)
63	*Gangetia miliacea* (Nevill, 1880)	Marshall & Bouchet (2016)
	Family IRAVADIIDAE	
64	*Iravadia annandalei* Preston, 1916	Tripathy & Mukhopadhyay (2014)
65	*Iravadia ennurensis* Preston, 1916	Tripathy & Mukhopadhyay (2014)
66	*Iravadia funerea* Preston, 1916	Tripathy & Mukhopadhyay (2014)
67	*Iravadia princeps* Preston, 1915	Tripathy & Mukhopadhyay (2014)
	Family ASSIMINEIDAE	
68	*Assiminea francessi* (Wood, 1828)	Madhyastha & Daniel (2012)
	Family THIARIDAE	
69	*Thiara amarula* (Linnaeus,1758)	Bouchet, P. (2015)
70	*Thiara rudis* (Lea,1850)	Tripathy & Mukhopadhyay (2014)
71	*Thiara scabra* (Mueller, 1774)	Glöer & Pešić(2012)
72	*Sermyla riqueti* (Grateloup,1840)	Glaubrecht, *et al*. (2009).
73	*Melanoides crebra* Lea, 1850	Tripathy & Mukhopadhyay (2014)
74	*Melanoides nevillei* (Brot, 1874)	Tripathy & Mukhopadhyay (2014)
75	*Melanoides nicobarica* (Moerch, 1859)	Tripathy & Mukhopadhyay (2014)
76	*Melanoides peddamunigalensis* Ray and Roy Chowdhury	Tripathy & Mukhopadhyay (2014)
77	*Melanoides tuberculata* (Muller, 1774)	Van Damme, & Lange, 2016.
78	*Stenomelania aspirans* (Hinds, 1874)	Glaubrecht *et al.* (2009), Glaubrecht and Podlacha (2010).
79	*Stenomelania plicaria* (Born, 1780)	Glaubrecht and Podlacha (2010).
80	*Stenomelania punctata* (Lamarck, 1822)	Glaubrecht and Podlacha (2010).
81	*Stenomelania tortulosa* (Bruguiere, 1789)	Glaubrecht and Podlacha (2010).
82	*Tarebia granifera* (Lamarck, 1822)	Pointier (ed.) (2015).
83	*Tarebia lineata* (Gray, 1828)	Tripathy & Mukhopadhyay (2014)
84	*Tarebia semigranosa* (von dem Busch, 1842)	Tripathy & Mukhopadhyay (2014)
	Family-PACHYCHILIDAE	
85	*Faunus ater* (Linnaeus,1758)	Bouchet (2015)
86	*Brotia fuscata* (Born)	Tripathy & Mukhopadhyay (2014)

Sl. No.	Species with new classification	References effecting nomenclature
87	*Brotia costula* (Rafinesque, 1833)	Bouchet (2015)
88	*Paracrostoma huegelii* (Philippi, 1841)	Kohler and Glaubrecht (2007)
89	*Paracrostoma martini* Kohler and Glaubrecht (2007)	Kohler and Glaubrecht (2007)
90	*Paracrostoma tigrina* Kohler and Glaubrecht (2007)	Kohler and Glaubrecht (2007)
	Family- PALUDOMIDAE	
91	*Paludomus annandalei* Preston, 1909	Tripathy & Mukhopadhyay (2014)
92	*Paludomus blanfordiana* Nevill, 1877	Tripathy & Mukhopadhyay (2014)
93	*Paludomus conica* (Gray, 1834) var. *kopilensis* Nevill	Tripathy & Mukhopadhyay (2014)
94	*Paludomus inflatus* Brot, 1880	Tripathy & Mukhopadhyay (2014)
95	*Paludomus obesus* (Philippi, 1842)	Tripathy & Mukhopadhyay (2014)
96	*Paludomus ornatus* Benson, 1856	Tripathy & Mukhopadhyay (2014)
97	*Paludomus pustulosa* Annandale, 1925	Tripathy & Mukhopadhyay (2014)
98	*Paludomus regulata* Benson, 1856	Tripathy & Mukhopadhyay (2014)
99	*Paludomus reticulata* Blanford, 1870	Tripathy & Mukhopadhyay (2014)
100	*Paludomus rotunda* Blanford, 1870	Tripathy & Mukhopadhyay (2014)
101	*Paludomus stephanus* (Benson, 1836)	Tripathy & Mukhopadhyay (2014)
102	*Paludomus transchauricus* (Gmelin)	Tripathy & Mukhopadhyay (2014)
103	*Paludomus sulcatus* Reeve, 1847	Tripathy & Mukhopadhyay (2014)
104	*Paludomus stomatodon* Benson, 1862	Tripathy & Mukhopadhyay (2014)
105	*Paludomus loricatus* Reeve, 1847	Tripathy & Mukhopadhyay (2014)
106	*Paludomus neritoides* Reeve, 1847	Tripathy & Mukhopadhyay (2014)
	Order HYGROPHILA Family LYMNAEIDAE	Tripathy & Mukhopadhyay (2014)
107	*Lymnaea stagnalis* (Linnaeus, 1758)	Tripathy & Mukhopadhyay (2014)
108	*Radix acuminata* (Lamarck, 1822)	Tripathy & Mukhopadhyay (2014)
109	*Radix biacuminata* (Annandale and Rao, 1925)	Tripathy & Mukhopadhyay (2014)
110	*Lymnaea horae* Annandale and Rao, 1925	Tripathy & Mukhopadhyay (2014)
111	*Lymnaea kashmirensis* Prashad,1925	Tripathy & Mukhopadhyay (2014)
112	*Radix luteola* (Lamarck, 1822)	Tripathy & Mukhopadhyay (2014)
113	*Radix ovalior* (Annandale and Prashad, 1921)	Tripathy & Mukhopadhyay (2014)
114	*Lymnaea andersoniana* (Nevill,1881)	Tripathy & Mukhopadhyay (2014)
115	*Orientogalba hookeri* (Reeve, 1850)	Tripathy & Mukhopadhyay (2014)
116	*Galba truncatula* (Mueller, 1774)	Tripathy & Mukhopadhyay (2014)
117	*Radix auricularia* (Linnaeus, 1758)	Tripathy & Mukhopadhyay (2014)

Sl. No.	Species with new classification	References effecting nomenclature
118	*Radix brevicauda* (Sowerby, 1873)	Tripathy & Mukhopadhyay (2014)
119	*Radix lagotis* (Schrank, 1803)	Tripathy & Mukhopadhyay (2014)
120	*Radix persica* (Issel, 1865)	Tripathy & Mukhopadhyay (2014)
121	*Stagnicola tungabhadraensis* Ray, 1967	Tripathy & Mukhopadhyay (2014)
	Family PHYSIDAE	
122	*Physa acuta* Draparnaud, 1805	Tripathy & Mukhopadhyay (2014)
	Family PLANORBIDAE	Tripathy & Mukhopadhyay (2014)
123	*Planorbis planorbis tangitarensis* Germain, 1918	Tripathy & Mukhopadhyay (2014)
124	*Planorbis rotundatus* Poiret, 1801	Tripathy & Mukhopadhyay (2014)
125	*Gyraulus barrackporensis* (Clessin, 1886)	Tripathy & Mukhopadhyay (2014)
126	*Gyraulus convexiusculus* (Hutton, 1849)	Tripathy & Mukhopadhyay (2014)
127	*Gyraulus euphraticus* (Mousson, 1874)	Tripathy & Mukhopadhyay (2014)
128	*Gyraulus labiatus* (Benson, 1850)	Tripathy & Mukhopadhyay (2014)
129	*Gyraulus ladacensis* Nevill,1878	Tripathy & Mukhopadhyay (2014)
130	*Gyraulus pankongensis* (von Martens, 1882)	Tripathy & Mukhopadhyay (2014)
131	*Gyraulus rotula* (Benson, 1850)	Tripathy & Mukhopadhyay (2014)
132	*Gyraulus saltensis* Germain,1922	Tripathy & Mukhopadhyay (2014)
133	*Gyraulus kosiensis* Glöer P. & Bössneck U. 2013	Tripathy & Mukhopadhyay (2014)
	Tribe Camptocerateae	Tripathy & Mukhopadhyay (2014)
134	*Camptoceras lineatum* Blanford, 1871	Tripathy & Mukhopadhyay (2014)
135	*Camptoceras subspinosum* Annandale and Prashad, 1920	Tripathy & Mukhopadhyay (2014)
136	*Camptoceras terebra* Benson,1843	Tripathy & Mukhopadhyay (2014)
	Tribe Segmentinineae	Tripathy & Mukhopadhyay (2014)
137	*Segmentina calatha* (Benson,1850)	Tripathy & Mukhopadhyay (2014)
138	*Segmentina taia* Annandale and Rao, 1925	Tripathy & Mukhopadhyay (2014)
139	*Segmentina trochoidea* (Benson, 1836)	Tripathy & Mukhopadhyay (2014)
140	*Hippeutis complanatus* (Linnaeus, 1758)	Tripathy & Mukhopadhyay (2014)
141	Intha *umbilicalis* (Benson,1836)	Tripathy & Mukhopadhyay (2014)
	Family PLANORBIDAE Subfamily BULLININAE	Tripathy & Mukhopadhyay (2014)
142	*Indoplanorbis exustus* (Deshayes, 1834)	Tripathy & Mukhopadhyay (2014)
	Subfamily BULLININAE	Tripathy & Mukhopadhyay (2014)
143	*Planorbella scalaris* Jay, 1839	Tripathy & Mukhopadhyay (2014)
144	*Planorbella duryi* (Wetherby, 1879)	Tripathy & Mukhopadhyay (2014)

Sl. No.	Species with new classification	References effecting nomenclature
	Family PLANORBIDAE Subfamily FERRISSINAE	Tripathy & Mukhopadhyay (2014)
145	Ferriss*ia baconi* (Bourguignat, 1853)	Tripathy & Mukhopadhyay (2014)
146	*Ferrissia ceylanica* (Benson, 1864)	Tripathy & Mukhopadhyay (2014)
147	*Ferrissia tenuis* (Bourguignat, 1862)	Tripathy & Mukhopadhyay (2014)
148	*Ferrissia verruca* (Benson, 1855)	Tripathy & Mukhopadhyay (2014)
149	*Ferrissia viola* Annandale and Prashad, 1923	Tripathy & Mukhopadhyay (2014)
150	*Ferrissia fivefallsiensis* Sankarappan, Chellapandian, Vimalanathan, Mani, Sundaram & Muthukalingan 2015	Sankarappan *et al.,* 2015
	Class BIVALVIA Subclass PTERIOMORPHIA Order ARCOIDA Superfamily ARCOIDEA Family ARCIDAE	
151	*Scaphula celox* Benson, 1836	Graf & Cummings (2015)
152	*Scaphula deltae* Blanford, 1867	Huber (2010), Graf & Cummings (2015)
153	*Scaphula nagarjunai* Janaki Ram and Radhakrishna, 1984	Graf & Cummings (2015)
	Subclass PALEOHETERODONTA Order UNIONOIDA Superfamily UNIONOIDEA Family UNIONIDAE Subfamily UNIONINAE	
154	*Arcidopsis footei* (Theobald, 1876)	Tripathy & Mukhopadhyay (2014)
155	*Physunio velaris* (Sowerby, 1868)	Graf & Cummings (2015)
156	*Scabies crispata* (Gould, 1843)	Graf & Cummings (2015)
157	*Solenaia soleniformis* (Benson, 1836)	Graf & Cummings (2015)
	Subfamily AMBLEMINAE (Quadrulinae) Tribe Amblemini	Graf & Cummings (2015)
158	*Lamellidens consobrinus* (Lea, 1859)	Graf & Cummings (2015)
159	*Lamellidens corrianus* (Lea, 1834)	Graf & Cummings (2015)
160	*Lamellidens generosus* (Gould, 1847)	Graf & Cummings (2015)
161	*Lamellidens jenkinsianus* (Benson, 1862) sub sp. *daccaensis* (Preston, 1912) sub.sp. *obesa* (Hanley and Theobald, 1877)	Graf & Cummings (2015)
162	*Lamellidens marginalis* (Lamarck, 1819)	Graf & Cummings (2015)

Sl. No.	Species with new classification	References effecting nomenclature
163	*Lamellidens phenchooganjensis* Preston, 1912	Graf & Cummings (2015)
164	*Parreysia annandalei* Preston, 1912	Graf & Cummings (2015)
165	*Parreysia burmanus* (Blanford, 1869)	Graf & Cummings (2015)
166	*Parreysia corbis* (Benson, 1856)	Graf & Cummings (2015)
167	*Parreysia corrugata* (Mueller, 1774)	Graf & Cummings (2015)
168	*Parreysia favidens* (Benson, 1862)	Graf & Cummings (2015)
169	*Parreysia gowhattensis* (Theobald, 1873)	Graf & Cummings (2015)
170	*Parreysia rajahensis* (Lea, 1841)	Graf & Cummings (2015)
171	*Parreysia sikkimensis* (Lea, 1859)	Graf & Cummings (2015)
172	*Parreysia smaragdites* (Benson, 1862)	Graf & Cummings (2015)
173	*Parreysia triembolus* (Benson, 1855)	Graf & Cummings (2015)
174	*Radiatula andersoniana* (Nevill, 1877)	Graf & Cummings (2015)
175	*Radiatula bonneaudi* (Eydoux, 1838)	Graf & Cummings (2015)
176	*Radiatula caerulea* (Lea, 1831)	Graf & Cummings (2015)
177	*Radiatula cylindrica* Annandale and Prashad, 1919	Graf & Cummings (2015)
178	*Radiatula involuta* (Benson, 1856)	Graf & Cummings(2015)
179	*Radiatula khadakvaslaensis* (Ray, 1966)	Graf & Cummings (2015)
180	*Radiatula lima* (Simpson, 1900)	Graf & Cummings (2015)
181	*Radiatula nuttalliana* (Lea, 1856)	Graf & Cummings (2015)
182	*Radiatula occata* (Lea, 1860)	Graf & Cummings (2015)
183	*Radiatula olivaria* (Lea, 1831)	Graf & Cummings (2015)
184	*Radiatula pachysoma* (Benson, 1862)	Graf & Cummings (2015)
185	*Radiatula shurtleffiana* (Lea, 1856)	Graf & Cummings (2015)
186	*Radiatula theobaldi* (Preston, 1912)	Graf & Cummings (2015)
187	*Lamellidens exolescens* (Gould, 1843)	Konopleva *et al.*, (2016)
	Superfamily MUTELOIDEA Family ETHERIIDAE	
188	*Pseudomulleria dalyi* (E.A. Smith)	Bogan (2010), Graf & Cummings (2015)
	Subclass HETERODONTA Super order IMPERIDENTIA Superfamily MACTRODEA Family SOLINIDAE	
189	*Neosolen aquaedulcioris* Ghosh, 1920	Huber (2010)
	Super order IMPERIDENTIA Superfamily MACTRODEA Family MACTRIDAE	
190	*Tanysiphon rivalis* Benson, 1858	Huber, (2010), Rosenberg (2015)

Sl. No.	Species with new classification	References effecting nomenclature
	Superfamily SOLENOIDEA Family PHARIDAE Subfamily NOVACULININAE	
191	*Novaculina gangetica* Benson, 1830	Rosenberg, (2015), Graf & Cumming (2015)
192	*Novaculina andamanensis* Preston,1910	Bogan (2010),Graf & Cummings (2015)
	Superfamily CORBICULOIDEA Family CYRENIDAE	
193	*Corbicula annandalei* Prashad, 1928	Graf & Cummings (2015)
194	*Corbicula assamensis* Prashad, 1928	Graf & Cummings (2015)
195	*Corbicula bensoni* Deshayes, 1854	Graf & Cummings (2015)
196	*Corbicula cashmiriensis* Deshayes, 1854	Graf & Cummings (2015)
197	*Corbicula krishnaea* Ray, 1967	Graf & Cummings (2015)
198	*Corbicula peninsularis* Prashad, 1928	Madhyastha (2014)
199	*Corbicula striatella* Deshayes, 1854	Graf & Cummings (2015)
200	*Batissa inflata* Prime, 1860	Rosenberg (2015)
201	*Batissa similis* Prime, 1859	Rosenberg (2015)
202	*Batissa violacea* Prime, 1859	Rosenberg (2015)
203	*Geloina bengalensis* (Lamarck)	Do, Budha & Daniel (2012)
204	*Geloina erosa* (Solander, 1786)	Bouchet (2014), He & Zhuang. 2013
205	*Villorita cornucopia* Prashad, 1921	OBIS (2012), Bogan (2010), Graf & Cummings (2015)
206	*Villorita corbiculoides* Prashad, 1927	Graf & Cummings (2015)
207	*Villorita cyprinoides* (Gray, 1925)	Madhyastha, 2011
	Family PISIDIIDAE (Sphaeriidae)	
208	*Pisidium casertanum* (Poli, 1791)	Clewing *et al.* (2013), Graf & Cumming (2015)
209	*Pisidium clarkeanum* G. and H. Nevill, 1871	Bolotov *et al.* (2015), Bogan (2010), Graf & Cummings (2015)
210	*Pisidium ellisi* Dance, 1967	Bogan (2010), Graf & Cummings (2015)
211	*Pisidium nevillianum* Theobald, 1876	Bogan (2010), Clewing *et al.* (2013:250), Bolotov *et al.* (2015), Graf & Cummings (2015)
212	*Pisidium mitchelli* Prashad, 1925	Bogan (2010), Graf& Cummings(2015)
213	*Pisidium atkinsonianum* Theobald, 1876.	Clewing *et al.* (2013:250), Bogan (2010), Graf & Cummings (2015)

Sl. No.	Species with new classification	References effecting nomenclature
214	*Pisidium kuiperi* Dance, 1967.	Clewing *et al.* (2013:250), Bogan (2010), Graf & Cummings (2015)
215	*Sphaerium austeni* Prashad, 1921	Bogan (2010), Graf & Cummings (2015)
216	*Sphaerium indicum* Deshayes, 1854	Bogan (2010), Graf & Cummings (2015)
217	*Sphaerium kashmirensis* Prashad, 1937	Bogan (2010), Graf & Cummings (2015)

Status of freshwater Molluscs in India:

Tripathy and Mukhopadhyay (2014) have documented 208 species of freshwater molluscs from India. In the presently updated work, nine species of mollusca have been added making the total documentation of 217 species of freshwater mollusca known from India. In India, the distribution of some of the freshwater Molluscs show discontinuous range. Some the species of gastropods *viz. Angulyagra oxytropis, A. microchaetophora, Filopaludina bengalensis f. balteata, Pila theobaldi, Lymnaea ovalior, L. horae,Paludomus oricatus, P.stephanus, P. reticulata, P. pustulosa, P. ornatus, P. conica v. kopiliensis ,Taia crassicallosa, Bithynia textum, Pila theobaldi,* and *Corbicula assamensis*, *Parreysia theobaldi*, *P. burmanus*, *P. nuttalliana*, *P. involuta, P. smaragdites, P. gowhattensis, P. corbis, Lamellideus exolescens, Sphaerium austeni, S. kuiperi, Camptoceras lineatum, Solenaia soleniformis, Scabis crispata,Physania velaris, Lamellidens jenkinsianus* subspecies *obesa, L. phenchooganjensis,* and *Ferrissia viola* are the bivalves which are exclusively distributed in the North eastern region of India. Their restricted distribution makes them vulnerable, threat prone and very rare.

Species *viz. Bithynia troscheli, Hippeutis complanatus, Gyraulus pankogensis, Planorbis rotundatus, P. tangitarensis, Radix auricularia, R. brevicauda, R. lagotis f. (form) costulata, R. lagotis f. defilippi, R. lagotis f. solidissima, R. lagotis f. striata, Galba truncatula, Bithynia tentaculata kashmirensis, Lymnaea stagnalis,Valvate piscinalis* are the gastropods and *Sphaerium mitchelli, S. kashmirensis, Pisidium casertanum* and *Corbicula cashmiriensis* are the bivalves which show restricted distribution from high altitude lakes, rivers of Jammu and Kashmir.

Some water bodies of Andaman and Nicobar Islands having fresh and estuarine waters which are the home of some isolated species and are no longer reported from the main land of India. We may call them as "exclusive Islands species". *Potamopyrgus nevilli, Tarebia semigranosa, Stenomelania punctata, S plicaria, S. aspirans, Melanoides nicobarica, M. nevilli, M. crebra, Thiara amarula, Stenothyra hangerfordiana, Neritodryas subsulcuta, Neritina variegata, N. turrita, Segmintina taia , Septaria porcellana, Theodoxus reticularis, T.bicolor* are the gastropods and *Battissa similis, Batissa violeciea* and *Batissa inflata* are the bivalves which are restricted in their distribution within Andaman and Nicobar group of Islands.

The Gangetic basin of West Bengal also shows isolated distribution of esturine and freshwater molluscs. *Novaculina gangetica, Tanysiphon rivalis*, are the bivalves and *Stenothyra woodmasoniana, S. solata, S. ornata, S. nana, S. deltae, Iravadia princeps, Assiminea francesi, Neritina smithi*, *Pila globosa, Pila incrassatula, Mainwaringia paludomoidea* are the gastropods which have restricted distribution from West Bengal only.

Some of the species *viz*. *Lymnaea brevissima*, *Paludomus obesus, P. inflatus, Physa acuta, Cremnoconchus conicus, C. carinatus, C. syhadrensis* and *Bithynia everzardi* are the gastropods and *Parreysia khadakvaslaensis* and *Parreysia cylindrical* are bivalves reported from Maharastra.

Kerala backwaters, a unique, area is also home to some restricted species such as *Paludomus neritoides, P.stomatodom, P. sulcatus, P. annandalei, Iravadia funereal, I. annandalei, Villorita cornucopia* and *V. prasadhi*, which are not reported from other parts of India. Species such as *Ferrissia tenuis* from Nilgiri Hills, *Stagnicola tugabhadraensis* from Kurnool, *Scaphula nagarjunai* from Andha Pradesh, *Faunus ater* from Goa and Andaman and Nicobar Islands, *Iravadia ennurensis* from Tamil Nadu have restricted distribution. As a whole Western Ghats, a unique biodiversity hotspot have the representation of 77 species of freshwater molluscs of which *Arcidopsis footei, Paludomus inflatus, Pila saxea, Neritina perottetiana, Neritna platyconche, N. reticulata, Paracrostoma tigrina, Paracrostoma martini, Cremnochonchus* sp. and *Psedomulleria dalyii* are some of the species which are endemic to this region. *Pseudomullaria dalyii* (Family: Etheridae), an endemic, cemented bivalve confined to a couple of rivers in the central Western Ghats, is a rare Gondwana land relict found in Western Ghats (Madhyastha, 2001). Some of the species are only known from their type localities and are represented by only a few species; further data regarding their population, biology, ecology, vulnerability and rarity are not much unknown. *Corbicula krishnaea* from Krishna river, *C. annandalei* from Kerala backwater, *Tricula graveli* from the bed of Narmada river near Hosangabad of Madhya Pradesh, (Ramkrishna *et al.,* 2007) *Bellamya micron, Filopaulodina bengalensis f. colairensis* from Kolleru lake and *Gyraulus saltensis* from Punjab are some of the examples .

An analysis of the endemism of freshwater molluscs in India reveals that 49 species are endemic to India, of which 33 are gastropods and 14 are bivalves; 02 species are endemic to Andhra Pradesh, 01 to Punjab, 07 to Assam, 03 to Manipur, 01 to Megalaya, 02 to Mizoram, 13 to West Bengal, 02 to Tamil Nadu, 06 to Maharastra, 03 to Andaman and Nicobar Islands, 05 to Kerala backwater and 04 to Jammu and Kashmir. Arvind *et al.* (2010) documented a total of 60 species of freshwater molluscs comprising 52 gastropods (12 families and 23 genera) and 25 bivalve species (five families and eight genera), of which 28 species are endemic to this region. But actually, the number is not as high as documented by the earlier authors.

Conservation Status

We present a summary which is based on the assessment of IUCN Red List Categories and Criteria (IUCN 2001). Of the 217 species of freshwater molluscs identified as being present in India, 107 species are gastropods and 59 species are bivalves; 08 of the extant species do not have sufficient data to assess their risk of threats including extinction. According to a report of IUCN, seven species

(12%) are assessed as threatened which are *Cremnochonchus syhadrensis*, *C. carrinatus, Arcidopsis footei, Pseudomulleria dalyi* are assessed as endangered and *Cremnochonchus conicus, Parreysia khadakvasiensis* and *scaphula nagarjunai* are assessed as vulnerable. However, majority (88%) are assessed as Least Concern (Arvind *et al.,* 2010).

Table 2. The number of species of freshwater molluscs under each IUCN Red List Category in the Indian Region

IUCN Red List category	Number of Species
Extinct	0
Extinct in Wild	0
Critically Endangered	0
Endangered	3
Vulnerable	3
Near Threatened	1
Least Concern	119
Data Deficient	38
Total	216

Table 3. The number of species of freshwater gastropods under each IUCN Red List Category in the Indian Region.

IUCN Red List category	Number of Species
Extinct	0
Extinct in Wild	0
Critically Endangered	0
Endangered	2
Vulnerable	1
Near Threatened	0
Least Concern	75
Data Deficient	27
Total	149

Table 4. The threatened freshwater gastropods in the Indian assessment region

Family	Species	Category
LYMNAEIDAE	*Lymnaea ovalior*	VU
LITTORINIDAE	*Cremnoconchus conicus / Cremnoconchus carinatus*	EN
LITTORINIDAE	*Cremnoconchus syhadrensis*	EN

Table 5. The number of species of freshwater bivalves under each IUCN Red List Category in the Indian Region.

IUCN Red List category	Number of Species
Extinct	0
Extinct in Wild	0
Critically Endangered	0
Endangered	1
Vulnerable	2
Near Threatened	1
Least Concern	44
Data Deficient	11
Total	67

Table 6. The threatened freshwater bivalves in the Indian assessment region.

Family	Species	Category
ARCIDAE	*Scaphula nagarjunai*	VU
UNIONIDAE	*Parreysia khadakvasiensis*	VU
ETHERIIDAE	*Pseudomulleria dalyi*	EN
PISIIDAE	*Sphaerium austeni*	NT

Table 7. State wise distribution of freshwater molluscs in India

Sl. No.	States	Families	Genera	Species	%
1	Andaman & Nicobar Islands	10	20	51	25.24
2	West Bengal	14	21	65	32.17
3	Bihar	13	19	55	27.22
4	Odisha	11	16	40	19.80
5	Andhra Pradesh	13	24	43	21.28
6	Kerala	13	23	60	29.70
7	Maharashtra	10	19	60	29.70
8	Jammu and Kashmir	8	16	35	17.32
9	Delhi	9	12	17	8.41
10	Madhya Pradesh	7	7	25	12.37
11	Jharkhand	9	8	23	11.38
12	Sikkim	5	5	9	4.45
13	Arunachal Pradesh	4	5	5 (partly Worked out)	2.4
14	Meghalaya	10	14	43	21.28

Sl. No.	States	Families	Genera	Species	%
15	Manipur	11	16	52	26
16	Nagaland	9	16	21	10.5
17	Rajasthan	6	8	13	6.4
18	Tripura	8	14	30	14.85

As vectors, freshwater molluscs are instrumental in the transmission of many diseases in livestock and human. They are the intermediate host of many trematodes, of which schistosomiasis is reckoned as a potential threat to human population. On the other hand many larval bivalves are parasitic on gills of fishes (Ramakrisha and Dey, 2007).

Table 8. Gastropod species and nematode disease hosts

Species	Diseases
Melanoides tuberculata	Paragonimiasis, Echinostomiasis, Heterophyiasis
Tarebia granifera	Paragonimiasis, Echinostomiasis
Thiara scabra	Paragonimiasis, Echinostomiasis
Brotia costula	Paragonimiasis, Echinostomiasis
Indoplanorbis exustus	Cercarial Dermatitis, Echinostomiasis, Amphistomiasis
Gyraulus convexiusculus	Echinostomiasis, Amphistomiasis
Intha umbilicalis	Fasiolopsiasis (*Fasiolopsis buski*)
Radix acuminata	Schistosomiasis (*Schistosoma spindale)*
Radix luteola	Schistosomiasis (*Schistosoma indicum)*
Bithynia pulchella	Amphistomiasis
Lymnaea auricularia	Schistosomiasis (*Orientobitahszia turkestanicum*), Amphistomiasis
Ferrisia tenuis	Schistosomiasis (*Schistosoma haematobium)*

Conservation issues

Information on population (wild stocks) sizes and levels of exploitation is too poor to determine whether or not particular species are being seriously over-exploited. Data on the life history, abundance, productivity and rates of exploitation from specific localities are required for every species involved in the shell trade. However, anecdotal evidence suggests that conservation problems are on the increase and makes it possible to predict which areas and species are most vulnerable. Depletion of mollusca population appears to be occurring on a local basis in India. Population of molluscs in accessible areas especially close to tourist centers are more vulnerable to over-collection than those in remote areas. There are several reports of over-collecting of freshwater mollusca in West Bengal in areas where collectors concentrate their efforts in order to meet tourist demand.

Most nonmarine molluscs produce numerous planktonic larvae with great dispersal capacity and these species are to a great extent able to withstand high levels of harvesting. However, in some states, collection pressure may be so heavy that even these species are under the threat of over-exploition. Species with less "opportunistic" life histories are clearly more vulnerable. There are many generalizations about organism which appear to be extinction-prone. Some of the characteristics are :

1. The "basket cases" animals and plants reroute to extinction as a result of natural causes;
2. K –selected species, that is, those with long lives and low fecundity;
3. Species which live on islands;
4. Species with long geographical ranges;
5. Species near the top of the pyramid of biomass or at the end of food chain;
6. Species with little or no power of dispersal;
7. Species with large body size;
8. Species requiring climax vegetation;
9. Species with small populations and
10. Species with specialized niches.(Kay,1986)

The listed characteristics, which emerge from a variety of studies of rare and endangered species, serve as a profile for each group of organism. Several edible and commercial species falls under the category of geographically widespread species heavily exploited throughout their range. They demonstrate how heavy demand and intensive fishing can have a considerable impact on population as a whole, even though the species themselves are not at risk of extinction. Many species of "ornamental" freshwater mollusca have a restricted geographical range and are therefore vulnerable to over-collection, particularly if they occur in shallow waters. The likelihood of populations being adversely affected is also increased if the species concerned has a natural low population density and/or low reproductive potential. Some shells have become important not simply because of their shape or beautiful colour, but because of their rarity in nature. In some cases rarity may be a genuine reflection of population densities in the wild. In other cases, a species may be rare in trade simply because the bulk of the population is inaccessible.

SUMMARY

Freshwater molluscan fauna in India is very rich and forms an important part of biodiversity, comprising about 217 described species of snails. Almost all these species are native to India, and half of them i.e. nearly 118 species are endemic. Some freshwater and land molluscs which are not truly native to India *viz*. *Physa acuta,* which is an exotic species or an invasive alien species, is also known recently from India. They have become a serious pest and cause a great damage to crops and vegetables. Recently three other exotic species *viz*. *Planorbella duryi, Planorbella scalaris* and *Pomacea diffusa* have been introduced into freshwater bodies of India. The threats from them on native species are either scarce or not adequately known,

Fig. 1

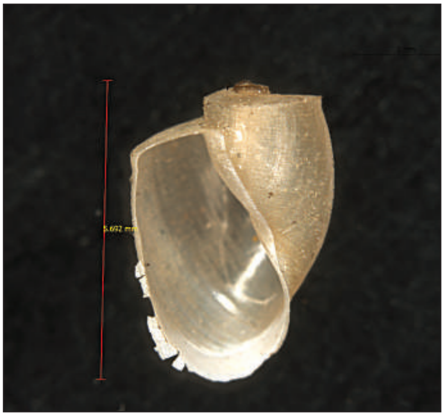

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 1-2. Dorsal and Ventral view of alien invasive species *Planorbella scalaris* (Jay, 1839)

Fig. 3-4. Dorsal and ventral view of *Physella acuta* Draparnaud; Fig. 5 Dorsal and ventral view of *Pomacea diffusa* Blume, 1957

Fig. 6. *Planorbella duryi* Top view

Fig. 7. *Planorbella duryi* Ventral view

and if they are not eradicated in time, they may alter the ecological niche of native species, eradicating them from their natural habitats.

Other ecological problems

Various activities connected with shell collecting can alter or degrade habitats. Common type of disturbance includes trampling and rock removal. Flow modification of river for construction of dam and other purposes are the threat for freshwater molluscs in India. Little attention has been paid to the consequences of selective removal of shells from the ecosystem as a whole, but problems exist. It has been observed in the exploration studies that the number of freshwater molluscs are reducing at alarming rate at polluted sites (Waghmare *et al.*2012, Verma and Saksena 2010).

Conservation measures

It is very much clear that conservation of freshwater invertebrates, including snails face particular challenges as a result of lack of awareness on the magnitude of their importance to ecosystems and human livelihoods (Dudgeon 2000a). The assessment of the impact of threats to molluscan biodiversity is further complicated by limited knowledge of freshwater mollusc fauna in the region. From the current assessment, we can anticipate a loss in biodiversity and gradual homogenization of the regional biota unless conservation action is put in place (Kholer *et al.* 2012). Reversal of these trends will require a change of focus by limnologists and water-resource managers, and also the urgent adoption of a conservation agenda in freshwater science in Asia (Dudgeon 2000a, Dudgeon *et al.,* 2006). There are several courses of action that can be taken to control trade in shells, and thus avoid over- exploitation and habitat damage. Conservation problems should not exist if the fisheries are properly managed on an ecologically sound, sustainable yield-basis. Producer countries can implement management programmes and control exports, and importing countries can control imports. The problems would also be lessened if demand for ornamental shells declined. A greater "public" awareness of the conservation issues could help in this respect.

A number of shells producing countries are now introducing legislation to control exports of shells. Exports may be controlled through a permit system, by prohibiting export of particular species or of unworked shells etc. In India twenty four species of molluscs are under Wild life Protection Act, 1972, but not any one of them from freshwater mollusca. But it is needed to include some of the endemic and isolated species of freshwater molluscs under this act to prohibit elimination of such species from nature. Legislation prohibiting the export of unworked shells is beneficial to the country concerned because it encourages the shell craft industry which is labour intensive and increases the export value of the shells. General awareness can be increased through various seminars, symposium, short documentary films, training programmes etc. to make aware the common people, college students, school children and the enforcement departmental personnel and forest managers about the conservation of molluscs and the role or significance of molluscs in the ecosystems. Power of knowledge exercised by the common people is evidently a great tool for conservation of nature and natural resources. Freshwater molluscs species *viz.*, *Batissa spp, Parreysia* spp, *Lamelliens* spp, *Corbicula* spp, *Villorita cornucopia* and *Villoritta cyprinoides* are extensively used as food and sold by low income groups for whom freshwater resources are often vital importance in sustaining livelihood and food security. For example the Andaman tribe, Zaroas often use *Batissa* spp. as a staple food in their everyday meal. Shell fishes are consumed throughout North East India. The community people with fishing villages around Vembanad Lake in Kerala are involved in the black calm fishery (*Villorita cornucopia* and *V. cyprinoides*). For most people in these villages, the black clam is their main source of income (Kripa *et al*., 2004).

Taxonomic research is central to ecological studies and conservation, but it is one of the most neglected disciplines, especially in biodiversity rich areas. Many type localities need to be resurveyed to confirm if described, range-restricted freshwater molluscs are still present or have already become extinct and to confirm the taxonomic status of the previously described species. The lack of trained malacologists and funding has greatly hampered research on freshwater molluscs. Except for a few commonly occurring species, information on ecology, population structure and dynamics, distribution, and habitat preference of a great many species are not known.

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Chapter 33

PISCES

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ABTRACT

Indian freshwater fish diversity is very rich with as many as 1027 species, comprising of primary, secondary and alien freshwater fishes. Among them, primary freshwater fishes include 858 species belonging to 167 genera under 40 families and 12 orders. Further, 137 species of secondary freshwater fishes that frequently enter and thrive in freshwater reaches of rivers are also known from India. Allien fishes that have become naturalized in Indian freshwater bodies account for 32 species, of which 16 are considered to be potentially invasive. More than 60.3% of the primary freshwater fishes of India are endemic to the country, with the highest endemicity found in Western Ghats biogeographic zone. As per the IUCN Red Data List, 17.25% among primary freshwater fishes are in threatened category, and less than 35% fishes are Least Concerned, while status of nearly 44% is not known. The present work, besides providing the checklist of freshwater fishes of India, discusses the the chalanges and threats to the freshwater fish diversity of India.

Key words: Freshwater Fish; Diversity; Endemics, Conservation.

INTRODUCTION

India is blessed with rich biodiversity of fish in its inland and marine waters. Since time immemorial, freshwater fishing has been a common avocation among people and the communities in villages and towns wherever water bodies with fish are available. Fish provides a staple diet and protein supplement of people, thus making it an important resource element in the economy of many nations. Many freshwater fish species are of immense aquaculture importance. Fish is an ideal tool for the studies in genetics, behaviour, ecology, evolution and physiology.

Fishes, in simple definition, are aquatic vertebrates that have gills throughout life and limbs, if any, in the shape of fins. Among vertebrates, "fishes" constitute an amazing group that exhibits remarkable diversity in their morphology, inhabiting habitats and biology. Fishes are a heterogeneous assemblage, yet they exhibit phylogenetic continuity, i.e., they are not a polyphyletic group (Nelson, 2006), and their evolutionary relationships suggest that the ray-finned fishes (Actinopterigii), the dominant fish group in species diversity, are more closely related to mammals than they are to the cartilaginous fishes like sharks (Nelson, 2006). In the sense of a monophyletic group, the term fish, would apply only to the actinopterygians

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(the ray-finned fishes). Whereas "fishes" in general designates an assemblage that is a paraphyletic group (wherein the most recent common ancestor is included but not all the descendants from the common ancestor), and not a monophyletic group (wherein all descendants from the common ancestor, including the most recent common ancestor, are included).

Historical resume

References to Fish as a source of food are reflected in Kautilya's *Arthasastra* as early as 300 B.C. (Hora, 1948). The Indian Emperor Ashoka prohibited consumption of fish in his kingdom during certain lunar period, as evidenced from the edicts on the second pillar of the King Ashoka, which Hora (1950) interpreted as historical evidence on fish conservation. Fish is not only a delectable delicacy on our food plate, but also a desired subject in art, craft and culture. Indian mythology has several stories on fish. Pisces, that is fish, is one of 12 zodiac signs in astrology. Fish was depicted in the Madhubani painting, a traditional form of wall art widely practiced in the Mithila region (Madhubani district of Bihar, India), a cultural region lying between the Ganges and the Terai.

The first reference to the scientific study on fishes of India may be of Carlos Linnaeus (1758), whose work on fishes included description of about 75 species from India, although many of them were erroneously tagged as from *'Habitat in India'*. M.E. Bloch also dealt with some fishes from Indian waters during 1790-1801. Russell (1803) made a pioneering work describing 200 fishes from the 'locality', Vizagapatnam, India, although his species documentation was not in binomial mode of nomenclature. Most of his illustrations were later used by several other authors to describe many species. Hamilton (1822) made a comprehensive work on '*An account of the fishes found in the River Ganges and its branches*' describing 260 species of fishes new to science of which at least 177 species are treated as being valid today. He provided apt illustrations of species with their excellent drawings which remained as 'equivalents' to the type specimens in the absence of true specimens preserved as types by him.

The freshwater fish fauna of India is highly diverse in nature. During the period of the second and third quarters of the 19th century (1830-1860), many British biogeographers as P. Bleeker; E. Blyth, J.E. Gray, T.C. Jerdon, J. McClelland, W.H. Sykes, etc., made great contributions to our knowledge on freshwater fishes of India. In the later part of the same century, the monumental treatise on fishes of the Indian region came out, namely *'The Fishes of India'* by Day (1875-78, 1888), which provided a consolidated illustration on the *'Fishes of British India'* that included 1418 species, under 342 genera, of both freshwater and marine fishes. This commendable memoir on Indian fishes still continues to be a valuable referable work for Indian ichthyologists.

In the twentieth century, several Indian ichthyologists continued to contribute to the studies on Indian fishes that had been begun by the British biogeographers in the previous century. A sustained interest for the studies on freshwater fish fauna was developed by the late Sunder Lal Hora, the former Director of the Zoological Survey of India. Hora was the first Indian pioneer in Ichthyology who throughout his life devoted to fish, and his interests were extended to a variety of fields, such as taxonomy, zoogeography, evolution, ecology and history of science, always with a connect to fish as the motif. The outstanding contributions of Hora lie in the field of fish taxonomy, almost wholly to the freshwater fishes of the Indian fauna. No student of Indian freshwater fishes of the oriental region can afford to ignore the extensive contribution of Hora in that field. Hora published a series of papers (as many as 427), describing dozens of new species, several new genera, revising many genera and some families, and proposing several new taxa (Jayaram, 1976). He was the unrivalled authority on fishes for three and half decades, publishing his first paper on fish in 1920, and reading the last paper in 1955 on the significance of *mahi-o-maratib,* a fish-insignia of the Moghul times. (While presiding over a meeting of the Asiatic Society of Bengal Calcutta, on the 5th December, 1955, in which he read the paper; he passed away on the 8th December at the age of sixty). Hora(1937) proposed the "*Satpura Hypothesis*", a zoo-geographical hypothesis, suggesting that the similarities between the Malayan fauna and the fauna of Peninsular India, without an apparent connecting link, were due to the migration from eastern regions to the western through the Satpura Range of Mountains in central India. His theory was mainly based on evidences from fishes inhabiting torrential streams of India with reference to their adaptation with special organs of attachments to hold onto rocks. However, his interpretations were later challenged and disputed as he could hardly provide any positive evidence in favour of the Satpura Hypothesis as an explanation of the discontinuity.

After Hora, several authors contributed to the knowledge on Indian freshwater fishes. K.S. Misra, another well-known Indian taxonomist on fishes, was Hora's co-worker in Zoological Survey of India. Among the leading fish taxonomists trained by Hora, A.G.K. Menon was one of the foremost Indian ichthyologists and zoogeographers of the 20th century. Menon (1950) strongly supported Dr. Hora's '*Satpura Hypothesis*' through his work on the Eastern Ghats ichthyofauna. However, later Menon reoriented the concept based on the critical analysis of the distribution of fishes in the Himalayas and fossil records of the Shivaliks. On the fish geography of the Himalayas, he surmised that the region had derived its fish fauna from the South Chinese region and this fauna had moved westwards as far as Africa. He also postulated the 'Age of the transgression of the Bay of Bengal and its significance in the evolution of the freshwater fish fauna of India' citing factors facilitating the south-westward migration of the fauna to the peninsular part. Menon's Checklist of Fishes of the Himalayas and the Indo-Gangetic Plains, explained the distribution of the torrential stream fishes along the Himalayas in terms of the palaeogeography of the region (Menon, 1974). His work on the 'Monograph of the Cyprinid fishes of the genus *Garra* Hamilton' revealed the importance of zoogeographical studies in phylogeny of widely distributed groups of animals (Menon, 1964).

Menon as an ichthyologist specialized in both marine and freshwater species has published over 100 scientific papers, including several monographs, as well as descriptions of 43 new species – ranging from the torrent-dwelling schizothoracine fish from Kumaon to a blind catfish from a deep well in Kottayam. Several fish species have been named after Menon by other ichthyologists. He published two fauna volumes on Homalopteridae and Cobitidae (Menon, 1987, 1992). In his project work on the large barbs of the west-flowing rivers of India, Dr. Menon made the discoveries of several species new to science and discussed the endemism of fish taxa and uniqueness of each west-flowing river compared to the east-flowing rivers. Menon (1999) published a comprehensive account on Indian fishes the "*Checklist of the Freshwater Fishes of India"*. Dr. Menon was the Founder President of the Indian Society of Ichthyologists.

K.C. Jayaram, trained and guided by S.L. Hora, was a contemporary of other renowned Indian Ichthyologists viz. A.G.K. Menon, E.G. Silas and P.K. Talwar. His '*Index Horana*' is a tribute to the work done by his mentor, S.L. Hora. Jayaram became an ichthyologist of both National and International repute because of his works such as the study of the taxonomy of Siluriform fishes, the zoogeography of freshwater fishes and his revisionary contributions on the freshwater fish genera viz. *Puntius, Labeo and Tor* including descriptions of new species and genera. His books on "*Freshwater Fishes of the Indian Region*" and the "*Fundamentals of Fish Taxonomy*" to those on identification of freshwater fishes are reference works for the aspiring ichthyologists and researchers. He has conducted intensive surveys of the large river systems such as Brahmaputra, Cauvery, Krishna and Mahanadi for documenting their fish fauna. His work on the Cauvery fish fauna is a comprehensive first-time account of the fish fauna of the entire river system. Several new species and genera have also been named after him. He also published the '*Catfishes of India*' in 2006 and the revised edition of the '*Freshwater Fishes of the Indian Region*' in 2010. The revised editionis a comprehensive handbook on the freshwater fish fauna of the Indian subcontinent, covering India, Pakistan, Bangladesh, Burma and Sri Lanka, providing information of all the known species classified according to the latest system, with their known range of geographical distribution, included with a key for their identification to meet the requirements of several Ichthyologists, naturalists, fishery workers, and environment scientists, interested in the fish fauna of India and the adjacent countries.

Talwar (1991) enumerated the Indian fish taxa of 2546 species, belonging to 969 genera and 254 families in 39 orders, occurring in the marine and inland waters of India. Talwar and Jhingran (1991), in their work on '*Inland Fishes of India and adjacent countries*', have included 930 species placed in 236 genera and 99 families. Dr. Jayaram published in 1999 the first edition of the Freshwater fishes of the Indian region. Kapoor *et al.* (2002) in their work on '*Fish biodiversity of India*' provided the information on 2118 species belonging to 209 families in 36 orders.

The turn of the 20th century, the period of nearly two decades, has been notable with much interest generated among fish biologists in the studies on fishes of the Indian region. Many ichthyological surveys were conducted in the little-explored areas of the country, especially in North-east India, Assam, and other biodiversity-rich regions by many ichthyologists, including notable foreign ichthyologists, namely, Eric Ahlander; R. Britz; D.R. Edds; Fang Fang; Carl Ferraris Jr., Maurice Kottelat; Musikasinthorn; Rohan Pethyagoda; Swen

Kullander; Heok Hee Ng; Walter Raiboth, Tyson Roberts, Stefan van der Voortand many others. The National Bureau of Fish Genetic Resources (NBFGR), Lucknow, initiated germplasm inventory and prepared a database of freshwater fishes. ZSI compiled fauna of several states (State Fauna Series), wildlife sanctuaries, National Parks etc and published checklists and several papers on fishes by many fish researchers, such as Arun Kumar, Yazdani, K. Rema Devi and her co-workers, R.P. Barman, A.K. Karmakar, K.C. Gopi, L. Kosygin etc. The Zoo Outreach Organization, Coimbatore, conducted camp workshops to assess the threatened categories and endangered status of several freshwater fishes and published the findings (Molur and Walker, 1998), and as well published several new discoveries and taxonomic accounts of fishes. Notable contribution to the taxonomic knowledge on Indian fishes came from the ichthyologists affiliated to universities and other research institutions as Arunachalam and his students; E.G. Silas; Gopalakrishnan; Madhusoodhana Kurup and his students; Nebeshwar; Srikantha; Vishwanath and his students; Biju Kumar; Raju Thomas; Ajith Kumar; Dahanukar; Rajive Raghavan; Anuradha; Shaji; Manimekhalan; Subbash Babu; Knight and several others contributed many papers on the taxonomy of Indian freshwater fishes. The Journal *Zootaxa* published many descriptions of freshwater fishes new to science by various ichthyologists, as cited above, from India. The journal also published the Checklist of Siluriform fishes known from the world by Carl Ferrarris Jr. (2007), which became the latest reference manual for the entire Siluriformes, including a large number of Indian taxa. During the last 20 years, much information on fishes from the Indian region has been generated and added to the literature of Indian fishes. Several changes have occurred in Siluriformes, especially in the families Siluridae and Sisoridae, and in Cypriniformes, notably in families Cyprinidae (with new generic taxa), and Balitoridae (with a family status for Nemacheilian loaches).

During the last 25 years, Zoological Survey of India, based on its survey collections and review of scattered literature, published *State Fauna Series* on the freshwater fishes of the stateslike Andhra Pradesh (including Telengana) (Barman, 1993); Arunachal Pradesh (Bagra *et al*., 2009); Assam (Sen, 1985); Delhi (Husain, 1997); Goa (Yadav, 2008); Himachal Pradesh (Mehta & Uniyal, 2005); Karnataka (Rema Devi *et al*., 2013); Madhya Pradesh (including Chhattisgarh) (Sharma, 2007); Maharashtra (Karmakar *et al*., 2012); Manipur (Karmakar & Das, 2005); Meghalaya (Sen, 1995); Mizoram (Karmakar & Das, 2007); Nagaland (Karmakar & Das, 2006); Odisha (Dutta *et al*., 1993); Puducherry (Remadevi 2015); Sikkim (Karmakar, 2006); Tamil Nadu (Remadevi *et al.,* 2000); Tripura (Barman, 2002); Uttarakhand (Uniyal, 2010); and West Bengal (Barman, 2007). There are several new records and new species described from India during the last two decades.

Classification and Systematics

Numerous classifications of fishes have been proposed throughout the world by the past biologists, such as P. Artedi, J. Müller, L. Agassiz, M.E. Bloch, G. Cuvier, A. Valenciennes, P. Bleeker, T.N. Gill, B.A. Boulenger, A. Günther, D.S. Jordan, C.T. Regan, S. Tanaka, K. Matsubara, G.S. Myers, C.L. Hubbs, and D.E. Rosen. Their contributions have made the classification of fishes much easier, and the present-day classifications are improvements over the past ones. Nelson (2006) presented a cladistic classification making use of reasonably sound phylogenetic information, based on morphological and, or, molecular data, available on fishes. He preferred the biological species concept and regarded the species as the only taxonomic unit with evolutionary reality, and accordingly dealt his classifications based on postulated genealogical branching points (the cladistic methodology), considering degrees of divergence. Where the evidence seemed uncertain, he maintained the already existing method. This chapter follows Nelson's classification, incorporated with the latest data on new families and genera of Indian fishes based on the morphological and, or, molecular works on taxa in the recent times.

Table 1. Indian Freshwater Fishes: Systematic Classification

Indian Freshwater Fishes: Systematic Classification	Genera (Nos.)	Species (Nos.)	Endemic (Nos.)
Phylum CHORDATA Subphylum CRANIATA Superclass GNATHOSTOMATA Class ACTINOPTERYGII Division TELEOSTEI Order OSTEOGLOSSIFORMES			
Family NOTOPTERIDAE	2	2	---
Order ANGUILLIFORMES			
Family ANGUILLIDAE	1	4	---
Order CLUPEIFORMES			
Family CLUPEIDAE	2	2	---
Order CYPRINIFORMES			
Family CYPRINIDAE	53	345	219
Family PSILORHYNCHIDAE	1	17	10
Family COBITIDAE	8	28	7
Family BALITORIDAE	5	16	14
Family NEMACHEILIDAE	12	113	77
Order SILURIFORMES			
Family AMBLYCIPITIDAE	1	10	08
Family AKYSIDAE	1	02	02
Family SISORIDAE	14	87	55
Family ERETHISTIDAE	4	29	19
Family KRYPTOGLANIDAE	1	1	01
Family SILURIDAE	4	13	07
Family CHACIDAE	1	1	---
Family CLARIIDAE	2	6	05

Indian Freshwater Fishes: Systematic Classification	Genera (Nos.)	Species (Nos.)	Endemic (Nos.)
Family HETEROPNEUSTIDAE	1	2	01
Family AILIIDAE	6	13	05
Family HORABAGRIDAE	3	5	04
Family PANGASIIDAE	1	1	---
Family BAGRIDAE	8	50	29
Order MUGILIFORMES			
Family MUGILIDAE	2	2	---
Order BELONIFORMES			
Family ADRIANICHTHYIDAE	1	4	01
Family BELONIDAE*	1	1	---
Order CYPRINODONTIFORMES			
Family APLOCHEILIDAE	1	7	3
Family CYPRINODONTIDAE	1	1	---
Order SYNGNATHIFORMES			
Family SYNGNATHIDAE	3	5	1
Order SYNBRANCHIFORMES			
Family SYNBRANCHIDAE	2	10	7
Family MASTACEMBELIDAE	2	9	4
Family CHAUDHURIIDAE	2	2	2
Order PERCIFORMES			
Family AMBASSIDAE*	2	9	5
Family NANDIDAE	1	2	1
Family PRISTOLEPIDIDAE	1	4	4
Family BADIDAE	2	19	18
Family CICHLIDAE	2	3	1
Family GOBIIDAE*	6	7	---
Family ANABANTIDAE	1	2	---
Family OSPHRONEMIDAE	3	7	1
Family CHANNIDAE	1	14	9
Order TETRAODONTIFORMES			
Family TETRAODONTIDAE*	2	3	2
Total 12 Orders 40 Families	**167**	**858**	**522**

* The genera under these 6 families exclusively found in freshwaters are included

Diversity of Indian freshwater fishes

The data on species diversity of freshwater fishes given here are the numbers of fishes of valid described species based on the latest taxonomic studies and revisions of families and genera carried out by specialists. The Web portals of Eschmeyer *et al*. (2017) and Froese and Pauly (2017) were used as guides to source the taxonomic literature and for all extant fish species available in India.

Fishes constitute more than one-half of the total number of the recognized living species of vertebrates, with more valid species of fishes than those of tetrapods. And still many groups of fishes are expanding with newly described species, with a net increase in species of fish in spite of many species being synonymised simultaneously. In the last 20 years, about 7000 fish species, including Indian fishes have been added to the world's total species of fishes, with the annual increase in the number of new species at an average of 200-500 species (Eshmeyer and Fong, 2017). In the Indian context, intensive systematic studies on fishes, often supplemented by molecular-based phylogenetic works, have prompted the revision of several taxa, especially families and genera of Cypriniformes and Siluriformes, resulting in the resurrection/ erection of new families, e.g., Nemacheilidae (Cypriniformes) and Kryptoglanidae, Horabagridae, Ailiidae (Siluriformes) (Kottelat, 2012; Britz *et al*., 2014; Jayaram, 2006; Wang *et al*., 2016), and the genera like *Dawkinsia, Haludaria, Pethia, Sahyadria* and *Ghatsa* of family Cyprinidae (Cypriniformes); and *Pachypterus* of Horabagridae and *Kryptoglanis* of Kryptoglanidae (Siluriformes), and the consequential nomenclatural changes among the respective taxa of freshwater fishes (Pethiyagoda *et al*., 2012; Raghavan *et al*., 2013; Randall and Page, 2015; Kottelat, 2013; Vincent and Thomas, 2011).

The freshwater fish families recognized from India with numbers of genera, and species in the 12 orders according to their systematic classification are given in Table-1. The number of the species is the count of the "native primary freshwater species" found only in freshwaters such as rivers, inland lakes, reservoirs, tanks and ponds,enlisted with their current nomenclature (with endemic species marked as 'E' within brackets)as provided in Table-2. These species may rarely occur in weak brackish water. Native primary freshwater fishes of India are recognized under 40 fish families of 12 orders, comprising 858 species belonging to 167 genera. This is about 2.5 percent of the total fish species (34320), and about 3.6 percent of total genera (5201) known in the world (world data, Eschmeyer and Fong, 2017, updated as on 30 March 2017). Among theIndian freshwater fishes, four families are most species-rich with 50 or more species as Cyprinidae (345 spp.), Nemacheilidae (113 spp.), Sisoridae (87 spp.), and Bagridae (50 spp.), and contain approximately 70% of the total species. Out of 40 families, 14 families, each with 10 or more species, hold the share of about 89 % of the total species of the freshwater fishes known from India. Five families have one species in one genus, of which two families, *viz*., Kryptoglanidae (endemic to India) and Chacidae, are monotypic, containing only one species. Eight families have two species, in one or two genera. Some 17 families known from India have only one genus, with a total of 76 species; the most species rich family with only one genus is the Psilorhynchidae (17 species), followed by Channidae (14 species) and Amblycipitidae (10 species). The average number of species per family is 20.

Table 2a. Native Primary Freshwater Fishes of India

Osteoglossiformes: **Notopteridae**

1. *Chitala chitala* (Hamilton 1822 NT
2. *Notopterus notopterus* (Pallas 1769) LC

Anguilliformes: **Anguillidae**

3. *Anguilla bengalensis* (Gray 1831) NT
4. *A. bicolor* McClelland 1844 NT
5. *A. marmorata* Quoy & Gaimard 1824 LC
6. *A. nebulosa* McClelland 1844 NA

Clupeiformes: **Clupeidae**

7. *Gonialosa manmina* (Hamilton 1822) LC
8. *Gudusia chapra* (Hamilton 1822) LC

Cypriniformes: **Cyprinidae**

9. *Amblypharyngodon atkinsonii* (Blyth 1860) LC
10. *A. melettinus* (Valenciennes 1844) LC
11. *A. microlepis* (Bleeker 1853) LC
12. *A. mola* (Hamilton 1822) LC
13. *Bangana almorae* (Chaudhuri 1912) (E)VU
14. *B. ariza* (Hamilton 1807) LC
15. *B. dero* (Hamilton 1822) LC
16. *B. diplostoma* (Heckel 1838) LC
17. *Barbodes bovanicus* (Day 1877) (E) CR
18. *B. carnaticus* (Jerdon 1849) (E) LC
19. *B. wynaadensis* (Day 1873) (E) CR
20. *Barilius ardens* Knight, Rai, d'Souza & Vijaykrishnan 2015 (E) NA
21. *B. arunachalensis* Nath, Dam & Anil Kumar 2010 (E) NA
22. *B. bakeri* Day 1865(E) LC
23. *B. barila* (Hamilton 1822) LC
24. *B. barna* (Hamilton 1822) LC
25. *B. bendelisis* (Hamilton 1822) LC
26. *B. canarensis* (Jerdon 1849) (E) EN
27. *B. chatricensis* Viswanath & Selim 2002 (E) VU
28. *B. dimorphicus* Tilak & Hussain 1990 (E) VU
29. *B. dogarsinghi* Hora 1921 VU
30. *B. evezardi* Day 1872(E) DD
31. *B. gatensis* (Valenciennes 1844) (E) LC
32. *B. howesi* Barman 1986 (E) NA
33. *B. lairokensis* Arunkumar & Tombi Singh 2000 (E) NT
34. *B. malabaricus* (Jerdon 1849) (E) NA
35. *B. modestus* Day, 1872 NA
36. *B. ngawa* Vishwanath & Manojkumar 2002 (E) VU
37. *B. profundus* Dishma & Vishwanath 2012 (E) NA
38. *B. radiolatus* Gunther 1868 DD
39. *B. shacra* (Hamilton 1822) LC
40. *B. tileo* (Hamilton 1822) LC
41. *B. vagra* (Hamilton 1822) LC
42. *Bengala elanga* (Hamilton 1822) LC
43. *Betadevario ramachandrani* Pramod, Fang, Rema Devi, Liao, Indra, Jameela Beevi & Kullander 2010 (E) DD
44. *Cabdio jaya* (Hamilton 1822) LC
45. *C. morar* (Hamilton 1822) LC
46. *C. ukhrulensis* (Selim & Vishwanath 2001)(E) DD
47. *Chagunius chagunio* (Hamilton 1822) LC
48. *C. nicholsi* (Myers 1924) LC
49. *Chela cachius* (Hamilton 1822) LC
50. *C. khujairokensis* Arunkumar 2000 (E) VU
51. *C. macrolepis* Knight & Rema Devi 2014 (E) NA
52. *Cirrhinus cirrhosus* (Bloch 1795)VU

53. *C. fulungee* (Sykes 1839) (E) LC
54. *C. mrigala* (Hamilton 1822) LC
55. *C. reba* (Hamilton 1822) LC
56. *Danio assamila* Kullander 2015 (E) NA
57. *D. dangila* (Hamilton 1822) LC
58. *D. jaintianensis* (Sen 2007) VU
59. *D. meghalayensis* Sen & Day 1985 (E) NA
60. *D. rerio* (Hamilton 1822) LC
61. *Danionella priapus* Britz 2009 (E) DD
62. *Dawkinsia arulius* (Jerdon, 1849) (E) EN
63. *D. assimilis* (Jerdon, 1849) (E) VU
64. *D. exclamatio* (Pethiyagoda & Kottelat 2005) (E) EN
65. *D. filamentosus* (Valenciennes 1844) (E) LC
66. *D. rohani* (Rema Devi, Indra & Knight 2010) (E) VU
67. *D. rubrotinctus* (Jerdon 1849) (E) NA
68. *D. tambraparniei* (Silas 1954) (E) EN
69. *Devario acuticephala* (Hora 1921) (E) VU
70. *D. aequipinnatus* (McClelland 1839) LC
71. *D. assamensis* (Barman 1984) (E) VU
72. *D. deruptotalea* Ramananda & Vishwanath 2014 (E) NA
73. *D. devario* (Hamilton 1822) LC
74. *D. fraseri* (Hora 1935)(E) VU
75. *D. horai* (Barman 1983) (E) EN
76. *D. malabaricus* (Jerdon 1849) LC
77. *D. manipurensis* (Barman 1987) (E) DD
78. *D. naganensis* (Chaudhuri 1912) (E) VU
79. *D. neilgherriensis* (Day 1867) (E) EN
80. *D. ostreographus* (Mcclelland 1839) (E) DD
81. *Diptychus maculatus* Steindachner 1866 NA
82. *Eechathalakenda opicephala* (Raj 1941) (E) EN
83. *Esomus barbatus* (Jerdon 1849) (E) LC
84. *E. danrica* (Hamilton 1822) LC
85. *E. malabaricus* Day 1867 (E) NA
86. *E. manipurensis* Tilak & Jain 1990 (E) NA
87. *E. thermoicos* (Valenciennes 1842) LC
88. *Garra abhoyai* Hora 1921 (E) NA
89. *G. alticaputus* Arunachalam, Nandagopal & Mayden 2013 (E) NA
90. *G. annandalei* Hora 1921 LC
91. *G. arunachalami* (Johnson & Soranam 2001) (E) NA
92. *G. arunachalensis* Nebeshwar & Vishwanath 2013(E) NA
93. *G. arupi* Nebeshwar, Vishwanath & Das 2009 (E) NA
94. *G. bicornuta* Narayan Rao, 1920 (E) NT
95. *G. birostris* Nebeshwar & Vashwanath 2013 NA
96. *G. ceylonensis* Bleeker 1863 NA
97. *G. chakpiensis* Nebeshwar & Vishwanath 2015 (E) NA
98. *G. chaudhurii* Hora 1921 (E) NA
99. *G. compressus* Kosygin & Vishwanath 1998 (E) VU
100. *G. cornigera* Shangningam & Vishwanath 2015 (E) NA
101. *G. dampaensis* Lalronunga, Lalnuntluanga & Lalramliana 2013 (E) NA
102. *G. elongata* Vishwanath & Kosygin 2000 (E) NT
103. *G. emarginata* Kurup & Radhakrishnan 2011(E) NA
104. *G. gotyla* (Gray 1830) LC

105. *G. gravelyi* (Annandale 1919) NT
106. *G. hughi* Silas 1955 (E) EN
107. *G. jenkinsonianum* Hora 1921 (E) NA
108. *G. jerdoni* (Day 1867) (E) NA
109. *G. joshuai* (Silas 1954) (E) NA
110. *G. kalakadensis* Rema Devi 1993 (E) EN
111. *G. kalpangi* Nabeswar, Bagra & Das 2012(E) NA
112. *G. kempi* Hora 1921 LC
113. *G. khawbungi* Arunachalam, Nandagopal & Mayden 2014 (E) NA
114. *G. kimini* Arunachalam, Nandagopal & Mayden 2013 (E) NA
115. *G. lamta* (Hamilton 1822) LC
116. *G. lissorhynchus* (McClelland 1842) LC
117. *G. litanensis* Vishwanath 1993 (E) VU
118. *G. magnidiscus* Tamang 2013 (E) NA
119. *G. manipurensis* Vishwanath & Sarojnalini 1988 (E) VU
120. *G. mcclellandi* (Jerdon 1849) (E) LC
121. *G. menoni* Rema Devi & Indra 1984 (E) VU
122. *G. minimus* Arunachalam, Nandagopal & Mayden 2013 (E) NA
123. *G. mlapparaensis* Kurup & Radhakrishnan 2010 (E) NA
124. *G. mullya* (Sykes 1839) LC
125. *G. naganensis* Hora 1921 (E) LC
126. *G. nambulica* Vishwanath & Joyshree 2005 (E) VU
127. *G. namyaensis* Shangningam & Vishwanath 2012 (E) NA
128. *G. nasuta* (McClelland 1838) LC
129. *G. nethravathiensis* Arunachalam & Nandagopal 2014 (E) NA
130. *G. nigricauda* Arunachalam, Nandagopal & Mayden 2013 (E) NA
131. *?G. notata* (Blyth 1860) LC
132. *G. palaniensis* (Rema Devi &Menon 1994) (E) VU
133. *G. palaruvica* Arunachalam, Raja, Nandagopal & Mayden 2013 (E) NA
134. *G. paralissorhynchus* Vishwanath & Shanta Devi 2005 (E) VU
135. *G. periyarensis* Gopi 2001 (E) VU
136. *G. platycephala* Narayan Rao 1920 (E) LC
137. *G. prashadi* Hora 1921 (E) NA
138. *G. quadratirostris* Nebeshwar & Vishwanath 2013 (E) NA
139. *G. rupecula* (McClelland 1839) (E) NT
140. *G. stenorhynchus* (Jerdon 1849) (E) LC
141. *G. surendranathanii* Shaji, Arun & Easa 1996 (E) EN
142. *G. tamangi* Gurumayum & Kosygin 2016 (E) NA
143. *G. trilobata* Shangningam & Vishwanath 2015 (E) NA
144. *G. tyao* Arunachalam, Nandagopal & Mayden 2014 (E) NA
145. *G. ukhrulensis* Nebeshwar & Vishwanath 2015 (E) NA
146. *Gibelion catla* (Hamilton 1822) LC
147. *Haludaria afasciata* (Jayaram 1990) (E) NA
148. *H. fasciata* (Jerdon 1849) (E) LC
149. *H. kannikattiensis* (Arunachalam & Johnson 2003) (E) LC
150. *H. melanampyx* (Day 1865) (E) NA
151. *Horadandia brittani* Rema Devi & Menon 1992 (E)NA
152. *Hypselobarbus basavarajai* Arunachalam, Chinnaraja & Mayden 2016 (E) NA
153. *H. bicolor* Knight, Rai, D'Souza, Philip, Dahanukar 2016 (E) NA
154. *H. canarensis* (Jerdon 1849) (E) NA
155. *H. curmuca* (Hamilton 1807) (E) EN

156. *H. dobsoni* (Day 1876) (E) DD
157. *H. dubius* (Day 1867) (E) EN
158. *H. gracilis* (Jerdon 1849) (E) NA
159. *H. jerdoni* (Day 1870) (E) LC
160. *H. keralaensis* Arunachalam, Chinnaraja & Mayden 2016 (E) NA
161. *H. kolus* (Sykes, 1839) (E) VU
162. *H. kurali* Menon & Rema Devi 1995 (E) LC
163. *H. kushavali* Arunachalam , Chinnaraja, Sivakumar & Mayden 2016 (E) NA
164. *H. lithopidos* (Day 1874) (E) DD
165. *H. menoni* Arunachalam, Chinnaraja, Chandran & Mayden 2014 (E) NA
166. *H. micropogon* (Valenciennes, 1842) (E) EN
167. *H. mussullah* (Sykes 1839) (E) EN
168. *H. nasutus* Arunachalam, Chinnaraja & Mayden 2016 (E) NA
169. *H. nilgiriensis* Arunachalam, Chinnaraja & Mayden 2016 (E) NA
170. *H. periyarensis* (Raj 1941) (E) EN
171. *H. pulchellus* (Day 1870) (E) CR
172. *H. tamiraparaniei* Arunachalam, Chinnaraja, Chandran & Mayden 2014(E) NA
173. *H. thomassi* (Day 1874) (E) CR
174. *H. vaigaiensis* Arunachalam, Chinnaraja, Chandran & Mayden 2014 (E) NA
175. *Labeo angra* (Hamilton 1822) LC
176. *L. bata* (Hamilton 1822) LC
177. *L. boga* (Hamilton 1822) LC
178. *L. boggut* (Sykes, 1839) LC
179. *L. caeruleus* Day 1877 NA
180. *L. calbasu* (Hamilton 1822 LC
181. *L. dussumieri* (Valenciennes 1842) LC
182. *L. dyocheilus* (McClelland 1839) LC
183. *L. fimbriatus* (Bloch 1795) LC
184. *L. gonius* (Hamilton 1822) LC
185. *L. kawrus* (Sykes 1839) LC
186. *L. kontius* (Jerdon 1849) (E) LC
187. *L. microphthalmus* Day 1877 LC
188. *L. nandina* (Hamilton 1822) NT
189. *L. nigrescens* Day 1870 (E) NA
190. *L. pangusia* (Hamilton 1822) NT
191. *L. porcellus* (Heckel 1844) LC
192. *L. potail* (Sykes 1839) (E)EN
193. *L. rajasthanicus* Datta & Majumdar 1970 (E) NA
194. *L. ricnorhynchus* (McClelland 1839) (E) NA
195. *L. rohita* (Hamilton 1822) LC
196. *Laubuka fasciata* (Silas 1958) (E) VU
197. *L. latens* Knight 2015 (E) NA
198. *L. laubuca* (Hamilton 1822) LC
199. *L. trevori* Knight 2015 (E) NA
200. *Lepidopygopsis typus* Raj 1941(E) EN
201. *Naziritor chelynoides* (McClelland 1839) VU
202. *Neochela dadiburjori* (Menon 1952) LC
203. *Neolissochilus dukai* (Day 1878) DD
204. *N. hexagonolepis* (McClelland, 1839) NT
205. *N. hexastichus* (McClelland 1839) NT
206. *N. spinulosus* (McClelland 1845) DD
207. *Opsarius cocsa* (Hamilton 1822) (E) DD
208. *Oreichthys andrewi* Marcus Knight 2014 (E) NA
209. *O. coorgensis* (Jayaram 1982) (E) NA
210. *O. cosuatis* (Hamilton 1822) LC
211. *O. crenuchoides* Schäfer 2009 (E) DD
212. *O. duospilus* Keith & Kumar 2015 (E) NA

213. *O. incognito* Keith & Kumar 2015 (E) NA
214. *Osteobrama alfredianus* (Valenciennes 1844) NA
215. *O. bakeri* (Day 1873) (E) LC
216. *O. belangeri* (Valenciennes 1844) NT
217. *O. cotio* (Hamilton 1822) LC
218. *O. cunma* (Day 1888) LC
219. *O. feae* Vinciguerra 1890 LC
220. *O. neilli* (Day 1873) (E) LC
221. *O. vigorsii* (Sykes 1839) (E) LC
222. *Osteochilichthys brevidorsalis* (Day 1873) (E) LC
223. *O. thomassi* (Day 1877) (E) LC
224. *Osteochilus longidorsalis* (Pethiyagoda & Kottelat 1994) (E) EN
225. *O. nashii* (Day 1869) (E) LC
226. *Parapsilorhynchus discophorus* Hora 1921 (E) VU
227. *P. elongatus* Singh 1994 (E) EN
228. *P. prateri* Hora & Misra 1938 (E) CR
229. *P. tentaculatus* (Annandale 1919) (E) LC
230. *Pethia ater* (Linthoingambi & Vishwanath 2007) (E) VU
231. *P. aurea* Marcus Knight 2013 (E) NA
232. *P. canius* (Hamilton 1822) (E) NA
233. *P. conchonius* (Hamilton 1822) LC
234. *P. expletiforis* Dishma & Vishwanath 2013 (E) NA
235. *P. gelius* (Hamilton 1822) LC
236. *P. guganio* (Hamilton 1822) LC
237. *P. khugae* (Linthoingambi & Vishwanath 2007) (E) VU
238. *P. longicauda* Katwate, Paingankar, Raghavan & Dahanukar 2014 (E) NA
239. *P. lutea* Katwate, Katwate, Raghavan, Paingankar & Dahanukar 2014 (E) NA
240. *P. manipurensis* (Menon, Rema Devi & Viswanath 2000) (E EN
241. *P. meingangbii* (Arunkumar & Tombi Singh 2003) LC
242. *P. narayani* (Hora 1937) (E) LC
243. *P. nigripinna* (Knight, Rema Devi, Indra & Arunachalam 2012) (E) NA
244. *P. ornata* (Vishwanath & Laisram 2004) VU
245. *P. phutunio* (Hamilton 1822) LC
246. *P. pookodensis* (Mercy & Jacob, 2007) (E) CR
247. *P. punctata* (Day, 1865) (E) LC
248. *P. rutila* Lalramliana, Knight & Laltlanhlua 2014 (E) NA
249. *P. sanjaymoluri* Katwate, Jadhav, Kumkar, Raghavan & Dahanukar 2016 (E) NA
250. *P. setnai* (Chhapgar & Sane 1992) (E) VU
251. *P. sharmai* (Menon & Rema Devi 1993) (E) EN
252. *P. stoliczkana* (Day 1871)LC
253. *P. striata* Atkore, Knight, Rema Devi & Krishnaswamy 2015 (E) NA
254. *P. ticto* (Hamilton 1822) LC
255. *P. yuensis* (Arunkumar & Tombi Singh 2003) (E) VU
256. *Poropuntius burtoni* (Mukerji 1933) LC
257. *P. clavatus* (McClelland 1845) NT
258. *Ptychobarbus conirostris* Steindachner 1866 NA
259. *Puntius ambassis* (Day 1869) (E) DD
260. *P. amphibious* (Valenciennes 1842) (E) DD
261. *P. arenatus* (Day 1878) (E) VU
262. *P. bimaculatus* (Bleeker 1863) LC
263. *P. cauveriensis* (Hora 1937)(E) EN
264. *P. chola* (Hamilton 1822) LC
265. *P. crescentus* Yazdani & Singh 1994 (E) EN

266. *P. deccanensis* Yazdani & Babu Rao 1976 (E) CR
267. *P. dolichopterus* Plamoottil 2015 (E) NA
268. *P. dorsalis* (Jerdon 1849) (E) LC
269. *P. euspilurus* Plamoottil 2016 (E) NA
270. *P. fraseri* (Hora & Misra, 1938) (E) EN
271. *P. khohi* Dobriyal, Singh, Uniyal, Joshi, Phurailatpam & Bisht 2004 (E) NA
272. *P. madhusoodani* Krishna Kumar, Pereira & Radhakrishnan 2012 (E) NA
273. *P. mahecola* (Valenciennes 1844) (E) DD
274. *P. melanostigma* (Day 1878) (E) NA
275. *P. mudumalaiensis* Menon & Rema Devi 1992 (E) VU
276. *P. muzaffarpurensis* Srivastava, Verma & Sharma 1977 (E) NE
277. *P. nangalensis* Jayaram 1990 (E) NA
278. *P. nelsoni* Plamoottil 2014 (E) NA
279. *P. nigronotus* Plamoottil 2014 (E) NA
280. *P. parrah* Day 1865 (E) LC
281. *P. puntio* (Hamilton 1822) NA
282. *P. sahyadriensis* Silas 1953 (E) LC
283. *P. sophore* (Hamilton 1822) LC
284. *P. sophoroides* (Günther 1868) (E) NA
285. *P. terio* (Hamilton 1822) LC
286. *P. viridis* Plamoottil & Abraham 2014 (E) NA
287. *P. vittatus* Day 1865 LC
288. *Raiamas bola* (Hamilton 1822) LC
289. *R. guttatus* (Day 1870) LC
290. *Rasbora ataenia* Plamoottil 2016 (E) NA
291. *R. caverii* (Jerdon 1849) LC
292. *R. dandia* (Valenciennes 1844) NA
293. *R. daniconius* (Hamilton 1822) LC
294. *R. hobelmani* Kottelat 1984 NA
295. *R. kobonensis* Chaudhuri 1913 (E) NA
296. *R. labiosa* Mukerji, 1935 (E) LC
297. *R. microcephalus* (Jerdon 1849) NA
298. *R. ornata* Vishwanath & Laisram 2005 (E) VU
299. *R. rasbora* (Hamilton 1822) LC
300. *Rohtee ogilbii* Sykes 1839 (E) LC
301. *Sahyadria chalakkudiensis* (Menon, Rema Devi & Thobias 1999) (E) EN
302. *S. denisonii* (Day 1865) (E) EN
303. *Salmostoma acinaces* (Valenciennes 1844) LC
304. *S. bacaila* (Hamilton 1822) LC
305. *S. balookee* (Sykes 1839) (E) LC
306. *S. belachi* (Jayaraj, Krishna Rao, Ravichandra Reddy, Shakuntala & Devaraj 1999) (E) VU
307. *S. boopis* (Day 1874) (E) LC
308. *S. horai* (Silas 1951) (E) VU
309. *S. novacula* (Valenciennes 1840) (E) LC
310. *S. orissaense* Banarescu 1968 (E) NA
311. *S. phulo* (Hamilton 1822) LC
312. *S. punjabense* (Day 1872) NA
313. *S. sardinella* (Valenciennes 1844) LC
314. *S. untrahi* (Day 1869) (E) LC
315. *Schismatorhynchos nukta* (Sykes 1839) (E) EN
316. *Schizopyge niger* (Heckel 1838) NA
317. *Schizopygopsis stolickai* Steindachner 1866 NA
318. *Schizothorax chivae* Arunkumar & Alphonsa Moyon 2016 (E) NA
319. *S. curvifrons* Heckel 1838 NA
320. *S. esocinus* Heckel 1838 NA
321. *S. huegelii* Heckel 1838 NA

322. *S. kumaonensis* Menon 1971 (E) DD
323. *S. labiatus* (McClelland 1842) NA
324. *S. microcephalus* Day 1877 (E) NA
325. *S. molesworthi* (Chaudhuri 1913) DD
326. *S. nasus* Heckel 1838 NA
327. *S. plagiostomus* Heckel 1838 NA
328. *S. progastus* (McClelland 1839) LC
329. *S. richardsonii* (Gray 1832) VU
330. *Securicula gora* (Hamilton 1822) LC
331. *Semiplotus manipurensis* Vishwanath & Kosygin 2000 DD
332. *S. modestus* Day 1870 DD
333. *S. semiplotus* (McClelland 1839) VU
334. *Systomus chryseus* Plamoottil 2014 (E) NA
335. *S. immaculatus* McClelland 1839 (E) NA
336. *S. jayarami* Vishwanath & Tombi Singh 1986 (E) NA
337. *S. laticeps* Plamoottil 2016 (E) NA
338. *S. orphoides* (Valenciennes 1842) NA
339. *S. rufus* Plamoottil 2014 (E) NA
340. *S. sarana* (Hamilton, 1822) LC
341. *S. sewelli* (Prashad & Mukerji 1929) NA
342. *Tariqilabeo burmanicus* (Hora 1936) LC
343. *T. diplochilus* (Heckel 1838) NA
344. *T. latius* (Hamilton 1822) LC
345. *T. periyarensis* (Menon & Jacob 1996) (E) EN
346. *Thynnichthys sandkhol* (Sykes 1839) (E) EN
347. *Tor barakae* Arunkumar & Basudha 2003 (E) DD
348. *T. khudree* (Sykes, 1839) EN
349. *T. kulkarnii* Menon 1992 (E) EN
350. *T. mosal* (Hamilton, 1822) (E) NA
351. *T. putitora* (Hamilton, 1822) EN
352. *T. remadeviae* Kurup & Radhakrishnan 2011(E) NA
353. *T. tor* (Hamilton 1822) NT

Cypriniformes: **Psilorhynchidae**

354. *Psilorhynchus amplicephalus* Arunachalam, Muralidharan & Sivakumar 2007(E) DD
355. *P. arunachalensis* (Nebeshwar, Bagra & Das 2007) DD
356. *P. balitora* (Hamilton 1822) LC
357. *P. breviminor* Conway & Mayden 2008 DD
358. *P. chakpiensis* Shangningam & Vishwanath 2013 (E) NA
359. *P. hamiltoni* Conway, Dittmer, Jezisek & Ng 2013 (E) NA
360. *P. homaloptera* Hora & Mukerji 1935 LC
361. *P. kaladanensis* Lalramliana, Lalnuntluanga & Lalronunga 2015 (E) NA
362. *P. khopai* Lalramliana, Solo, Lalronunga & Lalnuntluanga 2014 (E) NA
363. *P. konemi* Shangningam & Vishwanath 2016 (E) NA
364. *P. maculatus* Shangningam & Vishwanath 2013 (E) NA
365. *P. microphthalmus* Vishwanath & Manojkumar 1995 (E) EN
366. *P. ngathanu* Shangningam & Vishwanath 2013 (E) NA
367. *P. nudithoracicus* Tilak & Husain 1980 NA
368. *P. rowleyi* Hora & Misra 1941 NA
369. *P. sucatio* (Hamilton 1822) LC
370. *P. tenura* Arunachalam & Muralidharan 2008 (E) CR

Cypriniformes: **Cobitidae**

371. *Acantopsis dialuzona van* Hasselt 1823 LC
372. *A. spectabilis* (Blyth 1860) DD
373. *Botia almorhae* Gray, 1831 LC
374. *B. birdi* Chaudhuri 1909 NA

375. *B. dario* (Hamilton 1822) LC
376. *B. histrionica* Blyth 1860 LC
377. *B. lohachata* Chaudhuri 1912 NA
378. *B. rostrata* Günther 1868 VU
379. *B. striata* Narayan Rao 1920 (E) EN
380. *Canthophrys gongota* (Hamilton 1822) LC
381. *Lepidocephalichthys annandalei* Chaudhuri 1912 LC
382. *L. arunachalensis* (Datta & Barman 1984) (E) EN
383. *L. berdmorei* (Blyth 1860) LC
384. *L.coromandelensis* (Menon 1992) (E) LC
385. *L. goalparensis* (Pillai & Yazdani 1976) LC
386. *L. guntea* (Hamilton 1822) LC
387. *L. irrorata* Hora 1921 LC
388. *L. longipinnis* (Menon 1992) (E) NA
389. *L. micropogon* (Blyth 1860) LC
390. *L. thermalis* (Valenciennes 1846) LC
391. *Misgurnus anguillicaudatus* (Cantor 1842) LC
392. *Neoeucirrhichthys maydelli* Banarescu & Nalbant 1968 LC
393. *Pangio ammophila* Britz, Ali & Raghaban 2012 (E) NA
394. *P. apoda* Britz & Maclaine 2007 (E) DD
395. *P. goaensis* (Tilak 1972) (E) LC
396. *P. oblonga* (Valenciennes 1846) NA
397. *P. pangia* (Hamilton 1822) LC
398. *Syncrossus berdmorei* Blyth 1860 NT

Cypriniformes: **Balitoridae**

399. *Balitora brucei* Gray, 1830 NT
400. *B. chipkali* Kumar, Katwate, Raghavan & Dahanukar 2016 (E) NA
401. *B. jalpalli* Raghavan, Tharian, Ali, Jadhav & Dahanukar 2013 (E) NA
402. *B. laticauda* Bhoite, Yadhav & Dahanukar 2012 (E) NA
403. *B. mysorensis* Hora 1941 (E) VU
404. *Bhavania arunachalensis* Nath, Dam, Bhutia, Dey & Das 2007 (E) NA
405. *B. australis* (Jerdon 1849) (E) LC
406. *Ghatsa menoni* (Shaji & Easa 1995) (E) LC
407. *G. montana* (Herre 1945) (E) EN
408. *G. pillaii* (Indra & Rema Devi 1981) (E) LC
409. *G. santhamparaiensis* (Arunachalam, Johnson & Rema Devi 2002) (E) EN
410. *G. silasi* (Madhusoodana Kurup & Radhakrishnan 2011) (E) NA
411. *Homalopteroides manipurensis* (Arunkumar 1999) (E) LC
412. *?H. modestus* (Vinciguerra 1890) DD
413. *Travancoria elongata* Pethiyagoda & Kottelat, 1994 (E) EN
414. *T. jonesi* Hora 1941 (E) EN

Cypriniformes: **Nemacheilidae**

415. *Aborichthys cataracta* Arunachalam, Raja, Malaiammal & Mayden 2014 (E) NA
416. *A. boutanensis* (McClelland, 1842) NA
417. *A. elongatus* Hora 1921 (E) LC
418. *A. garoensis* Hora 1925 (E) VU
419. *A. tikaderi* Barman 1985 (E) VU
420. *A. verticauda* Arunachalam, Raja, Malaiammal & Mayden 2014 (E) NA
421. *A. waikhomi* Kosygin 2012 (E) NA
422. *Acanthocobitis pavonacea* (McClelland 1839) (E) VU
423. *Indoreonectes evezardi* (Day 1872) (E) LC
424. *I. keralensis* (Rita & Nalbant 1978) (E) VU
425. *Mesonoemacheilus guentheri* (Day 1867) (E) LC

426. *M. herrei* Nalbant & Banarescu 1982 (E) CR
427. *M. menoni* (Zacharias & Minimol 1999) (E) VU
428. *M. pambarensis* (Rema Devi & Indra 1994) (E) VU
429. *M. periyarensis* (Madhusoodana Kurup & Radhakrishnan 2005) (E) VU
430. *M. petrubanarescui* (Menon 1984) (E) EN
431. *M. pulchellus* (Day 1873) (E) EN
432. *M. remadeviae* Shaji 2002 (E) LC
433. *M. triangularis* (Day 1865) (E) LC
434. *Nemacheilus anguilla* Annandale 1919 (E) LC
435. *N. kaimurensis* Husain & Tilak 1998 (E) NA
436. *N. menoni* Zacharias & Minimol 1999 (E) VU
437. *N. monilis* Hora 1921 (E) LC
438. *N. stigmofasciatus* Arunachalam & Muralidharan 2009 (E) DD
439. *Nemachilichthys ruepelli* (Sykes 1839) (E) LC
440. *Neonoemacheilus assamensis* (Menon 1987) (E) NT
441. *N. labeosus* (Kottelat 1982) LC
442. *N. morehensis* Arunkumar 2000 DD
443. *N. peguensis* (Hora, 1929) NA
444. *Paracanthocobitis aurea* (Day 1872) (E) NA
445. *P. botia* (Hamilton 1822) LC
446. *P. mackenziei* (Chaudhuri 1910) NA
447. *P. moreh* (Sykes 1839) (E) LC
448. *P. zonalternans* (Blyth 1860) LC
449. *Paraschistura punjabensis* (Hora 1923) NA
450. *Physoschistura chhimtuipuiensis* Lalramliana, Lalhlimpuia, Solo & Vanramliana 2016 (E) NA
451. *P. chindwinensis* Lokeswar & Vishwanath 2012 (E) NA
452. *P. elongata* Sen & Nalbant 1982 VU
453. *P. tuivaiensis* Lokeswar, Vishwanath & Shanta 2012 (E) NA
454. *P. walongensis* Tamang & Sinha 2016 (E) NA
455. *Schistura aizawlensis* Lalramiana 2012 (E) NA
456. *S. altipedunculata* (Bănărescu & Nalbant 1968) (E) NA
457. *S. andrewi* Solo, Lalramliana, Lalronunda & Lalnuntluan 2014 (E) NA
458. *S. beavani* (Günther 1868) LC
459. *S. bhimachari* (Hora 1937) (E) NA
460. *S. carletoni* (Fowler 1924) (E) NA
461. *S. chindwinica* (Tilak & Husain 1990) (E) VU
462. *S. cincticauda* (Blyth 1860) DD
463. *S. corica* (Hamilton 1822) LC
464. *S. dayi* (Hora 1935) (E) LC
465. *S. denisoni* (Day 1867) (E) LC
466. *S. devdevi* (Hora 1935) NT
467. *S. doonensis* (Tilak & Husain 1977) (E) DD
468. *S. fasciata* Lokeshwor & Vishwanath 2011 (E) DD
469. *S. ferruginea* Lokeshwor & Vishwanath 2013 (E) NA
470. *S. gangeticus* (Menon 1987) (E) NA
471. *S. himachalensis* (Menon 1987) NA
472. *S. horai* (Menon 1952) NA
473. *S. inglisi* (Hora 1935) (E) NA
474. *S. kangjupkhulensis* (Hora 1921) EN
475. *S. kangrae* (Menon 1952) (E) NA
476. *S. khugae* Vishwanath & Shanta 2004 (E) VU
477. *S. kodaguensis* (Menon 1987) (E) VU
478. *S. koladynensis* Lokeshwar & Vishwanath 2012 (E) NA
479. *S. liyaiensis* Lokeshwor & Vishwanath 2014 (E) NA

480. *S. maculosa* Lalronunga, Lalnuntluanga & Lalramliana 2013 (E) NA
481. *S. manipurensis* (Chaudhuri 1912) NT
482. *S. minuta* Vishwanath & Shanta Kumar 2006 (E) EN
483. *S. mizoramensis* Lalramliana, Lalronunga, Vanramliana & Lalthanzara 2014 (E) NA
484. *S. montana* McClelland 1838 (E) NA
485. *S. multifasciata* (Day 1878) LC
486. *S. nebeshwari* Lokeshwor & Vishwanath 2013 (E) NA
487. *S. nagaensis* (Menon 1987) (E) VU
488. *S. nagodiensis* Sreekantha, Gururaja, Remadevi, Indra & Ramachandra 2006 (E) EN
489. *S. nilgiriensis* (Menon 1987) (E) LC
490. *S. obliquofascia* Lokeshwor, Barat, Sati, Darshan, Vishwanath & Mahanta 2012 (E) NA
491. *S. papulifera* Kottelat, Harries & Proudlove 2007 (E) CR
492. *S. paucireticulata* Lokeshwor, Vishwanath & Kosygin, 2013 (E) NA
493. *S. phamhringi* Shangningam, Lokeshwor & Vishwanath 2014 (E) NA
494. *S. porocephala* Lokeshwor & Vishwanath 2013 (E) NA
495. *S. prashadi* (Hora, 1921) (E) VU
496. *S. rajasthanica* (Mathur & Yazdani 1971) (E) NA
497. *S. reticulate* Vishwanath & Nebeshwar Sharma, 2004 (E) EN
498. *S. reticulofasciata* (Singh & Banarescu 1982) (E) VU
499. *S. rosammae* (Sen 2009) (E) NA
500. *S. rupecula* McClelland 1838 LC
501. *S. savona* (Hamilton 1822) LC
502. *S. scaturigina* McClelland 1839 LC
503. *S. scyphovecteta* Lokeshwor & Vishwanath 2013 (E) NA
504. *S. semiarmata* (Day 1867) (E) LC
505. *S. sharavathiensis* Sreekantha, Gururaja, Remadevi, Indra & Ramachandra 2006 (E) VU
506. *S. shebbearei* (Hora 1935) (E) NA
507. *S. sijuensis* (Menon 1987) (E) EN
508. *S. sikmaiensis* (Hora 1921) LC
509. *S. singhi* (Menon 1987) (E) VU
510. *S. striata* (Day 1867) (E) EN
511. *S. tigrina* Vishwanath & Nebeshwar Sharma 2005 (E) EN
512. *S. tirapensis* Kottelat 1990 (E) LC
513. *S. vinciguerrae* (Hora 1935) LC
514. *S. zonata* McClelland 1839 (E) DD
515. *Hedinichthys yarkandensis* (Day 1877) NA
516. *Indotriplophysa yasinensis* (Alcock 1898) NA
517. *Triplophysa drassensis* (Tilak 1990) (E) NA
518. *T. gracilis* (Day 1877) NA
519. *T. kashmirensis* (Hora 1922) NA
520. *T. ladacensis* (Günther 1868) NA
521. *T. marmorata* (Heckel 1838) NA
522. *T. microps* (Steindachner 1866) LC
523. *T. shehensis* Menon 1987 (E) NA
524. *T. stewarti* (Hora 1922) LC
525. *T. stolickai* (Steindachner 1866) NA
526. *T. tenuicauda* (Steindachner 1866) NA
527. *T. tenuis* (Day 1877) NA

Siluriformes: **Amblycipitidae**

528. *Amblyceps accari* Dahanukar, Raghavan, Ali & Britz 2016 (E) NA
529. *A. apangi* Nath & Dey 1989 (E) LC
530. *A. arunchalensis* Nath & Dey 1989 (E) EN
531. *A. cerinum* Ng & Wright 2010 (E) NA

532. *A. laticeps* (McClelland 1842) LC
533. *A. mangois* (Hamilton 1822) LC
534. *A. tenuispinis* Blyth 1860 (E) DD
535. *A. torrentis* Linthoingambi & Viswanath 2008 (E) DD
536. *A. tuberculatum* Linthoingambi & Viswanath 2008 (E) DD
537. *A. waikhomi* Darshan, Kachari, Dutta, Ganguly & Das 2016 (E) NA

Siluriformes: **Akysidae**

538. *Akysis manipurensis* (Arunkumar 2000) (E) DD
539. *A. prashadi* Hora 1936 (E) LC

Siluriformes: **Sisoridae**

540. *Bagarius bagarius* (Hamilton 1822) NT
541. *B. yarrelli* (Sykes 1839) NT
542. *Creteuchiloglanis arunachalensis* Sinha & Tamang 2014 (E) NA
543. *C. kamengensis* (Jayaram 1966) DD
544. *C. payjab* Darshan, Dutta, Kachari, Gogoi, Aran & Das 2014 (E) NA
545. *Exostoma barakensis* Vishwanath & Joyshree 2007 (E) DD
546. *E. labiatum* (McClelland 1842) LC
547. *E. sawmteai* Lalramliana, Lalronunga, Lalnuntluanga & Ng 2015 (E) NA
548. *E. stuarti* (Hora 1923) DD
549. *E. tenuicaudata* Tamang, Sinha & Gurumayum 2015 (E) NA
550. *E. vinciguerrae* Regan 1905 DD
551. *Gagata cenia* (Hamilton 1822) LC
552. *G. dolichonema* He 1996 LC
553. *G. gagata* (Hamilton 1822) LC
554. *G. itchkeea* (Sykes 1839) (E) VU
555. *G. sexualis* Tilak 1970 LC
556. *Glaridoglanis andersonii* (Day 1870) DD
557. *Glyptosternon maculatum* (Regan 1905) LC
558. *G. reticulatum* McClelland 1842 NA
559. *Glyptothorax alaknandi* Tilak 1969 LC
560. *G. anamaliensis* Silas 1952 (E) VU
561. *G. annandalei* Hora 1923 (E) LC
562. *G. ater* Anganthoibi & Vishwanath 2011 (E) NA
563. *G. botius* (Hamilton 1822) (E) LC
564. *G. brevipinnis* Hora 1923 (E) DD
565. *G. caudimaculatus* Anganthoibi & Vishwanath 2011 (E) NA
566. *G. cavia* (Hamilton 1822) LC
567. *G. chimtuipuiensis* Anganthoibi & Vishwanath 2010 (E) DD
568. *G. chindwinica* Vishwanath & Linthoingambi 2007 (E) LC
569. *G. churamanii* Rameshori & Vishwanath 2012 (E) NA
570. *G. clavatus* Yumnam & Vishwanath 2014 (E) NA
571. *G. conirostris* (Steindachner 1867) DD
572. *G. davissinghi* Manimekalan & Das 1998 (E) EN
573. *G. dikrongensis* Tamang & Chaudhry 2011 (E) NA
574. *G. dorsalis* Vinciguerra 1890 LC
575. *G. elankadensis* Plamoottil & Abraham 2013 (E) NA
576. *G. garhwali* Tilak 1969 LC
577. *G. gracilis* (Günther 1864) DD
578. *G. granulus* Vishwanath & Linthoingambi 2007 (E) LC
579. *G. housei* Herre 1942 (E) EN
580. *G. indicus* Talwar 1991 LC
581. *G. jayarami* Rameshori & Vishwanath 2012 (E) NA
582. *G. kashmirensis* Hora 1923 CR
583. *G. kudremukhensis* Gopi 2007 (E) CR
584. *G. lonah* (Sykes 1839) (E) LC

585. *G. maceriatus* Ng & Lalramliana 2012 (E) NA
586. *G. madraspatanus* (Day 1873) (E) EN
587. *G. malabarensis* Gopi 2010 (E) DD
588. *G. manipurensis* Menon 1955 (E) VU
589. *G. mibangi* Darshan, Dutta, Kachari, Gogoi & Das 2015 (E) NA
590. *G. nelson* Ganguly, Datta & Sen 1972 (E) NA
591. *G. ngapang* Vishwanath & Linthoingambi, 2007 LC
592. *G. pantherinus* Anganthoibi & Wishwanath 2013 (E) NA
593. *G. pasighatensis* Arun Kumar, 2016 (E) NA
594. *G. pectinopterus* (McClelland, 1842) LC
595. *G. poonaensis* Hora, 1938 (E) EN
596. *G. punjabensis* Mirza & Kashmiri 1971 NA
597. *G. radiolus* Ng & Lalramliana, 2013 (E) NA
598. *G. saisii* (Jenkins, 1910) (E) VU
599. *G. scrobiculus* Ng & Lalramiana 2012 (E) NA
600. *G. senapatiensis* Premananda, Kosygin & Saidullah 2015 (E) NA
601. *?G. sinensis* (Regan 1908) DD
602. *G. stolickai* (Steindachner 1867) LC
603. *G. striatus* (McClelland 1842) (E) NT
604. *G. sykesi* (Day, 1873) (E) NA
605. *G. telchitta* (Hamilton 1822) LC
606. *G. trewavasae* Hora 1938 (E) VU
607. ?*G. trilineatus* Blyth 1860 LC
608. *G. ventrolineatus* Vishwanath & Linthoingambi 2006 (E) LC
609. *G. verucosus* Rameshori & Vishwanath 2012 (E) NA
610. *Gogangra viridescens* (Hamilton 1822) (E) LC
611. *Myersglanis jayarami* Vishwanath & Kosygin 1999 (E) VU
612. *Nangra assamensis* Sen & Biswas 1994 LC
613. *N. nangra* (Hamilton 1822) LC
614. *Oreoglanis majuscule* Linthoingambi & Vishwanath 2011 (E) NA
615. *O. pangenensis* Sinha & Tamang 2015 (E) NA
616. *Parachiloglanis hodgarti* (Hora 1923) LC
617. *Pseudecheneis koladynae* Anganthoibi & Vishwanath 2010 (E) NA
618. *P. sirenica* Vishwanath & Darshan 2007 (E)VU
619. *P. sulcata* (McClelland 1842) LC
620. *P. suppaetula* Ng 2006 (E) DD
621. *P. ukhrulensis* Vishwanath & Darshan 2007 (E) VU
622. *Sisor barakensis* Vishwanath & Darshan 2005 (E) VU
623. *S. chennuah* Ng & Lahkar 2003 (E) DD
624. *S. rabdophorus* Hamilton 1822 (E) LC
625. *S. rheophilus* Ng 2003 (E) DD
626. *S. torosus* Ng 2003 (E) DD

Siluriformes: **Erethistidae**

627. *Conta conta* (Hamilton 1822) DD
628. *C. pectinata* Ng 2005 (E) DD
629. *Erethistes hara* (Hamilton 1822) LC
630. *E. horai* (Misra 1976) (E) LC
631. *E. jerdoni* Day 1870 LC
632. *E. koladynensis* (Anganthoibi & Vishwanath 2009) (E) DD
633. *E. nareshi* (Mahapatra & Kar 2015) (E) NA
634. *E. pusillus* Müller & Troschel 1849 LC
635. *Erethistoides infuscatus* Ng 2006 DD

636. *E. montana* Hora 1950 DD
637. *E. pipri* Hora, 1950 (E) DD
638. *E. senkhiensis* Tamang, Chaudhry & Choudhury 2008 (E) DD
639. *E. sicula* Ng 2005 (E) DD
640. *Pseudolaguvia austrina* Radhakrishnan, Sureshkumar & Ng 2011 (E) DD
641. *P. ferruginea* Ng 2009 (E) DD
642. *P. ferula* Ng 2006 (E) DD
643. *P. flavida* Ng 2009 (E) DD
644. *P. foveolata* Ng 2005 (E) DD
645. *P. fucosa* Ng, Lalramliana & Lalronunga 2016 (E) NA
646. *P. jiyaensis* Tamang & Sinha 2014 (E) NA
647. *P. kapuri* (Tilak & Husain 1975) LC
648. *P. lapillicola* Britz, Ali & Raghavan 2013 (E) NA
649. *P. magna* Tamang & Sinha 2014 (E) NA
650. *Pseudolaguvia nubila* Ng, Lalramliana, Lalronunga & Lalnuntluanga 2013 (E) NA
651. *P. ribeiroi* (Hora 1921) LC
652. *P. shawi* (Hora 1921) LC
653. *P. spicula* Ng & Lalramliana 2010 NA
654. *P. virgulata* Ng & Lalramliana 2010 (E) DD
655. *P. viriosa* Ng & Tamang 2012 (E) NA

Siluriformes: **Kryptoglanidae**

656. *Kryptoglanis shajii* Vincent & Thomas 2011 (E) NA

Siluriformes: **Siluridae**

657. *Ompok bimaculatus* (Bloch 1794) NT
658. *O. canio* (Hamilton 1822) (E) NA
659. *O. karunkodu* Ng 2013 (E) NA
660. *O. malabaricus* (Valenciennes 1840) (E) LC
661. *O. pabda* (Hamilton 1822) NT
662. *O. pabo* (Hamilton 1822) NT
663. *Pinniwallago kanpurensis* Gupta, Jayaram & Hajela 1981 (E) NA
664. *Pterocryptis barakensis* Vishwanath & Nebeshwar Sharma, 2006 (E) EN
665. *P. berdmorei* (Blyth 1860) LC
666. *P. gangelica* Peters 1861 DD
667. *P. indicus* (Datta, Barman & Jayaram 1987) (E) DD
668. *P. wynaadensis* (Day 1873) (E) EN
669. *Wallago attu* (Bloch & Schneider 1801) NT

Siluriformes: **Chacidae**

670. *Chaca chaca* (Hamilton 1822) LC

Siluriformes: **Clariidae**

671. *Clarias dayi* Hora 1936(E)NA
672. *C. dussumieri* Valenciennes 1840 (E) NT
673. *C. magur* (Hamilton 1822) EN
674. *Horaglanis abdulkalami* Subhash Babu 2012 (E)NA
675. *H. alikunhii* Subhash Babu & Nayar 2004 (E) DD
676. *H. krishnai* Menon 1950(E)DD

Siluriformes: **Heteropneustidae**

677. *Heteropneustes fossilis* (Bloch 1794) LC
678. *H. longipectoralis* Rema Devi & Raghunathan 1999 (E) DD

Siluriformes: **Ailiidae (earlier in Schilbeidae)**

679. *Ailia coila* (Hamilton, 1822) NT
680. *Ailiichthys punctata* Day, 1872 DD
681. *Clupisoma bastari* Datta & Karmakar, 1980 (E) DD
682. *C. garua* (Hamilton 1822) LC
683. *C. montana* Hora 1937 LC
684. *Eutropiichthys cetosus* Ng, Lalramliana, Lalronunga & Lalnuntluanga 2014 (E) NA

685. *E. goongwaree* (Sykes 1839) DD
686. *E. murius* (Hamilton 1822) LC
687. *E. vacha* (Hamilton 1822) LC
688. *Proeutropiichthys buchanani* (Valenciennes 1840) (E) DD
689. *P. taakree* (Sykes 1839) (E) NA
690. *Silonia childreni* (Sykes 1839) (E) EN
691. *S. silondia* (Hamilton 1822) LC

Siluriformes: **Horabagridae**

692. *Horabagrus brachysoma* (Günther 1864) (E) VU
693. *H. nigricollaris* Pethiyagoda & Kottelat 1994 (E) EN
694. *Pachypterus atherinoides* (Bloch 1794) LC
695. *P. khavalchor* Kulkarni 1952 (E) DD
696. *Pseudeutropius mitchelli* Günther 1864 (E) EN

Siluriformes: **Pangasiidae**

697. *Pangasius pangasius* (Hamilton 1822) LC

Siluriformes: **Bagridae**

698. *Batasio affinis* Blyth 1860 DD
699. *B. batasio* (Hamilton 1822) LC
700. *B. convexirostrum* Darshan, Anganthoibi & Vishwanath 2011 (E) NA
701. *B. fasciolatus* Ng 2006 (E) LC
702. *B. flavus* Plamoottil 2015 (E) NA
703. *B. merianiensis* (Chaudhuri 1913) (E) DD
704. *B. sharavatiensis* Bhatt & Jayaram 2004 (E) EN
705. *B. spilurus* Ng 2006 (E) DD
706. *B. tengana* (Hamilton 1822) LC
707. *B. travancoria* Hora & Law 1941 (E) VU
708. *Chandramara chandramara* (Hamilton 1822) LC
709. *Hemibagrus maydelli* (Rössel 1964) (E) LC
710. *H. menoda* (Hamilton 1822) LC
711. *H. microphthalmus* (Day 1877) LC
712. *H. punctatus* (Jerdon 1849) (E) CR
713. *Mystus armatus* (Day 1865)LC
714. *M. bleekeri* (Day 1877) LC
715. *M. canarensis* Grant 1999 (E) NA
716. *M. carcio* (Hamilton 1822) LC
717. *M. catapogon* Plamoottil 2016 (E) NA
718. *M. cavasius* (Hamilton 1822) LC
719. *M. dibrugarensis* (Chaudhuri 1913) (E) LC
720. *M. gulio* (Hamilton 1822) LC
721. *M. heoki* Plamoottil & Abraham 2013 (E) NA
722. *M. indicus* Plamoottil & Abraham 2013(E) NA
723. *M. keletius* (Valenciennes 1840) (E) LC
724. *M. keralai* Plamoottil & Abraham 2014 (E) NA
725. *M. malabaricus* (Jerdon 1849) (E)NT
726. *M. menoni* Plamoottil & Abraham 2013 (E) NA
727. *M. montanus* (Jerdon 1849) (E) LC
728. *M. ngasep* Darshan, Vishwanath, Mahanta & Barat 2011 (E) NA
729. *M. oculatus* (Valenciennes 1840) (E) LC
730. *M. seengtee* (Sykes 1839) (E) LC
731. *M. tengara* (Hamilton 1822) LC
732. *M. vittatus* (Bloch 1794) LC
733. *Rama rama* (Hamilton 1822) NA
734. *Rita bakalu* Lal, Dwivedi & Singh 2016 (E) NA
735. *R. chrysea* Day, 1877 (E) LC
736. *R. gogra* (Sykes 1839) (E) LC
737. *R. kuturnee* (Sykes 1839) (E) LC
738. *R. macracanthus* Ng 2004 NA
739. *R. rita* (Hamilton 1822) LC
740. *Sperata aor* (Hamilton 1822) LC

741. *S. aorella* (Blyth 1858) LC
742. *S. seenghala* (Sykes 1839) LC
743. *Olyra astrifera* Arunachalam, Raja, Mayden & Chandran 2013(E) NA
744. *O. horae* (Prashad & Mukerji 1929) DD
745. *O. longicaudata* McClelland 1842 LC
746. *O. praestigiosa* Ng & Ferraris 2016 (E) NA
747. *O. saginata* Ng, Lalramliana & Lalthanzara 2014(E) NA

Mugiliformes: **Mugilidae**

748. *Rhinomugil corsula* (Hamilton 1822) LC
749. *Minimugil cascasia* (Hamilton 1822) LC

Beloniformes: **Adrianichthyidae**

750. *Oryzias carnaticus* (Jerdon 1849) LC
751. *O. dancena* (Hamilton 1822) LC
752. *O. melastigma* (McClelland 1839) LC
753. *O. setnai* (Kulkarni 1940) (E) LC

Beloniformes: **Belonidae**

754. *Xenentodon cancila* (Hamilton 1822) LC

Cyprinodontiformes: **Aplocheilidae**

755. *Aplocheilus andananicus* (Köhler 1906)(E) NA
756. *A. blockii* Arnold 1911 LC
757. *A. dayi* Steindachner 1892 NA
758. *A. kirchmayeri* Berkenkamp & Etzel 1986 (E) NA
759. *A. lineatus* (Valenciennes 1846) (E) LC
760. *A. panchax* (Hamilton 1822 LC
761. *A. parvus* (Sundara Raj 1916) NA

Cyprinodontiformes: **Cyprinodontidae**

762. *Aphanius dispar* (Rüppell 1829 LC

Syngnathiformes: **Syngnathidae**

763. *Doryichthys martensii* (Peters 1868) LC
764. *Microphis cuncalus* (Hamilton 1822) LC
765. *M. deocata* (Hamilton 1822) NT
766. *Oostethus brachyurus* (Bleeker 1853) NA
767. *O. insularis* (Hora 1925) (E) VU

Synbranchiformes: **Synbranchidae**

768. *Monopterus albus* (Zuiew 1793) LC
769. *M. cuchia* (Hamilton 1822) LC
770. *M. digressus* Gopi 2002 (E) DD
771. *M. eapeni* Talwar 1991 (E) DD
772. *M. fossorius* (Nayar 1951) (E) EN
773. *M. hodgarti* (Chaudhuri 1913) (E) DD
774. *M. ichthyophoides* Britz, Lalremsanga, Lalrotluanga & Lalramliana 2011 (E) NA
775. *M. indicus* (Silas & Dawson 1961 (E) VU
776. *M. roseni* Bailey & Gans 1998 (E) DD
777. *Ophisternon bengalense* McClelland 1844 LC

Synbranchiformes: **Mastacembelidae**

778. *Macrognathus albus* Plamoottil & Abraham 2014 (E) NA
779. *M. aral* (Bloch & Schneider 1801) LC
780. *M. fasciatus* Plamoottil & Abraham 2014(E) NA
781. *M. guentheri* (Day 1865) (E) LC
782. *M. lineatomaculatus* Britz 2010DD
783. *M. morehensis* Arunkumar & Tombi Singh 2000 LC
784. *M. pancalus* Hamilton 1822 LC
785. *Mastacembelus armatus* (Lacepède 1800) LC
786. *M. malabaricus* Jerdon 1849 (E) NA

Synbranchiformes: **Chaudhuriidae**

787. *Garo khajuriai* (Talwar, Yazdani & Kundu 1977) (E) NT
788. *Pillaia indica* Yazdani 1972 (E) EN

Perciformes: **Ambassidae**

789. *Chanda nama* Hamilton 1822 LC
790. *Parambassis baculis* (Hamilton 1822) LC
791. *P. bistigmata* Geethakumari 2012 (E) NA
792. *P. dayi* (Bleeker 1874) (E) LC
793. *P. lala* (Hamilton 1822) NT
794. *P. ranga* (Hamilton 1822) LC
795. *P. serrata* Dishma & Vishwanath 2015 (E) NA
796. *P. thomassi* (Day 1870) (E) LC
797. *P. waikhomi* Geethakumari & Basudha 2012 (E) NA

Perciformes : **Nandidae**

798. *Nandus andrewi* Ng & Jaafar 2008 (E) DD
799. *N. nandus* (Hamilton 1822) LC

Perciformes : **Pristolepididae**

800. *Pristolepis malabarica* (Günther 1864) (E) NA
801. *P. marginata* Jerdon 1849 (E) LC
802. *P. pentacantha* Plamoottil 2014 (E) NA
803. *P. rubripinnis* Britz, Kuman & Baby 2012 (E) NA

Perciformes: **Badidae**

804. *Badis andrewraoi* Valdesalici & van der Voort 2015 (E) NA
805. *B. assamensis* Ahl 1937 (E) NA
806. *B. autumnum* Valdesalici & van der Voort 2015(E) NA
807. *B. badis* (Hamilton 1822) LC
808. *B. blosyrus* Kullander & Britz 2002 (E) LC
809. *B. britzi* Dahanukar, Kumkar, Katwate & Raghavan 2015 (E) NA
810. *B. dibruensis* Geetakumari & Vishwanath 2010 (E) DD
811. *B. kanabos* Kullander & Britz 2002 (E) DD
812. *B. kyanos* Valdesalici & van der Voort 2015 (E) NA
813. *B. laspiophilus* Valdesalici & van der Voort 2015 (E) NA
814. *B. pancharatnaensis* Basumatary, Choudhury, Baishya, Sarma & Vishwanath 2016 (E) NA
815. *B. singenensis* Geetakumari & Kadu 2011 (E) NA
816. *B. soraya* Valdesalici & van der Voort 2015 (E) NA
817. *B. triocellus* Khynriam & Sen 2013 (E) NA
818. *B. tuivaiei* Vishwanath & Shanta 2004 (E) NA
819. *Dario dario* (Hamilton 1822) (E)DD
820. *D. huli* Britz & Ali 2015(E) NA
821. *D. kajal* Britz & Kullander 2013 (E) NA
822. *D. urops* Britz, Ali & Philip 2012 (E) NA

Perciformes: **Cichlidae**

823. *E. suratensis* (Bloch 1790) LC
824. *Etroplus canarensis* Day 1877 (E) NA
825. *Pseudetroplus maculatus* (Bloch 1795) LC

Perciformes: **Gobiidae**

826. *Brachyamblyopus brachysoma* (Bleeker 1853) NA
827. *Brachygobius nunus* (Hamilton 1822) NA
828. *Caragobius urolepis* (Bleeker 1852) LC
829. *Pseudogobiopsis oligactis* (Bleeker 1875) LC
830. *Sicyopterus griseus* (Day 1877) LC
831. *S. microcephalus* (Bleeker 1855) NA
832. *Schismatogobius deraniyagalai* Kottelat & Pethiyagoda 1989 DD

Perciformes : **Anabantidae**

833. *Anabas cobojius* (Hamilton, 1822) DD
834. *A. testudineus* (Bloch, 1792) DD

Perciformes : **Osphronemidae**

835. *Ctenops nobilis* McClelland 1845 NT
836. *Pseudosphromenus cupanus* (Cuvier 1831) LC
837. *P. dayi* (Engmann 1909) (E) VU
838. *Trichogaster chuna* (Hamilton 1822) LC
839. *T. fasciata* (Bloch & Schneider 1801) LC
840. *T. labiosa* Day 1877 LC
841. *T. lalius* (Hamilton 1822) LC

Perciformes: **Channidae**

842. *Channa amphibeus* (McClelland 1845) (E) LC
843. *C. andrao* Britz 2013 (E) NA
844. *C. aurantimaculata* Musikasinthorn, 2000 (E) DD
845. *C. aurantipectoralis* Lalhlimpuia, Lalronunga & Lalramliana 2016 (E) NA
846. *C. barca* (Hamilton 1822) (E) DD
847. *C. bleheri* Vierke 1991 (E) NT
848. *C. diplogramma* (Day 1865) VU
849. *C. gachua* (Hamilton 1822) LC
850. *C. marulius* (Hamilton 1822) LC
851. *C. melanostigma* Geetakumari & Vishwanath 2010 (E) NA
852. *C. pardalis* Knight 2016 (E) NA
853. *C. punctata* (Bloch 1793) LC
854. *C. stewartii* (Playfair 1867) LC
855. *C. striata* (Bloch 1793) LC

Tetraodontiformes: **Tetraodontidae**

856. *Carinotetraodon imitator* Britz & Kottelat 1999 (E) DD
857. *C. travancoricus* (Hora & Nair 1941) (E) VU
858. *Leiodon cutcutia* (Hamiton 1822) LC

Abbreviatons used. (E): Endemic species, CR: Criticaly Endanged, EN: Endangerd, V: Vullerable, NT: Near Threatned, LC: Least Concern, DD: Data Deficient, NA: Not Assessed.

Table 2b. Introduced Alien fishes in Indian inland waters: (32 species)

Cypriniformes: **Cyprinidae**

859. *Barbonymus gonionotus* (Bleeker 1849)
860. *Carassius auratus* (Linnaeus 1758)*
861. *C. carassius* (Linnaeus 1758)
862. *Ctenopharyngodon idella* (Valenciennes 1844)*
863. *Cyprinus carpio* Linnaeus 1758*
864. *Hypophthalmichthys molitrix* (Valenciennes, 1844)*
865. *H. nobilis* (Richardson 1845)*
866. *Tinca tinca* (Linnaeus 1758)*

Characiformes: **Serrasalmidae**

867. *Piaractus brachypomus* (Cuvier 1818)*

Siluriformes : **Loricariidae**

868. *Pterygoplichthys anisitsi* Eigenmann & Kennedy 1903
869. *P. disjunctivus* (Weber 1991)*
870. *P. multiradiatus* (Hancock 1828)
871. *P. pardalis* (Castelnau 1855)*

Siluriformes : **Clariidae**

872. *Clarias gariepinus* (Burchell, 1822)*

Siluriformes : **Pangasidae**

873. *Pangasianodon hypophthalmus* (Sauvage 1878)

Salmoniformes: **Salmonidae**

874. *Oncorhynchus mykiss* (Walbaum 1792)*
875. *O. nerka* (Walbaum 1792)
876. *Salmo trutta* Linnaeus 1758*
877. *Salvelinus fontinalis* (Mitchill 1814)*

Cyprinodontiformes: **Poeciliidae**

878. *Gambusia affinis* (Baird and Girard 1853)*

879. *G. holbrooki* Girard, 1859
880. *Poecilia reticulata* Peters, 1859
881. *Xiphophorus hellerii* Heckel, 1848
882. *X. maculates* (Günther, 1866)

Perciformes : **Cichlidae**

883. *Amphilophus trimaculatus* (Günther 1867)
884. *Oreochromis aureus* (Steindachner, 1864)
885. *O. mossambicus* (Peters, 1852)*
886. *O. niloticus* (Linnaeus, 1758)*

Perciformes : **Osphronemidae**

887. *Osphronemus goramy* Lacepède 1801
888. *Macropodus opercularis* (Linnaeus 1758)
889. *Trichopsis vittata* (Cuvier 1831)
890. *Trichopodus trichopterus* (Pallas 1770)

Table 3. Secondary Freshwater Fishes of India

Carcharhiniformes: **Carcharhinidae**

1. *Carcharhinus leucas* (Valenciennes 1839)
2. *C. melanopterus* (Quoy & Gaimard 1824)
3. *Glyphis gangeticus* (Müller & Henle 1839)
4. *Scoliodon laticaudus* Müller & Henle 1838
5. *Rhizoprionodon acutus* (Rüppell 1837)

Myliobatiformes: **Dasyatidae**

6. *Urogymnus polylepis* (Bleeker 1852)
7. *Himantura uarnak* (Gmelin 1789)
8. *Pastinachus sephen* (Forsskål 1775)

Elopiformes: **Elopidae**

9. *Elops machnata* (Forsskal 1775)

Elopiformes: **Megalopidae**

10. *Megalops cyprinoides* (Broussonet 1782)

Anguilliformes: **Moringuidae**

11. *Moringua raitaborua* (Hamilton 1822)
12. *M. guthriana* (McClelland 1844)

Anguilliformes: **Muraenidae**

13. *Strophidon sathete* (Hamilton 1822)
14. *Gymnothorax tile* (Hamilton 1822)

Anguilliformes: **Ophichthidae**

15. *Lamnostoma orientale* (McClelland 1844)
16. *Pisodonophis boro* (Hamilton 1822)
17. *P. cancrivorus* (Richardson 1848)
18. *P. hijala* (Hamilton 1822)

Anguilliformes: **Muraenesocidae**

19. *Muraenesox cinerius* (Forsskal 1775)

Clupeiformes: **Clupeidae**

20. *Anodontostoma chacunda* (Hamilton 1822)
21. *Corica soborna* Hamilton 1822
22. *Dayella malabarica* (Day 1873)
23. *Ehirava fluviatilis* Deraniyagala 1929
24. *Hilsa kelee* (Cuvier 1829)
25. *Nematalosa nasus* (Bloch 1795)
26. *Pellona ditchela* Valenciennes 1847
27. *Tenualosa ilisha* (Hamilton 1822)
28. *T. toli* (Valenciennes 1847)

Clupeiformes: **Pristigasteridae**

29. *Ilisha filigera* (Valenciennes 1847)
30. *I. kampeni* (Weber & de Beaufort 1913)
31. *I. megaloptera* (Swainson 1838)

Clupeiformes: **Engraulidae**

32. *Setipinna brevifilis* (Valenciennes 1848)
33. *S. phasa* (Hamilton 1822)

34. *Coilia dussumieri* Valenciennes 1848
35. *C. reynaldi* Valenciennes 1848

Gonorhynchiformes: **Chanidae**

36. *Chanos chanos* (Forsskål 1775)

Siluriformes: **Plotosidae**

37. *Plotosus canius* Hamilton 1822
38. *P. limbatus* Valenciennes 1840

Siluriformes: **Ariidae**

39. *Arius gagora* (Hamilton 1822)
40. *Cephalocassis jatius* (Hamilton 1822)
41. *Hemiarius sumatranus* (Anonymous [Bennett] 1830)
42. *Ketengus typus* Bleeker 1846

Mugiliformes: **Mugilidae**

43. *Crenimugil buchanani* (Bleeker 1853)
44. *Ellochelon vaigiensis* (Quoy & Gaimard 1825)
45. *Mugil cephalus* Linnaeus 1758
46. *Osteomugil cunnesius* (Valenciennes 1836)
47. *Planiliza macrolepis* (Smith 1846)
48. *P. melinoptera* (Valenciennes 1836)
49. *P. parsia* (Hamilton 1822)
50. *P. tade* (Forsskål 1775)

Beloniformes: **Belonidae**

51. *Strongylura strongylur*a (van Hasselt 1823)

Beloniformes: **Hemiramphidae**

52. *Hyporhamphus limbatus* (Valenciennes 1847)
53. *H. xanthopterus* (Valenciennes 1847)

Beloniformes: **Zenarchopteridae**

54. *Dermogenys pusilla* Kuhl& van Hasselt 1823
55. *Zenarchopterus buffonis* (Valenciennes 1847)
56. *Z. dispar* (Valenciennes 1847)
57. *Z. ectuntio* (Hamilton 1822)
58. *Z. striga* (Blyth 1858)

Syngnathiformes: **Syngnathidae**

59. *Hippichthys heptagonus* Bleeker 1849
60. *H. cyanospilos* (Bleeker 1854)
61. H. penicillus (Cantor 1849)
62. *Ichthyocampus carce* (Hamilton 1822)

Scorpaeniformes: **Tetrarogidae**

63. *Tetraroge nigra* (Cuvier 1829)

Perciformes: **Latidae**

64. *Lates calcarifer* (Bloch 1790)

Perciformes: **Ambassidae**

65. *Ambassis ambassis* (Lacepède 1802)
66. *A. buton* Popta 1918
67. *A. gymnocephalus* (Lacepède 1802)
68. *A. interrupta* Bleeker 1853
69. *A. miops* Günther 1872
70. *A. nalua* (Hamilton 1822)
71. *A. urotaenia* Bleeker 1852

Perciformes: **Carangidae**

72. *Caranx sexfasciatus* Quoy & Gaimard 1825

Perciformes: **Leiognathidae**

73. *Leiognathus equula* (Forsskål 1775)
74. *Secutor ruconius* (Hamilton 1822)

Perciformes: **Lutjanidae**

75. *Lutjanus ehrenbergii* (Peters 1869)
76. *L. fulvus* (Forster 1801)

Perciformes: **Datnioididae**

77. *Datnioides polata* (Hamilton 1822)

Perciformes: **Polynemidae**

78. *Eleutheronema tetradactylum* (Shaw 1804)
79. *Polynemus paradiseus* Linnaeus 1758

Perciformes: **Sciaenidae**

80. *Dendrophysa russelii* (Cuvier 1829)
81. *Johnius amblycephalus* (Bleeker 1855)
82. *J. coitor* (Hamilton 1822)
83. *J. gangeticus* Talwar 1991
84. *Pama pama* (Hamilton 1822)

Perciformes: **Toxotidae**

85. *Toxotes chatareus* (Hamilton 1822)
86. *T. jaculatrix* (Pallas 1767)

Perciformes: **Blenniidae**

87. *Omobranchus ferox* (Herre 1927)

Perciformes: **Eleotridae**

88. *Bunaka gyrinoides* (Bleeker 1853)
89. *Butis amboinensis* (Bleeker 1853)
90. *B. butis* (Hamilton 1822)
91. *B. gymnopomus* (Bleeker 1853)
92. *B. koilomatodon* (Bleeker 1849)
93. *Eleotris fusca* (Bloch & Schneider 1801)
94. *E. melanosoma* Bleeker 1853
95. *Giuris margaritaceus* (Valenciennes 1837)
96. *Odonteleotris macrodon* (Bleeker 1853)
97. *Ophiocara porocephala* (Valenciennes 1837)

Perciformes: **Gobiidae**

98. *Acentrogobius griseus* (Day 1876)
99. *A. madraspatensis* (Day 1868)
100. *Apocryptes bato* (Hamilton 1822)
101. *Apocryptodon madurensis* (Bleeker 1849)
102. *Awaous grammepomus* (Bleeker 1849)
103. *A. melanocephalus* (Bleeker 1849)
104. *A. ocellaris* (Broussonet 1782)
105. *Bathygobius ostreicola* (Chaudhuri 1916)
106. *Drombus globiceps* (Hora 1923)
107. *D. triangularis* (Weber 1909)
108. *Favonigobius reichei* (Bleeker 1854)
109. *Glossogobius bicirrhosus* (Weber 1894)
110. *G. celebius* (Valenciennes 1837)
111. *G. giuris* (Hamilton 1822)
112. *Gobiopterus chuno* (Hamilton 1822)
113. *Hemigobius hoevenii* (Bleeker 1851)
114. *Istigobius diadema* (Steindachner 1876)
115. *Odontamblyopus rubicundus* (Hamilton 1822)
116. *Periophthalmodon septemradiatus* (Hamilton 1822)
117. *Periophthalmus argentilineatus* Valenciennes 1837
118. *P. chrysospilos* Bleeker 1853
119. *P. kalolo* Lesson 1831
120. *Pseudapocryptes elongatus* (Cuvier 1816)
121. *Pseudogobius javanicus* (Bleeker 1856)
122. *P. poicilosoma* (Bleeker 1849)
123. *Stigmatogobius sadanundio* (Hamilton 1822)
124. *Taenioides anguillaris* (Linnaeus 1758)
125. *T. cirratus* (Blyth 1860)
126. *T. gracilis* (Valenciennes 1837)
127. *Yongeichthys nebulosus* (Forsskål 1775)

Perciformes: **Terapontidae**

128. *Terapon jarbua* (Forsskål 1775)
129. *T. theraps* Cuvier 1829
130. *T. puta* Cuvier 1829

Perciformes: **Scatophagidae**

131. *Scatophagus argus* (Linnaeus 1766)

Perciformes: **Kuhliidae**

132. *Kuhlia rupestris* (Lacepède 1802)

Perciformes: **Kurtidae**

133. *Kurtus indicus* Bloch 1786

Pleuronectiformes: **Soleidae**

134. *Brachirus orientalis* (Bloch & Schneider 1801)

Tetraodontiformes: **Tetraodontidae**

135. *Dichotomyctere fluviatilis* (Hamilton 1822)

136. *D. nigroviridis* (Marion de Procé 1822)

137. *Chelonodontops patoca* (Hamilton 1822)

The species that are usually diadromous, e.g., the catadromous eels, like *Anguilla bengalensis,* or the anadromous fishes, like *Sicyopterus griseus*, which are observed to have populations thriving in upland freshwaters, have also been included among the freshwater species. Such species frequently occur in freshwater as they are diadromous, entering the freshwater in substantial numbers. The ecological significance of these species is that if freshwater habitats were not accessible to them they either would not exist or their range would be markedly reduced.

As many as 32 species of alien fishes belonging to 21 genera of 9 families and 7 orders are found in the freshwater systems of India (Table 2 b). Out of these, at least 16 species (marked with asterisks (*) in the Table 2 (b) are well-known, potential invasive alien fishes in India. Alien fishes such as *Pterygoplichthys* spp., seemingly very innocuous exotics in their new freshwater habitats, have already shown their impacting effects of infestation in the freshwater systems affecting the indigenous aquatic fauna, including fishes.The inland waterbodies of India have a combined potential of freshwater fish diversity of 890 species, including 32 species of introduced exotic fishes (Table 2a & b).

There are many species of fish which are usually marine or brackish water forms, but sometimes enter freshwaters of the lower-and-above reaches of rivers. Several fishes, usually occurring in brackish waters but not known to enter fresh waters, have been excluded, which include some of them enlisted in Jayaram (2010). After an assessment on the distributional visitations of the species to the freshwaters, based on literature study, 137 species have been enlisted as secondary freshwater fishes, as provided in Table 3. Some of these species have been listed as freshwater species in the check-list of freshwater fishes of India in the earlier published works. The status of diversity of freshwater fishes in the inland waters of India isconsidered, taken into all the three components of the fish diversity , i.e., primary and secondary freshwater fishes as well as the introduced alien fishes, India has an overall potential of 1027 species of fishes (Tables 2 a & b; 3)

Study of ichthyofaunal diversity in different administrative states of our country is documented during last three decades, mainly by the scientists of the Zoological Survey of India. Table 4 depicts diversity of fish faunain each state. However, several other species have recorded or described from the given state after the cited document prepared, which are not included here. Further, documentation from four states, viz., Bihar (including Jharkhand), Jammu & Kashmir, Haryana, and Punjab, is awaited. Only for the states of Kerala and

Arunachal Pradesh, publications of Bijukumar and Raghavan (2015) and Bagra *et al.* (2009) respectively were considered, while others are documented by the scientists of the Zoological Survey of India, Kolkata.

Table 4. Ichthyofaunal divercity in different states of India

Sl. No.	State	Family	Genera	Species	Reference
1.	Andhra Pradesh	27	68	158	Barman, 1993
2.	Arunachal Pradesh	31	93	213	Bagra *et al.*, 2009
3.	Assam	29	83	187	Sen, 1985
4.	Bihar & Jharkhand	30	76	134	Karmakar *et al.*, (in press)
5.	Delhi	24	55	87	Husain, 1997
6.	Goa	20	31	58	Yadav, 2008
7.	Gujarat	24	58	119	Sen & Banerjee, 2000
8.	Haryana	19	46	74	Sharma (in press)
9.	Himachal Pradesh	14	48	104	Mehta & Uniyal, 2005
10.	Jammu & Kashmir				Yet to be carried out.
11.	Karnataka	30	89	213	Rema Devi *et al.*, 2013
12.	Kerala	35	88	188	Bijukumar & Raghavan 2015
13.	Madhya Pradesh (including Chhattisgarh)	27	68	172	Sharma, 2007
14.	Maharashtra	32	93	216	Karmakar *et al.*, 2012
15.	Manipur	24	64	141	Karmakar& Das, 2005
16.	Meghalaya	28	74	152	Sen, 1995
17.	Mizoram	20	49	89	Karmakar & Das, 2007
18.	Nagaland	20	57	108	Karmakar & Das, 2006
19.	Odisha	25	70	143	Dutta *et al.*, 1993
20.	Puducherry	24	43	67	Rema Devi, 2015
21.	Punjab	21	50	88	Kumar (in press)
22.	Rajasthan	15	36	75	Datta & Majumdar, 1970
23.	Sikkim	15	43	64	Karmakar, 2006
24.	Tamil Nadu	27	78	160	Remadevi *et al.* 2009
25.	Tripura	33	78	129	Barman, 2002
26.	Uttar Pradesh	34	89	153	Gopi & Kosygin 2015
27.	Uttarakhand	27	67	132	Uniyal, 2010
28.	West Bengal	49	147	239	Barman, 2007

Biological diversity

Freshwater fishes in India also exemplify amazing diversity not only in fish morphology but in their behaviour also. Some species like freshwater herrings, like their marine counterparts travel in schools in substantial numbers, enter through fresh-brackish water zones of the rivers in the coastal plain, while others are highly territorial. Fishes are adapted to a wide variety of foods, many are phytophagous on aquatic algae and weeds, detritivores or heterotrophs, and some are adapted to feed on items as zooplankton. Big catfishes, like African catfish (*Clarias gariepinus*), and murrels (snakeheads) like *Channa marulius* and *C. striatus* are predators feeding on small fishes, snails, and tadpoles, and omnivores also. Most fishes are ectotherms. Fishes like Tilapia, *Oreochromis mossambicus*, exhibit parental care for their offspring. Fishes of the order Anguilliformes have larval stage and undergo metamorphosis. Lifespan in fishes may vary from a little over 1 year to many years, up to 15 years or more among *Tor* species.

Habitat diversity

Freshwater fishes of India live in almost every conceivable type of aquatic habitat, from natural ponds in the coastal plains to the 1st order streamlets in the Trans Himalayan areas at elevations up to 5,000 meters (m) in Ladakh, where highest-dwelling fish in India, the nemacheilid, *Triplophysa stolickai* (Steindachner) has been observed occurring in the streamlets formed by the glacial melts. The smallest-known fish from India, an adrianichthid, the *Oryzias setnai* (Kulkarni) is sporadically distributed in backwaters and tanks along the West Coast from Gujarat to Kerala. Catfishes like *Clarias magur* (Hamilton), *C. dayi* Hora as part of spawning migration conduct short excursions onto land immediately after onset of monsoon and heavy showers. Synbranchids like *Monopterus eapeni*, *M. roseni* and *M. degressus*; *Horaglanis krishnai* Menon, *Horaglanis alikunhii* Subhash Babu & Nayar, *H. abdulkalami* Subhash Babu, (Clariidae), *Kryptoglanis shajii* Vincent & Thomas (Kryptoglanidae) are subterranean, or hypogean, fishes confined to total darkness, in underground springs, occasionally collected from deep wells in Kerala. The nemacheilid, *Schistura sijuensis* (Menon) is found in Siju caves of Garo hills in Meghalaya. Some Siluriformfishes have acquired air-breathing organs, and can live in stagnant, tropical swamps. Hill stream fishes like nemacheilids and species of *Garra* demand well-oxygenated waters to sustain life.

Morphological diversity

Among Indian freshwater fishes, the sizes range from the smallest ones, viz., *Oryzias setnai* (Kulkarni) (Adrianichthydae) and the carplet, *Horadandia brittanii*, ranging in size 2-3cm to the largest ones, like the cyprinid, *Tor putitora* and the catfish *Pangasius* sp. range in size from 1-1.5 m. Small puffer fishes like *Carinotetraodon travancoricus* (Hora & Nair) and *Carinotetraodon imitator* Britz & Kottelat (Tetraodontididae) have oblong bodies. Most of the species of the cyprinid genera *Danio, Devario*, *Dawkinsia, Haludaria, Pethia, Sahyadria*, some cobitid species and almost all balitorid and nemacheilid fishes are brilliantly coloured. All the subterranean or hypogean species do have vestigial or no eyes. Scales may be present or absent in closely related species. Some teleost species lack paired fins (pelvic and pectoral) and scales. Species of the genus *Monopterus* (Synbranchidae) lack paired fins, and rudimentary fin-ridges in place of dorsal, caudal and anal fins. Dorsal fin in Kryptoglanid, *Kryptoglanis shajii,* and pelvic fins in eels are missing, or modified into holdfast organs as in *Oryzias setnai*. Tetraodontid puffer fishes have inflatable body.

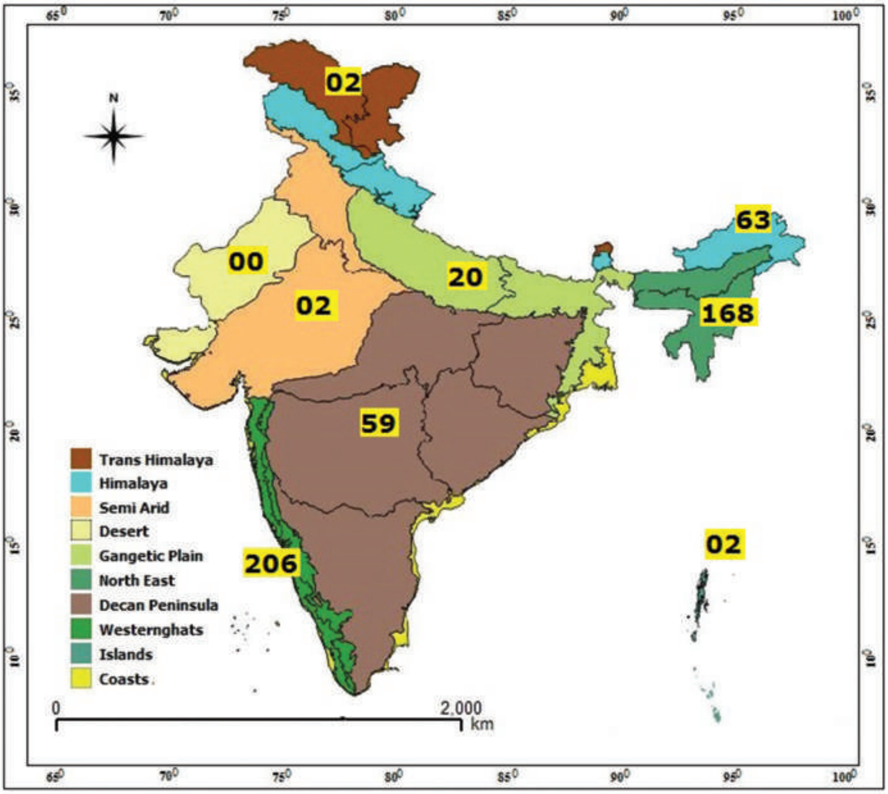

Fig. 1a. Indian biogeographic zones with endemic freshwater fishes (numbers)

Endemism

Endemism is the indigenousness or nativeness of a species by virtue of its natural origin or occurrence in a given location or region and nowhere else in the world, and such endemic species are confined to those particular place or region only. Endemism is the manifestation of a unique step in the process of evolution which could be perpetuated and sustained only in the locality concerned depending on the environmental quality of habitat. In a vast country like India, the concept of endemism very much depends on the knowledge of the geographical range of a species reflecting their far greater significance and higher value in biodiversity perspectives.

A high degree of endemism is found among the freshwater fishes of India. The endemic fishes of India are indicated in Table 2a with (E) marked with species name. More than 60.3% of the primary freshwater fishes are endemic to the country. Number of endemic fishes in different families is given in Table-1. Almost 95% of fishes of the family Badidae known from India are endemics, followed by 87.5% of the family Balitoridae and 80% of the family Amblycipitidae. In the Indian biogeographic-zone perspectives of endemism of fishes, among the total endemic species, 40% are from Western Ghats; 32% from north-eastern India (including Brahmaputra River-basin, but excluding Arunachal Pradesh of eastern Himalaya, and Darjeeling (West Bengal) and Sikkim of Central Himalaya zones); 12% from Himalaya; 11% from Gangetic Plain; and 4% from Deccan peninsular region (Fig. 1a & b). The endemic status of conspicuous taxa like icthyofauna (and herpetofauna, birds, mammals also) tend to be more stable as they are comparatively well-studied, unlike that of large and complex groups of small organisms (e.g., insects). In the present work, endemism among fishes of India is worked out based on their known geographic-range endemic status, and postulating the same to national endemism of Indian freshwater fishes.

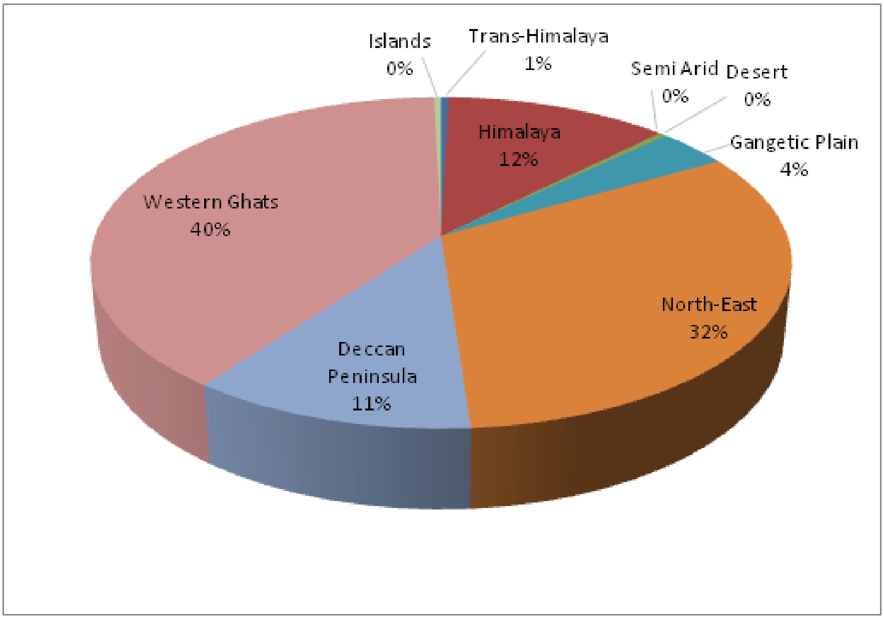

Fig. 1b. Percentage of endemic fishes in different Biogeographic zones

Prospective studies on Indian fishes

In the recent decades, the world over, there has been an impressive increase of information on extant and fossil material and on morphological and molecular-based phylogenies of fishes. In the Indian context, it is evinced that more work is needed on species diversity of fishes from diverse aquatic ecosystem habitats. Systematists are to analyse various characters to determine homologies for the understanding of how evolution has produced the diversity of fishes that exists today. There is a continuous need for large efforts to do more systematic research. Much effort needs to be made on exploring, discovering and describing all available living species in the natural aquatic habitat systems, and identifying and designating the status of species for assessing their risk of becoming endangered or extinct due to human causes. The concerns over problems of extinction of fish species in freshwater are ever-increasing, with much conservation effort spent on saving populations and species that are under severe risk.

Threats to Freshwater fish diversity

Fresh waters are the most threatened ecosystems in the world. Human dependence on freshwater resources combined with localized and distant disturbances in the river-drainage basins, right from upstream networks to lower river reaches, and other freshwater bodies have consequently resulted in loss of biodiversity, notably species extinctions, comparatively at a faster pace and rates, and further exacerbated by anthropogenic climate change (Vörösmarty *et al*., 2010).

In the Indian context, as also in the global scenario, fish and their habitats face threats from both natural and man-made hazards. The fish population face varied threats of natural hazards like floods, earthquakes, changes in the river course, glacial water discharge, erosion, cloud burst, natural discharge of organic/ inorganic elements and diseases. The threats are further compounded by man-made hazards like pollution, river encroachment and embankments, sand mining, and hydro-electric and irrigation dams.Hydroelectric and irrigation dams across the rivers and flow regulation, changing the lotic environment to lentic and homogenisation of habitats; conversion of wetlands into other forms of land uses, destruction of riparian vegetation, etc. have deleterious effect on biodiversity, very vulnerable to rare and endemic species, species with large home ranges, species with limited dispersal potential as well as low reproductive potential, species with short life cycles, and diadromous species. Destruction of riparian vegetation upsets and damages stream substrate composition that is used by several fishes for their shelter and foraging.

Pollution by chemicals or inorganic elements, like arsenic,is also degrading the aquatic systems as, e.g., arsenic poisoning in fishes reported by Maheshwari *et al*. (2010). Many harmful chemicals as xenobiotics, pesticides, weedicides etc are largely used in agricultural and cash-crop (tea) programmes, which directly and indirectly pollute and degrade both soil and water. Plant-based poisons are widely used in fishing by the community people in both the biodiversity hotspots of Western Ghats and Northeastern India.Scientists believe that the global temperature rise and the consequent effect of climate change could unleash deleterious effect on biodiversity and its complexity on a global level. The climate-induced changes on a pan-India scale also portend serious threat to Indian biodiversity, especially the diversity of fishes and their populations thriving in the freshwaters. Indian biodiversity-rich 'hot spots' are vulnerable to the glacial-lake outburst floods as occurring in Himalayas and northeastern India (Das, 2010), or to monsoonic cloud outburst and massive landslides in northeastern India and Western Ghats, heavily eroding and decimating biodiversity, especially of the rheophilic fish populations, in the highland river tributaries and mountain streams.

Conservation status of each primary freshwater species (Table-5) as per the IUCN Red Data list (IUCN, 2016) were taken in to account and observed that as many as 148 species (17.25%) are in threatened category (13 Critically Endangered, 63 Endangered and 72 Vulnerable), while 36 species are Near Threatened that liked to slip in to threatenrd category if proper conservation measures not taken. Less than 35% of primary freshwater fishes are Least Concerned that can be consideratively explored for human consumption. However, conservation status of more than 44% of fishes is not known.

Table 5. Conservation status of species in different families (IUCN 2016)

Sl. No.	Family	CR	EN	VU	NT	LC	DD	NA	Species
1.	Notopteridae	--	--	--	1	1	--	--	2
2.	Anguillidae	--	--	--	2	1	--	1	4
3.	Clupeidae*	--	--	--	--	2	--	--	2
4.	Cyprinidae	7	32	37	13	116	21	119	345
5.	Psilorhynchidae	1	1	--	--	3	3	9	17
6.	Cobitidae	--	2	1	1	17	2	5	28
7.	Balitoridae	--	4	1	1	4	1	5	16
8.	Nemacheilidae	2	9	17	3	27	6	49	113
9.	Amblycipitidae	--	1	--	--	3	3	3	10
10.	Akysidae	--	--	--	--	1	1	--	2
11.	Sisoridae	2	4	9	3	28	15	26	87
12.	Erethistidae	--	--	--	--	7	14	8	29
13.	Kryptoglanidae	--	--	--	--	--	--	1	1
14.	Siluridae	--	2	--	4	2	2	3	13
15.	Chacidae	--	--	--	--	1	--	--	1
16.	Clariidae	--	1	--	1	--	2	2	6
17.	Heteropneustidae	--	--	--	--	1	1	--	2
18.	Ailiidae	--	1	--	1	5	4	2	13
19.	Horabagridae	--	2	1	--	1	1	--	5
20.	Pangasiidae	--	--	--	--	1	--	--	1
21.	Bagridae	1	1	1	1	27	4	15	50
22.	Mugilidae*	--	--	--	--	2	--	--	2
23.	Adrianichthyidae	--	--	--	--	4	--	--	4
24.	Belonidae*	--	--	--	--	1	--	--	1
25.	Aplocheilidae	--	--	--	--	3	--	4	7
26.	Cyprinodontidae	--	--	--	--	1	--	--	1
27.	Syngnathidae	--	--	1	1	2	--	1	5
28.	Synbranchidae	--	1	1	--	3	4	1	10
29.	Mastacembelidae	--	--	--	--	5	1	3	9

Sl. No.	Family	CR	EN	VU	NT	LC	DD	NA	Species
30.	Chaudhuriidae	--	1	--	1	--	--	--	2
31.	Ambassidae*	--	--	--	1	5	--	3	9
32.	Nandidae	--	--	--	--	1	1	--	2
33.	Pristolepididae	--	--	--	--	1	--	3	4
34.	Badidae	--	1	--	--	2	3	13	19
35.	Cichlidae	--	--	--	--	2	--	1	3
36.	Gobiidae*	--	--	--	--	3	1	3	7
37.	Anabantidae	--	--	--	--	--	2	--	2
38.	Osphronemidae	--	--	1	1	5	--	--	7
39.	Channidae	--	--	1	1	6	2	4	14
40.	Tetraodontidae*	--	--	1	--	1	1	--	3
	TOTAL	**13**	**63**	**72**	**36**	**295**	**95**	**284**	**858**

Abbreviatons used. CR: Criticaly Endanged, EN: Endangerd, V: Vulerable, NT: Near Threatned, LC: Least Concern, DD: Data Deficient, NA: Not Assessed.

* Fishes of these families are primarily marine inhabitants.

Discussion

Fishes are strongly dependent on lotic and lentic waters of rivers, streams and other wetland systems. Species and their taxonomy being well-known, available data on their diversity are sufficient enough to model their current distributions. Therefore, their diversity and depletion trends in the aquatic ecosystems can be taken as an effective biodiversity tool to assess the protection level of ecosystems and species, and take steps towards identifying systematic conservation priorities for fresh waters and the biodiversity they support. The level of human-induced disturbances that influence condition of rivers, their stream reaches and other wetlands both within and outside of terrestrial protected areas, are to be appropriately assessed and quantified. Variable number of human-induced disturbances reflects global trends of the state of fresh waters and their supported biodiversity (Dudgeon *et al*. (2006).

The scientific studies and research need to address the knowledge gap, regarding the mismatch in the level of understanding about the factual, or reasonably accurate knowledge on the biodiversity potential of the freshwater systems (i.e., dimensions of biodiversity attributes of the freshwater ecosystems, including their ecological services), management policies and biodiversity-conservation strategies for freshwater systems, especially the river drainage systems, their tributaries, streams and associated wetlands/floodplains.

Given the interconnected nature of freshwater ecosystems and the limited protection afforded to them, comprehensive assessments on the disturbances, including the problems caused by the invasive alien species, that might affect these ecosystems and their biodiversity are imperative measures and strategies to mitigate the problems. Terrestrial protected areas seldom afford effective protection to fresh waters and their biota, including fishes, as evidenced by upland rivulets, riparian stream-reaches and their associated wetlands being modified, altered or influenced by the great pressure of human-induced disturbances. Reserves alone are not adequate for nature conservation though they are the cornerstone on which regional strategies are built (Marguels and Pressey, 2000).

The identification of disturbances and their proximity to protected areas can further demonstrate the level of effectiveness of terrestrial protected areas for abating threats to freshwater ecosystems and species (Sanchez-Arguello *et al*. 2010). The poor protection of fresh waters causing the consequent ill-effects on their biodiversity warrants attention with regard to policy, biodiversity planning and implementation of conservation actions. Planning for the conservation of fresh waters and their dependent species requires holistic consideration of the whole-of-catchment connectivity of the drainage basin and the disturbances.Globally, there has been very little emphasis on designating protected areas for the primary purpose of conserving fresh waters (Nel *et al*., 2007). Many wetlands in India, listed under IUCN category II protection, are facing serious threats, their protection being highly fragmented. Wetlands lying in the floodplains of most catchments have been filled or have had riparian vegetation heavily cleared for agriculture or susceptible to landscape alterations and weed infestations.

The estuarine wetlands, in continuity with their upriver freshwater stretches are important for freshwater biodiversity and ecosystem services, and are prioritised for protection by the Convention on Biodiversity. Given the greatest level of protection afforded to such wetlands, there is a need for greater conservation action to protect, restore and maintain ecosystem functioning of these wetlands in the region. It meets the international conservation targets, and as well ensures conservation of critical habitats that support a number of endemic and range-restricted species in the specific ecosystem.

Fish species and their diversity may be poorly represented in areas of higher elevation, while most freshwater fish species occur in the mid and lowlands. However endemic and rare fish species inhabit more in mid and upper elevations. The rarity and endemism of many fish species warrant greater conservation action than at present to protect and save them from the endangerment of extinction. Many fish species could be at high risk because their prime habitat is in the poorly protected upper streams, midland rivers and floodplains and coastal inland waters.

The inadequacy of the protected-area network in representing important freshwater ecosystems and species underscores the need for freshwater-specific conservation. The terrestrial protected area includes a large proportion of land coverage. However, its spatial distribution is far from optimal in providing adequate coverage of fresh waters and the fish species they support, especially endemics. A major challenge to quantifying the effectiveness of protected areas for representing species is the incomplete information on freshwater biodiversity. The terrestrial protected areas are sometimes shown for their effectiveness taken into account the occurrence of many freshwater fish species—as data are available. However, data are inadequate for other taxa, like many invertebrate groups, amphibians, reptiles and birds that are also reliant on fresh waters.

The entire catchment protection may be preferred from a conservation standpoint. But given the multiple demands on resources that catchments and fresh waters experience, it is rarely a feasible proposition. Although the existing protected area network does not include broad representation of fresh waters, additional network can be established for further protection, or existing undisturbed areas can be linked with other critical areas through restoration. Identifying fresh waters and species that are particularly vulnerable to local and upstream/downstream disturbances is an imperative measure. In conservation perspective, there is even a need for off-reserve management of fresh waters on both public and private lands (Linke *et al*., 2007).

In the current era of conservation programmes, there is an important aspect to consider the threat of global climate changes that are hard to plan for or manage. Changes in rainfall are likely to entail variability of discharge and reduce the extent of higher-order streams, which support richer diversity of fish; reduced dry-season discharge in upland streams could unleash resultant changes in habitat, negatively affecting many endemic species of fish and amphibians. Wetland protection tends to focus on specific sites, especially lentic systems, such as freshwater protected areas, e.g. Ramsar wetlands, and ignores the interconnected network across catchments. Protected areas cannot act as the only strategy for achieving freshwater conservation challenges. There is a need to build on existing protected areas networks to provide protection to focal freshwater ecosystems, and connect this with whole-of-catchment management. Holistic approaches to conservation ensuring spatial-temporal protection of specific, relevant habitat cum species conservation management would lessen or moderate the impacts, providing ecosystem and species persistence under current pressures and anticipated global change.

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PLATE I
Some Endemic Fishes of India

Barilius bakeri Day

Barilius canarensis (Jerdon)

Garra periyarensis Gopi

Garra arupi Nabeshwar, Vishwanath *& Das*

Garra elongata Vishwanath & Kosygin

Garra tamangi Gurumayum & Kosygin

Pethia punctata (Day)

Puntius mahecola (Valenciennes)

Dawkinsia tambraparniei (Silas)

Glyptothorax maceriatus Ng & Lalramliana

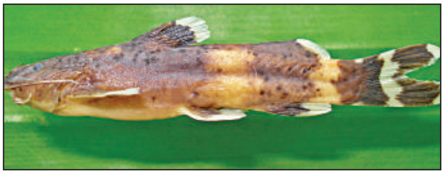
PLATE II

Some Endemic Fishes of India

Sahyadria denisoni (Day)

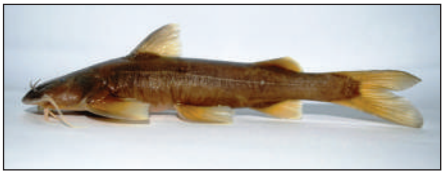
Tor khudree (Sykes)

Glyptothorax kudremukhensis Gopi



Glyptothorax malabarensis Gopi

Glyptothorax senapatiensis Premananda, Kosygin & Saidullah

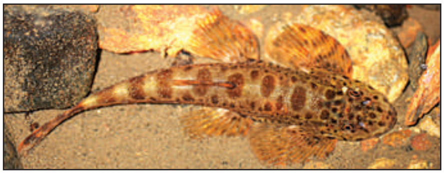


Glyptothoraxs crobiculus Ng & Lalramliana

Aborichthys waikhomi Kosygin

Schistura prashadi (Hora)

Horaglanis alikunhii Subhash Babu & Nayar



Bhavania australis (Jerdon)

Chapter 34

AMPHIBIA

KAUSHIK DEUTI

ABSTRACT

Of the 386 species of amphibians known from India till date, about 275 species belonging to 48 genera and 13 families dwell primarily in fresh-water ecosystems. 11 families of Anurans (frogs and toads) comprising of 42 genera and 234 species breed in fresh-water or have tadpoles that develop in fresh-water. Both the species of Urodelans (salamanders: Salamandridae) found in India have gilled tadpoles with well-developed limbs that develop in fresh-water mountain lakes. 3 families of Caecilians (limbless amphibians) comprising of 5 genera and 39 species all have larval stages that are aquatic. Deforestation, damming of rivers, over-fishing and pollution by domestic, agricultural and industrial sewage like pesticides, fungicides, heavy metals, aromatic hydrocarbons; capture of frogs for frog-leg trade; acidification, climate change and global warming and effect of UV-B radiation as a result of ozone layer depletion are primary causes for the population decline of fresh-water amphibians in India.

Key words: Amphibia, Anurans, Caecilians, Urodelans, India.

INTRODUCTION

Amphibians are represented today by three living orders: Anura/Salientia (frogs and toads with 6706 species worldwide), Caudata/Urodela (salamanders and newts with 693 species worldwide) and Gymnophiona /Apoda (caecilans or limbless amphibians with 205 species worldwide). Thus 7604 species of amphibians are known globally now. Of these, 386 species belonging to 59 genera and 15 families of all three living orders of amphibians are known from India up to 2016. This comprises about 5% of the species known from the world. In India, there are 345 species of frogs and toads (Anura), 2 species of salamanders (Caudata / Urodela) and 39 species of caecilans or limbless amphibians (Gymnophiona). Of the 386 species of Indian amphibians, about 275 species are aquatic and dwell in fresh-water.

Fossil History

There are no fossil records of fresh-water Indian amphibians.

Historical Resume (Review of Literature)

Pre 1900: Systematic collection of Indian amphibians started with the foundation of the Asiatic Society of Bengal. Large number of zoological curiosities including

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amphibians from all over the British Indian Empire and far beyond, including the Middle East, Africa, North America, Central Asia, Sri Lanka, the Malay Peninsula and eastern China began to arrive at the Society after about 1828. These were either sent as gifts to the Society or collected by the staff of the Society during the many expeditions to the then poorly explored parts of Asia. In 1866, with the passing of the Indian Museum Act, this collection was handed over to the Indian Museum. With the establishment of the Zoological Survey of India in 1916, the zoological collections of the two former institutions were passed on to this organization which is now regarded as the National Zoological Collection (NZC) of India.

The first curator of the Asiatic Society was Edward Blyth during the period 1841-1863. Blyth did little field collection himself (although he described many species like *Rana livida, Rana nigrovittata* and *Microhyla* berdmorei) but built up the finest zoological collection in the East by persuading friends such as Surgeon-Major Thomas ClaverhillJerdon (1811-1872), Colonel Arthur PurvesPhayre (1812-1885), Brian Houghton Hodgson (1800-1894) and Dr. Edward Fredrick Kelaart (1819-1860) to send him specimens from all over India and other parts of the British Empire, particularly from Sri Lanka, Nepal and Myanmar. Jerdonalso made a catalogue of the reptiles inhabiting the peninsula of India in 1853 and published the notes on Indian herpetology in 1870 in which he described several new species of amphibians. Blyth also sent huge number of these collections to the British Museum in London where the then curators Albert Gunther and then George Albert Boulenger described a large number of new Indian amphibian species.It was thought necessary to establish a formal museum, which led to the establishment of the Indian Museum in 1874. Its first superintendent was John Anderson and during his time, several important expeditions were organized to different parts of India which add significantly to the collection of the Museum. Anderson listed the amphibians accessed by the Indian Museum from 1865-1870, described the Himalayan newt (*Tylototriton* verrucosus) from western Yunnan in 1871 and reported a caecilian from Goalpara (Assam) and Shillong (Khasi hills). William Thomas Blanfordreported caecilians from Himalayas and Central India and the genus *Pyxicephalus*from India and those donated to the Museum by Ferdinand Stoliczka who made observations on Indian and Malayan amphibians and described the new species, *Rana vicina* from Punjab. William Theobald also contributed numerous novelties to the collection of the Museum. The first effort to prepare a catalogue of the herpetological holdings in the Indian Museum in 1866 was made by Theobald. The last catalogue of the amphibians in the Indian Museum was prepared by William LutleySclaterin 1892 who also described some new species. Colonel Richard Henry Beddome an officer of the British Army who collected in Southern India described several new reptiles from the Madras Presidency and described the rare Black Microhylid frog (*Melanobatrachus indicus*) in 1878.

1900-1947: Thomas Nelson Annandale joined as Deputy Superintendent of the Indian Museum in 1904 and later became the Superintendent in 1907. He founded the Zoological Survey of India in 1916. Annandale worked on the amphibians of the Chilika lagoon, their eggs and distribution of the Himalayan salamander and fauna of Yunnan and made an expedition to the Abor hills of Arunachal Pradesh and Tibet from which he described several new species of amphibians. He also worked on the tadpoles of the families Ranidae and Bufonidae. Annandale's own student Sunder LalHoraalthough best known as an ichthyologist and biogeographer also published several important papers in herpetology including the development and evolution of the suctorial oral disc in hill-stream tadpoles of the genus *Amolops*and *Megophrys*between 1920-1934. C.R.N. Rao, a teacher at the Central College in Bangalore, also described a number of amphibians from Peninsular India like *Nyctibatrachus sanctipalustris modestus, Bufo stomaticus peninsularis, Rana gracilis montanus, Rana bhagamandlensis, Rana limnocharis mysorensis* and the new genus *Ramanella*. B.R. Seshachar also worked during this period (1935-1948) on the reproduction, egg laying and cytogenetics of caecilians in Karnataka.

1948-2014: After India's independence, the scientists of the Zoological Survey of India initially took up the leading role in the study of India's amphibians. Hora's junior colleague, Mira Mansukhani studied the tadpoles with suctorial discs from Darjeeling hills and the amphibians of Rajasthan, Tripura, Midnapore district of West Bengal, described a new toad (*Bufo camortensis*) from Camorta Island of Nicobars. R.S. Pillai also of the Zoological Survey of India, described several new species from different parts of India like *Microhylachakrapani, Micryletta inornata, Micrixalus nudis, Rana murthii, Micrixalus thampii, Bufosilentvalleyensis, Ansonia rubigina, Micrixalusgadgili*etc between 1977-1991. He along with S.K. Chanda described some species from North-eastern India like *Ranadanieli, Rana mawphlangensis, Rana bilineata*between 1973-1981. Shyamal KumarChanda also described a number of new species from North-eastern India like *Rana senchalensis, Rana ghoshi, Rana mawlyndipi*etc between 1986-1989. Anurup Kumar Sarkar also studied the amphibians of Namdapha Tiger Reserve in Arunachal Pradesh. He also studied the amphibians of West Bengal, Orissa, Andhra Pradesh, Gujarat, Chotanagpur plateau in Bihar. J.C. Daniel and A.G. Sekar of the Bombay Natural History Society studied the amphibians of the Western Ghats and Goa respectively between 1963-1989 and 1988-1996. Thereafter, several teachers and researchers like Sushil Kumar Dutta studied the taxonomy and life history of the amphibians of Orissa and other parts of India and described some new species like *Limnonectes orissaensis, Microhyla sholigari, Kalophrynus orangensis* between 1983-2003. Robert Inger and S.K. Dutta prepared the first list of Indian amphibians in 1986. Indraneil Das studied the morphology and systematics of the amphibians of South India and Andaman & Nicobar Islands and described several new species like *Limnonectes shompenorum, Rana charlesdarwini, Kaloula assamensis, Nanorana mokokchungensis, Leptolalaxkhasiorum*etc between 1994-2010. Satyabhama Das Biju and Franky Bossuyt made the significant discovery of the Pig-nosed frog (*Nasikabatrachus sahyadrensis*) in 2003 and since then have described many species from Western Ghats and North-eastern India.Varad Giri along with Mark Wilkinson and David Gower worked on the caecilans of the northern Western Ghats and described species like *Gegeneophis danieli, G. pareshi, Indotyphlus maharashtraensis* while Gopal Krishna Bhatta worked on the caecilians of southern Western Ghats and described 5 species between 2004-2011. Rachenliu

Kamei with Mark Wilkinson, David Gower and S.D. Biju worked on the caecilans of North-eastern India and described 4 new species including the genus *Chikila.*

Diversity

(a) Global Status: 7604 species of amphibians are known from all over the world now. This includes 6706 species of Anurans (frogs and toads), 693 species of Urodeles (salamanders and newts) and 205 species of Gymnophionans (caecilians).

(b) Indian Status: As of 2016, the known amphibian species from India was 386 belonging to 59 genera and 15 families of all three living orders of amphibians. This comprises about 5% of the species known from the world. In India, there are 345 species of frogs and toads (Anurans), 2 species of salamanders (Urodela) and 39 species of Caecilans (limbless amphibians). About 275 species belonging to 48 genera and 13 families of Indian amphibians dwell primarily in fresh-water ecosystems.

Table 1. The taxonomic status of Indian fresh-water amphibians with the names of families, genera and number of species in each genus

Order ANURA (frogs & toads)

Family	Genera	Number of Species
Bufonidae	*Bufoides*	1
	Bufotes	1
	Duttaphrynus	19
	Ghatophryne	2
	Ingerophrynus	1
	Pedostibes	2
	Xanthophryne	2
Dicroglossidae	*Allopaa*	2
	Chrysopaa	1
	Euphlyctis	5
	Fejervarya	4
	Hoplobatrachus	2
	Ingerana	2
	Limnonectes	8
	Minervarya	2
	Occidozyga	2
	Ombrana	1
	Paa	9
	Sphaerotheca	4
	Zakerana	18

Family	Genera	Number of Species
Megophryidae	*Leptobrachium*	3
	Leptolalax	4
	Megophrys	3
	Scutiger	2
	Xenophrys	9
Micrixalidae	*Micrixalus*	23
Microhylidae	*Kalophrynus*	1
	Kaloula	4
	Melanobatrachus	1
	Microhyla	8
	Micryletta	1
	Ramanella	6
	Uperodon	2
Nasikabatrachidae	*Nasikabatrachus*	1
Nyctibatrachidae	*Nyctibatrachus*	28
Ranidae	*Amolops*	13
	Clinotarsus	2
	Humerana	1
	Hylarana	19
	Odorrana	3
	Pterorana	1
Ranixalidae	*Indirana*	11

Order URODELA / CAUDATA (Salamanders)

Family	Genera	Number of Species
Salamandridae	*Tylototriton*	2

Order GYMNOPHIONA (Caecilians)

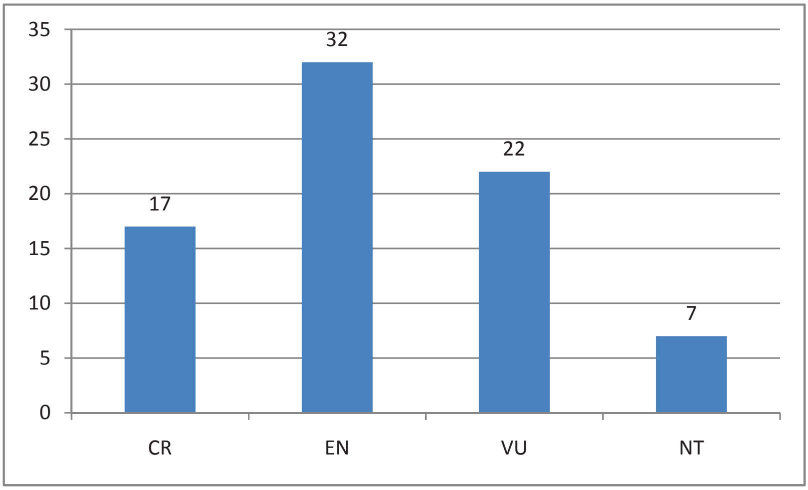
Family	Genera	Number of Species
Chikilidae	*Chikila*	4
Ichthyophiidae	*Ichthyophis*	15
	Uraeotyphlus	7
Indotyphliidae	*Gegeneophis*	11
	Indotyphlus	2

Distribution: Out of the Indian amphibians about 196 species are found in the Western Ghats and another 102 species in North-eastern India. The rest of the species are distributed throughout the rest of the country and some of them are common all over India.

Endemism: Out of the amphibians known from India, 234 species are endemic (68.42%). Of these 234 endemic species, 167 species are endemic to the Western Ghats (71.36%) and 54 species are endemic to North-eastern India (23.07%), making these two areas as biodiversity hotspots. Besides, 2 species are endemic to Eastern Himalayas, 2 species are endemic to Western Himalayas, 1 species to Eastern Ghats, 5 species to Andaman & Nicobar Islands, 1 species to Northern India, 1 species to Central India and 1 species to Northern Bengal.

THREATENED TAXA

Of the Indian amphibians, 78 species are threatened according to IUCN. Of these, 78 threatened species, 17 species are listed as Critically Endangered, 32 species as Endangered, 22 species as Vulnerable and 7 species as Near Threatened. According to the IUCN Red list of threatened species, the status of Indian amphibians is 4.97% Critically endangered; 9.35% Endangered; 6.43% Vulnerable and 2.04% Near Threatened. Out of the 386 species of known Amphibians from India, 74 species (21.63%) are yet to be evaluated and 81 species (23.68%) are still under the data deficient category.



Number of Species of Threatened Amphibians in different threat categories.

Threats: The various threats responsible for population decline of amphibians in India are:

Deforestation and Habitat destruction

Deforestation has affected not only the population of canopy-dwelling primates and other forest-dwelling wild animals but also the forest-dwelling amphibians. In some places, the opening up of the canopy has resulted in desiccation of the moist leaf litter which has severely affected the population of the litter-dwelling amphibians. With the rain-forest canopy no longer providing shade to the small rain pools on the forest floor, the small frogs can no longer find their suitable breeding habitat. Certain forestry practices such as removal of the leaf litter are also causing amphibian population decline. Many of these amphibian species are so far known from only one small forest patch, i.e., they are point endemic and with the destruction of these small forest patches, these small endemic amphibians are vanishing before scientists are discovering anything about their life and habits.

In some places, the excessive clearing of undergrowth (understory vegetation) for housing purposes and landscape gardening has resulted in the decrease in the presence of the bush frogs and tree frogs.

Damming of rivers

India has a number of rivers and rivulets that debouch from the hills into the vast plains and these become turbulent during the monsoons. Engineers use the potential of these rivers to tap hydro-electricity by damming them. As a result the forests downstream have often been severely affected and with them the many small living creatures including the amphibians. Besides the construction of innumerable small check-dams over the hill-streams, has resulted in drying of these streams, thus affecting the stream-dwelling amphibians.

Over-fishing and pollution

Moreover, over fishing in these hill-streams, often by using poisons and electric charge from portable generators to shock the fishes has decimated the meager population of hill-stream amphibians.

Pesticides and Fungicides

Many scientists believe that increasing use of pesticides and fungicides may be responsible for frog deaths. Spraying of pesticides not only poison frogs directly, it also wipes out their food supply. Amphibians are susceptible to at least 211 different pesticides. Organo-phosphate insecticides, like malathion, are known to disturb the frog's development, distorting the growth of their limbs at the egg and tadpole stages. Frog deformities such as multiple or missing limbs and body abnormalities because of unchecked use of chemicals have already been reported from many areas. Amphibians are highly vulnerable to toxics because they have thin permeable skin that readily absorb contaminants and their eggs lack protective shells and are highly permeable as well. Pollution by heavy metals, pesticides, aromatic hydrocarbons and radioactive waste is frequently invoked as a cause for local declines. In some heavily industrialized areas, pollution is so intense that it is a wonder that there are any amphibians left.

Global Trade and Capture of frogs

Uncontrolled international trade in amphibians is also threatening several species. The Convention on International Trade in Endangered Species (CITES) or the Washington Convention, has already banned trade in two amphibian species – Indian Bull Frog (*Hoplobatrachustigerinus*) and Green Pond Frog (*Euphlyctishexadactylus*). As many as 30 frogs are killed to make a kilogram of frog legs. India exported as much as 4000 tonnes of frog legs a year in the mid-1980s. After the ban in India, Bangladesh and Indonesia have become major exporters of frog legs. But not even a total ban can prevent the killings; the illegal export continues to thrive in all the three countries. Frogs are particularly important for a country such as India, where the agricultural sector plays a vital role in the economy. They devour pests which pose a threat to crops and prevent the spread of vector-borne diseases like malaria because they consume parasites responsible for the disease. An adult frog devours its own weight of insects daily. Thus if its population goes down, the insect population goes up. The decimation of frogs means increasing the use of pesticides which poses serious health hazards to all living organisms. According to experts at the Bombay Natural History Society, in many parts of western Maharashtra, crops have been badly hit by proliferating insects as a result of large-scale slaughter of frogs.

Climate change and Global warming

The exact effects of climate change and global warming on the Indian amphibians are not known, or whether they are affected by any specific disease. The stresses of a changing climate could make amphibians more susceptible to infection. A change in the moisture regime or a change in water temperature might weaken amphibian immune systems. Warmer water might also affect a pathogen's virulence, or its capacity to move from one animal to another. Warmer air might increase the range of insects that carry it.

Acidification

Another anthropogenic disturbance that is suspected to have a negative effect on amphibian populations is acidification of water bodies. In the industrialized nations this is happening because of increasing sulphur dioxide (SO_2) and nitrogen dioxide (NO_2) emissions. SO_2 (in the presence of sunlight) and NO_2 react with water vapour to form sulphuric and nitric acids. The rain water contaminated with these acids affects flora and fauna both on land and water adversely.

UV Radiation

UV radiation affects amphibian eggs in shallow lakes and ponds which either fail to hatch or produce deformed tadpoles. It is likely that increased UV levels are injuring other amphibians, particularly those at higher altitudes where the ozone layer tends to be weaker. Amphibians at higher elevations could be especially susceptible, since the higher you go, the less atmosphere there is to filter out the Ultra-violet radiation.

Human significance

The first vertebrate animal to which virtually everyone is introduced to in their high school practical classes is undoubtedly the common Indian toad (*Duttaphrynus melanostictus*). Every year millions of amphibians are killed throughout the world to acquaint the young biologist with the intricacies of vertebrate anatomy. Perhaps still greater is the number that is sacrificed in research and clinical laboratories the world over for experiments on physiology, pharmacology and medicine. In fact, the first successful heart transplantation was performed on a frog about 65 years ago and till recently amphibians were widely employed in human pregnancy tests until better methods were devised. The venoms of some South American Poison-dart frogs are used for the production of anti-fungal ointments while some other colourful species are keptas pets in aquariums by private collectors and zoos.

Amphibians render incalculable services to agriculture. By sowing vast areas with food and other crops, we create the most suitable conditions for the life and reproduction of insect pests that feed on these plants. And they infact take advantage of these ideal living conditions to inflict considerable and sometimes catastrophic losses on our agriculture. This is where the significance of amphibians is the greatest. Wherever we have not sharply reduced their numbers they become active defenders of our crops and help us in saving the harvest.

The overall importance of the amphibians in the biological control of pests has not yet been fully documented. Investigations on the amphibian diet in our country and worldwide has revealed that the insects they feed on are mostly destructive. Frogs and toads devour whatever small living creatures they see more often and owing to the fact that insect pests are more numerous in our agriculture fields than other insects, they make up 80-85% of the food consumed by them. For instance, a single toad can eat 22,500 destructive insect pests during the growing season from May till September at the rate of 150 per day. Therefore toads are valuable additions to the fauna of the agricultural areas despite their warts and unappealing appearance. Every year amphibians thus protect crops worth crores of rupees.

One major feature of the hunting habits of frogs and toads has made them the most versatile protectors of our crops. Insectivorous birds feed only during the daytime. Hence their diet comprises only of pests that are active during the day time. But amphibians hunt round the clock – mostly at twilight and by night and even sometimes during the morning. Therefore they render great service to mankind by exterminating the nocturnal insects that are not taken by the birds. They also feed on poisonous insects and do not abstain from takingcertain caterpillars that are brightly coloured and are avoided by the majority of birds. They help in reducing the number of many blood-sucking insects which are vectors of deadly diseases. Adults actively feed on mosquitoes and flies while the tadpoles and young froglets consume their larvae and pupae. Tadpoles also consume many kinds of organic materials that might otherwise pollute our ponds and rivers and sometimes act as scavengers by feeding on dead animals. Thus in every respect they may be considered as our true friends.

The most important function of amphibians in nature has been grossly underestimated. While on the one hand they are active predators, on the other hand they constitute a vital link in the food chain of life by serving as prey base for apex predators in the ecosystem. Being extremely voracious they are natural population regulators of the numerous invertebrate species that they feed on. In their turn, amphibians are extremely prolific breeders, capable of rapid growth and intensive utilization of available food resources. Thus they are able to increase their number and biomass very rapidly and so govern the population of the secondary predators who feed on them. They furnish food for several kind of fishes, turtles, snakes and birds and serve as staple diet for many endangered species in the wild.

Amphibians are also utilized as food by humans in many parts of the world. Frogs' legs are considered a delicacy in Europe and the United States. Therefore since 1959 the export of 'froen frog-legs' worth lakhs of rupees had steadily caught up. The species involved were the Indian Bull Frog (*Hoplobatrachus tigerinus*), the Jerdon's Bull Frog (*Hoplobatrachus crassus*), the Green Pond Frog (*Euphlyctis hexadactylus*) and sometimes the Skittering Frog (*Euphlyctis cyanophlyctis*). It has been estimated that 15-20 edible frogs are required to make a decent meal for a single person and in favourable weather a frog-catcher could collect 50-60 in a single night. This sort of wanton destruction of the entire frog population resulted in depletion of the large-sized frogs, affecting the status of these species as well as its commercial value. Due to this merciless removal of these common frogs from nature, villagers in many areas felt a disturbance in the balance of nature.

Conservation value

The Indian Wildlife (Protection) Act, 1972 has enlisted 3 species of amphibians in Schedule II of the Act (*Tylototriton verrucosus, Pedostibeskempi*and *Pedostibes*tuberculosus) besides enlisting all the Ranid frogs under Schedule IV. Since 1st April, 1986, the Government of India has banned the processing and exporting of frozen frog-legs and thus stopped the trade in frogs like the Indian Bull Frog (*Hoplobatrachus tigerinus*), the Jerdon's Bull Frog (*Hoplobatrachus crassus*) and Green Pond Frog (*Euphlyctis hexadactylus*) which used to be killed and exported in vast quantities. Of the Indian amphibians, 78 species are listed as threatened according to IUCN (International Union for Conservation of Nature and Natural Resources). Of these, 78 threatened species, 17 species are listed as Critically Endangered, 32 species as Endangered, 22 species as Vulnerable and 7 species as Near Threatened. Apart from these, the Convention on International Trade in Endangered Species (CITES) or the Washington Convention, has already banned trade in two Indian amphibian species – Indian Bull Frog (*Hoplobatrachus tigerinus*) and Green Pond Frog (*Euphlyctis hexadactylus*) and included them under Appendix II. Many of the Government and Non Governmental Organizations in India are actively organizing conservation awareness programs among the citizens and local people against the harmful effects of habitat destruction, deforestation, jhum cultivation, fragmentation, opening up of rain-forest canopy, damming of rivers, pollution (industrial and chemical fertilizers and organo-chlorine and organo-phosphate pesticides), climate change and global warming etc which are all responsible in conserving the amphibian species of the country.

Gaps in research

Although some work has been done on the taxonomy and biodiversity of Indian amphibians in some areas of India like the Western Ghats, this work remains to be done in many other important areas like the Eastern Ghats, Eastern and Western Himalayas and North-eastern India. Besides, except for a handful of common species, nothing is known about the biology (habitat ecology, habit and behavior, call, reproduction, larval development, metamorphosis and food habits) of most Indian amphibians. Without knowing anything about the biological characteristics of most Indian amphibian species, it is difficult or impossible to understand the specific threats they are facing (adverse effects of deforestation, habitat modification, fragmentation, diseases, pollution, global warming, climate change and increasing UV radiation). Therefore, there is immediate need to take up specific research projects on biological features of most of the Indian amphibian species as well on their ecology to understand which specific factors are leading to their decline. However, this work is not possible without properly identifying the species being studied. So there is an urgent need to develop expertise in morpho taxonomy as well as molecular taxonomy to understand the systematics and phylogeny of the Indian species which have many origins (African, Chinese, Malayan, Central Asian as well as Indian). Similarly there is need to do bioacoustical analysis on the calls of the Indian species to understand their species diversity. Practically nothing is known about the larvae of most Indian species. This study must be taken up immediately along with studies on their life cycle and developmental biology. Specific studies must also be taken up to understand the density (numbers) of amphibians in most important ecosystems as no quantitave data exists on all the Indian species and therefore their decline in numbers cannot be estimated. A thorough understanding of their habitat ecology is needed to understand the effects of habitat modification, fragmentation, pollution, global warming and climate change on their numbers.

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PLATE I

Aloysi Skittering Frog (*Euphlyctis aloysii*)

Annandale's Hill Frog (*Paa annandalii*)

Cricket Frog (*Fejervarya* sp.)

Indian Bull Frogs (*Hoplobatrachus tigerinus*)

Indian Bull Frog (sub-adult)

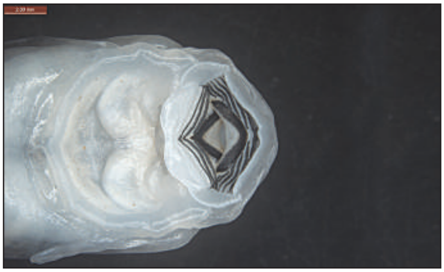
Green Pond Frog (*Euphlyctis hexadactylus*)

Long-tongued Frog (*Hylarana leptoglossa*)

Mangrove Crab-eating Frog (*Fejervarya moodiei*)

PLATE 2

Marbled Stream Frog
(*Amolops marmoratus*)



Tadpole of Marbled Stream Frog with ventral sucker for attaching to underwater rocks

Skittering Frog
(*Euphlyctis cyanophlyctis*)

Terai Cricket Frog
(*Fejervarya teraiensis*)

Caecilian

Marbled Toad (*Duttaphrynus stomaticus*)

Himalayan Salamander
(*Tylototriton himalayanus*)

Tadpole of Himalayan Salamander

Chapter 35

REPTILIA

VARADARAJU

ABSTRACT

The study deals with 46 species of fresh-water reptiles known from India. This includes 2 species of Crocodiles belonging to 2 families, 21 species of turtles belonging to 2 families, 3 species of lizards belonging to 2 families and 20 species of snakes belonging to 4 families. The distribution, endemism and biology of fresh water reptiles are also given along with the recent threats & conservation status.

Key words: Reptilia, Crocodiles, Lizards, Snakes, Turtles, Freshwater, India.

INTRODUCTION

Reptiles were the first terrestrial, poikilothermic and omniote vertebrates found to occur in all kinds of environment in the world except the severe cold region, they produce shelled eggs with large yolk which helps the species to live on land. Reptiles are characterised by dry and cornified skin usually covered with epidermal scales or scutes. The integumentary glands are a few scent glands that help to attract the opposite mates during breeding season. Two pairs of pentadactyle limbs which end in clawed digits (absent in snakes and limbless lizards).

There are 566 species of reptiles so for reported from India, of which 3 species are Crocodiles, 33 species of Testudines, 234 species of lizards and 296 species of snakes. Out of these 234 species (42%) are endemic to Indian subcontinent. The present work deals with 46 species of fresh water reptiles comprising one species of Crocodylia, one species of Gavialidae, 21 species of Testudines, one species of skink, two species of monitor lizard and 20 species of snakes which are completely or partially found to occur in fresh water habitat.

Fossil History

The Mosasaur (means the Lizard of the Meuse River (Mosa stands for Meuse river in Holland-location where it was first described) were the first aquatic reptiles that are closely related to snakes and monitor lizards of today. Classified under Class: reptilia, Order: Squamata, Superfamily: Mosasauroidea, Family: Mosasauridae Subfamily: Mosasaurinae and Tylosaurinae, Mosasaurs are considered one of the Great Marine Reptiles that ruled the sea during the Cretaceous period. It was extinct at the end of Cretaceous during Cretaceous mass extinction event. *Pannoniasaurus*, the creature was the first mosasaur thought to spend its entire life in freshwater. The Fossils belonging to an 84-million-year-old freshwater sea monster have been found in Hungary, according to

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a new study Gallagher, 2005. The new mosasaur was discovered in the waste dump of a coal mine in western Hungary. Scientists uncovered thousands of fossils belonging to several *Pannoniasaurus* individuals ranging from three feet (one meter) to 13 feet (4 meters) in length at the site. The discovery of so many *Pannoniasaurus* specimens at one site also suggests the species was a true freshwater dweller and not just a marine mosasaur that occasionally ventured into rivers, the way some sharks do (Lindgren John *et al.,* 2014).

Table-1. Global diversity (Family/ Genera/Species wise) of fresh water Reptiles

Region-Order/Family	PA*	NA	NT	AT	OL	AU	PAC	ANT	WAS
1. Order CROCODYLIA Family ALLIGATORIDAE	0	1(1)	5 (3)	0	1(1)	0	0	0	7# (4)**
Family CROCODYLIDAE	2 (1)	1(1)	4(1)	3 (2)	5(1)	4(1)	0	0	14 (2)
Family GAVIALIDAE	1(1)	0	0	0	2(2)	0	0	0	2(2)
Total									23(8)
2. Order CHELONIA Family CHELIDAE			23(7)			23(7)			56(14)
Family PELOMEDUSIDAE				19(2)					19(2)
Family PODOCNEMIDIDAE			7(2)	1(1)					8(3)
Family CARETTOCHELIDAE						1(1)			1(1)
Family CHELYDRIDAE		2(2)	2(1)						4(3)
Family DERMATEMYDIDAE			1(1)						1(1)
Family EMYDIDAE	1(1)	42(11)	6(1)						48(12)
Family GEOEMYDIDAE	3(1)		9(1)		57(23)				68(24)
Family KINOSTERNIDAE		12(2)	17(3)						26(4)
Family PLATYSTERNIDAE					1(1)				1(1)
Family TRYONICHIDAE	4(4)	3(1)		5(3)	17(10)				26(15)
Total									257(79)
3. Order SQUAMATA Suborder SAURIA Family AGAMIDAE					4	2			5
Family CORYTOPHANIDAE			4						4
Family GERRHOSAURIDAE				1					1
Family GYMNOPTHALMIDAE			7						7
Family LANTHANOTIDAE					1				1
Family POLYCHROTIDAE			7						7
Family SCINCIDAE				6	21	4	1		32
Family TEIIDAE			3						3
Family TROPIDURIDAE			1						1
Family VARANIDAE				2	1	8	1		11
Family XENOSAURIDAE					1				1
Total									73

Region-Order/Family	PA*	NA	NT	AT	OL	AU	PAC	ANT	WAS
Suborder SERPENTES Family ACROCHORDIDAE					1	1			2
Family BOIDAE			4						4
Family COLUBRIDAE	6	21	34	11	35	1			108
Family ELAPIDAE			1	8	3	1			13
Family HOMALOPSIDAE					25	4			29
Family VIPERIDAE		1							1
Total									153(44)

(Source: Bour (2008); Oliver *et al.* (2008); Bauer and Jackman (2008); #: indicates number of species ; **: indicate number of genera.

*: PA- Palearctic; NA- Nearctic; NT- Neotropical; AT- Afrotropical; OL-Oriental; AU Australasian; PAC- Pacific oceanic islands; ANT- Antarctic; WAS: World aquatic species.

Classification of Reptiles of India:

1. Order CROCODYLIA — Crocodiles, gharials, and alligators comprises 3 species
2. Order SQUAMATA — Sub Order Sauria (Lizards) comprises 234 species

   Sub Order SERPENTES (Snakes) comprises 296 species
3. Order TESTUDINES — Turtles and tortoises: approximately comprises 33 species

Table 2. Diversity of Fresh water Reptiles across family and genera in India.

Sl. No.	Name of Family	Number of Genera	Number of species
1.	Crocodylidae	01	01
2.	Gavialidae	01	01
3.	Geoemydidae	08	13
4.	Trionychiidae	05	08
5.	Scincidae	01	01
6.	Varanidae	01	02
7.	Colubridae	06	16
8.	Hydrophiidae	02	02
9.	Xenopeltidae	01	01
10.	Acrochordidae	01	01
Total	10 Family	27 Genera	46 Species

FRESH WATER CROCODILE

Crocodiles have smooth skin on their bellies and sides, while their dorsal surfaces are armoured with large osteoderms. The armoured skin has thick, rugged scales providing protection to the animal. The scales have pores believed to be sensory in function, analogous to the lateral lines of fishes. The species are characterized by having streamlined body it helps to swim swiftly in water and also webbed foot, allow them to make fast turns and sudden moves in the water. Alligators are fresh water in habit.

Crocodylus paluster or Mugger Crocodile

Endemism: None of the species of Crocodiles and Alligators are endemic to India.

Biology:

Food: Crocodiles mainly feed on fish, amphibia, crustacea, mollusca, reptiles and also some mammals. In addition it also cannibalise smaller crocodiles. The feeding habit of Crocodiles varies with species , size of the animal and age of the animal.

Reproduction: Crocodiles lays eggs either in a hole or mound nest depending on the species. Hole nest is excavated in sand and mound nest built by vegetation. Mating take place in water, where male and female mate several times. Nesting lasts for few weeks to six months and lays egg at night where female protect their nests and young ones.

Behaviour: These are highly social and not territorial animals, congregate in rivers during feeding and basking. The mugger crocodile shows toleration in group feedings and congregate in certain areas. However, males of all species are aggressive towards each other during mating season, to gain access to females.

Habitat: Most of the crocodiles prefer slow moving rivers, swamps, and lakes. It also found to occur in coastal swamps. Alligators are found in fresh water habitat.

Threats: Alligators and Crocodiles are hunted for their hides (hides are fashioned into shoes, handbags and suitcases for the luxury trade), skin (leather goods) and meat. Hence they are listed as endangered species.

Conservation and Human Significance: They are under varying degree of threat and conservation measure initiated by listing under Vulnerable and Critically endangered as per IUCN, Appendix I of CITES and Schedule I of IWP Act. Crocodiles and alligators are at the top of food chains. They weed out overpopulated fishes, including the voracious piranha, and dig water holes in times of drought that save the lives of numerous animals.

FRESH WATER TURTLES

Distribution: Fresh water turtles are distributed throughout the Indian subcontinent

Endemism: There are only two species of fresh water turtles namely Cochin forest Cane turtle,*Vijachelys silvatica* (Henderson, 1912) which is endemic to the Western Ghats and Leith's softshell turtle, *Nilssonia leithii* (Gray, 1872) endemic to peninsular India.

Batagur baska (Photo Courtesy: P.K. Pandit)

Chitra indica

Biology

Food: Adult turtles feed on aquatic plants, invertebrates such as insects, snails, and worms. Several small freshwater species are carnivorous, feed on small fish and a wide range of aquatic life.

Reproduction: Turtles lay eggs that are slightly soft and leathery. Large number of eggs are deposited in holes dug into mud or sand. They are then covered and left to incubate by themselves.

Behaviour: Turtles are not social animals. However, members of same species congregate along stream and during basking on a log.

Habitat: Most of the fresh water turtles inhabit fresh water ponds, lakes and rivers.

Threats: Fresh water turtles population declining due to Habitat degradation, in addition to commercial exploitation for trade its meat regionally and globally.

Conservation and Human Significance: Many came forward to protect these species namely IUCN/SSC Tortoise and Freshwater Turtle Specialist Group (TFTSG). It helped stimulate and mobilize CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora) and protected many fresh water turtles under various categories of IUCN. The Turtles are major biodiversity components of the ecosystems they inhabit, often serving as keystone species from which other animals and plants benefit in the ecosystem

Gaps in research: From the studies carried out on fresh water turtles in India, available information on behavior, reproduction is scanty.

FRESH WATER MONITOR LIZARDS

Monitor lizards have a long neck, powerful tail, claws and well-developed limbs. Majority are terrestrial, some are arboreal and semi-aquatic monitors are also known. While most monitor lizards are carnivorous, feeds on eggs, smaller reptiles, fish, birds and small mammals, some also eat fruit and vegetation, depending on where they live.

Varanus salvator (Photo Courtesy: P.K. Pandit)

Distribution: Monitor lizards are distributed throughout Southern Asia, from India in the west to the Philippines and the Indo-Australian islands in the east.

Endemism: It is not endemic to India.

Biology

Food: Water monitors are carnivorous, feed on variety of prey like fish, frogs, rodents, birds, crabs, snakes and also turtles and also crocodiles and their eggs.

Reproduction: Water monitor breeds in April to October depending on moist and season. Female produce up to 40 eggs in two-three clutches laid in natural mounds such as termite mounds or hollow tree trunks or excavated burrows. The nest is then covered and incubation may last for a few months.

Behaviour: The Monitor lizards try to defend themselves using their tails, claws, and jaws. They are excellent swimmers, using the raised fin on their tails to steer through water. It tears chunks of meat with their sharp teeth while holding it with their front legs and then separating different parts of the fish.

Habitat: It is semi-aquatic and inhabits primary forests and mangrove swamps.

Threats: Water Monitors are exploited for pet trade and also hunted for their skin in India .

Conservation and Human Significance: It is protected under Appendix II of CITES and Schedule I of IWP Act.

Gaps in research: No comprehensive study on behavior and ecology

FRESH WATER SNAKES

Freshwater snake scales are keeled, raised ridge down the center, making them rough to the touch. The pupils in their eyes are round. The markings and coloration vary somewhat from species to species, but for most of them they are brown, gray, olive green or reddish with dark blotches or bands on their backs.

Cerberus rhynchops

Endemism: None of the species are endemic to India

Biology

Food: Fresh water snakes are carnivorous, feeds on fish and amphibians (frogs, toads and salamanders). They prefer slow-moving fish.

Reproduction: They are ovoviviparous, which means that eggs incubate inside the female body. Most species of snakes lay eggs which they abandon shortly after laying. Mating in spring. Males pursue females. Usually only one male mates with a female per season. Females gestate for three to five months.

Behaviour: Snakes often flick its tongue, and use their forked tongue to smell the air.Hibernate in winter and shed their skin three to six times per year.

Habitat: Found in wide variety of fresh water habits like ponds, streams creeks and rivers

Threats: The habitat loss and killing mistakenly as venomous and poisonous lead to the declining population and threat to the species.

Conservation and Human Significance: Most of the snake species are not endangered.

Gaps in research: No consolidated study on fresh water snakes in India

Table 3. Shows Fresh water Reptiles of India and their conservation status

Sl. No.	Scientific Name	Common Name	IUCN Category	CITES List	IWPA
	Order CROCODYLIA Family CROCODYLIDAE				
1.	*Crocodylus palustris* Lesson, 1831	Mugger Crocodile	EN	App I	Sch I
	Family GAVIALIIDAE				
2.	*Gavialis gangeticus* (Gmelin, 1789)	Gharial	Cr EN	App I	Sch I
	Order CHELONIA Family GEOEMYDIDAE				
3.	*Batgur baska* (Gray, 1830)	River Terrapin	Cr EN	App I	Sch I
4.	*Batagur dhongoka* (Gray, 1832)	Three-striped Roofed Turtle	EN	App II	
5.	*Batagur kachuga* (Gray, 1831)	Red Crowned Roofed Tyrtle	Cr EN	App II	
6.	*Cuora amboinensis* (Daudin, 1802)	South-east Asian Box Turtle	VU	App II	
7.	*Cyclems gemeli* Fritz *et al.*, 2008	Indian Leaf Turtle	NE		
8.	*Geoclemys hamiltonii* (Gray, 1831)	Black Spotted Pond Turtle	VU	App I	Sch I
9.	*Hardella thurjii* (Gray, 1831)	Crowned River Turtle	VU	App II	
10.	*Melanochelys trijuga* (Schweigger, 1812)	Indian Black Pond Turtle	LR/nt	App II	
11.	*Morenia petersi* (Anderson, 1879)	Indian Eyed Turtle	VU	App II	
12.	*Pangshura smithii* (Gray, 1863)	Brown Roofed Turtle	LR/nt	App II	Sch I
13.	*Pangshura sylhetensis* (Jerdon, 1870)	Assam Roofed Turtle	EN	App II	
14.	*Pangshura tectum* (Gray, 1830)	Indian Roofed Turtle		App I	Sch I
15.	*Pangshura tentoria* (Gray, 1834)	Indian Tent Turtle		App II	
	Family TRIONYCHIDAE				
16.	*Amyda cartilaginea* (Boddaert, 1770)	Asiatic Softshell Turtle	VU	App II	
17.	*Chitra indica* (Gray, 1831)	Narrow-headed Softshell Turtle	Cr EN	App II	Sch IV
18.	*Lissemys punctata* (Bonnaterre, 1789)	Indian Flapshell Turtle	LC		Sch I

Sl. No.	Scientific Name	Common Name	IUCN Category	CITES List	IWPA
19.	*Nilssonia gangetica* (Cuvier, 1825)	Indian Softshell Turtle	VU	App I	Sch I
20.	*Nilssonia hurum* (Gray, 1831)	Peacock Soft-shell Turtle	VU		Sch I
21.	*Nilssonia leithii* (Gray, 1872)	Leith's Soft-shell Turtle	VU	App II	Sch IV
22.	*Nilssonia nigricans* (Anderson, 1875)	Black Soft-shell Turtle		App I	
23.	*Pelochelys cantorii* Gray, 1864	Frog-faced Softshell Turtle	EN	App II	
	Order SQUAMATA Sub-Order SAURIA Family SCINCIDAE				
24.	*Tropidophorus assamensis* Annandale, 1912	North-eastern Water Skink	DD		
	Family VARANIDAE				
25.	*Varanus flavescens* (Hardwicke & Gray, 1827)	Yellow Monitor Lizard		App I	Sch I
26.	*Varanus salvator* (Laurenti, 1768)	Water Monitor Lizard		App II	Sch I
	Sub-Order SERPENTES Family ACROCHORDIDAE				
27.	*Acrochordus granulatus* (Schneider, 1799)	Wart Snake			
	Family COLUBRIDAE				
28.	*Atretium schistosum* (Daudin, 1803)	Olive Keelback Water Snake		App III	Sch II
29.	*Cerberus rhynchops* (Schneider, 1799)	Dog-faced Water Snake		App III	Sch II
30.	*Enhydris dussumierii* (Dumeril & Bibron, 1854)	Dussumier's Smooth Scaled Water Snake	LC		
31.	*Enhydris enhydris* (Schneider, 1799)	Common Smooth Water Snake	LC		
32.	*Enhydris plumbea* (Boie, 1827)	Plumbeous Smooth Scaled Water Snake	LC		
33.	*Enhydris sieboldii* (Schlegel, 1837)	Siebold's Smooth Scaled Water Snake	LC		
34.	*Fordonia leucobalia* (Schlegel, 1837)	White-bellied Mangrove Snake	LC		
35.	*Gerarda prevostianus* (Eydoux & Gervais, 1837)	Glossy Marsh Snake	LC		

Sl. No.	Scientific Name	Common Name	IUCN Category	CITES List	IWPA
36.	*Xenochrophis cerasogaster* (Cantor, 1839)	Painted Keelback Water Snake	LC		
37.	*Xenochrophis flavipunctatus* (Hallowell, 1861)	Yellow Spotted Keelback Water Snake	LR/nt		
38.	*Xenochrophis piscator* (Schneider, 1799)	Chequered Keelback Water Snake		App III	Sch II
39.	*Xenochrophis punctulatus* (Gunther, 1858)	Spotted Keelback Water Snake	LR/nt		
40.	*Xenochrophis sanctijohannis* (Boulenger, 1890)	St. John's Keelback Water Snake	LR/nt		
41.	*Xenochrophis schnurrenbergeri* Kramer, 1977	Kramer's Keelback Water Snake	LR/nt		
42.	*Xenochrophis trianguligerus* (Boie, 1827)	Triangle-backed Water Snake	LR/nt		
43.	*Xenochrophis tytleri* (Blyth, 1863)	Tytler's Keelback Water Snake	LR/nt		
	Family HYDROPHIIDAE				
44.	*Enhydrina schistosa* (Daudin, 1803)	Hook-nosed Snake	LC		
45.	*Laticauda colubrina* (Schneider, 1799)	Banded Sea Snake	LC		
	Family XENOPELTIDAE				
46.	*Xenopeltis unicolor* Boie, 1827	Sunbeam Snake	LC		

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Chapter 36

WETLAND BIRDS

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ABSTRACT

A total of two hundred and forty three species of birds including wetland dependent were recorded from the wetlands of India till date. Clearance, conversion and degradation of natural forests, grassland and wetlands are the most far reaching causes of endangerment in Asia, affecting nearly all bird species. Studies on different aspects on the ecology and habitat modeling of migratory birds with satellite tracking to be initiated in the wetlands of India.

Keywords: Waterbirds, Endandered, Poaching, Foraging

INTRODUCTION

Wetlands are important habitats for the variety of waterbirds and wetland dependent birds (Weller, 1999). It serves as feeding, breeding, resting and roosting areas for different species of resident and migratory birds during different seasons of the year (Broyer and Calenge, 2010). Presence of various microhabitats in the wetland such as open water, shallow water, mudflats, submerged vegetation, emergent vegetation increases the available foraging area and subsequently the abundance and richness and diversity of avifauna (Murphy *et al.,* 1984; Safran*et al.*, 1997). The waterbird population tends to be high in the wetlands which possess a variety of microhabitat. The most interesting facts that birds rely mainly on wetlands free from pollution, rich in food availability and the lack of anthropogenic pressure (Paracuellos, 2006).

Endemism

Endemism in wetland is not so well studied. A total of 44 species are known to be endemic in Indian wetlands (Alfred and Nandi, 2000). An attempt is made here to compile the avifauna of wetlands based on the field surveys and published information.

METHODOLOGY

This chapter is prepared based on the field studies conducted by the authors (Venkataraman and Muthukrishnan, 1993; Venkatraman, 2008; Venkatraman and Gokula 2009; Venkatraman *et al.*, 2012; Sivaperuman and Jayson, 2000;

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Jayson and Sivaperuman, 2003; Jayson and Sivaperuman, 2004; Jayson and Sivaperuman, 2005; Sivaperumanand Jayson 2009; Sivaperuman, 2011; 2013; Sivaperuman *et al*., 2010). In addition, the available important literatures also consulted (Sampath, 1989; Sampath and Krishnamurthy, 1989; Balachandran, 1990, 1995 & 2006; Kurup, 1991 & 1996; Anon 1992, 1993;; Jayson and Easa, 1996; Acharya and Kar 1996; Nagarajan and Thiyagesan 1996; Oswin, 1999; Verma *et al*., 2002; Biju Kumar, 2006; Gopi and Pandav, 2007; Pawar, 2011; Kannan and Pandiyan, 2002; Ramamurthy and Rajakumar, 2014; Kurian, 2014; Kumar *et al.,* 2005; Gopi and Hussain, 2014). Birds were classified as migratory or resident species based on Ali and Ripley (1983). The Common and scientific names are after Manakadan and Pittie (2001).

DIVERSITY

Two hundred and forty three taxa of birds including wetland dependent were recorded from the wetlands of India, which belong to 23 Families under 9 Orders (Table 1 and 2). Family wise analysis revealed that Anatidae (Swans, Geese and Ducks), Scolopacidae (Sandpipers, Stints, Snipes, Godwits and Curlews), Laridae (Gulls, Terns and Noddies) and Ardeidae (Herons, Egrets and Bitterns) were the four most dominating families with 62% of all waterbirds falling under these families. (Table 3). At least 67 forest birds, which are partially wetland dependant, are not included in the given list here under. Out of 310 Indian wetland species 130 (c. 42%) are migrant, 173 resident, however the status is unknown for seven species. Of the migrants, 107 are winter migrants, six have some passage population(s), 13 are summer migrants, and the remaining four are purely passage migrants. Of the 173 resident species, 53 are completely resident, 38 are part resident and part winter migrant, and 50 undertake local movements chiefly depending on water conditions. In terms of abundance, Indian wetland birds can be categorized as Very Common (four species), Common (26), Locally Common (115), Un-Common (45), Rare (67), Very Rare (five), Vagrant (47) and Probably Extinct (one).

Table 1. Checklist of Waterbirds in India

Sl. No.	Common Name	Scientific Name	Status Resident/ Abundance
	Grebes	Family PODICIPEDDIDAE	
1	Little Grebe	*Tachypaptus ruficollis* (Pallas 1764)	LC/R
2	Great Crested Grebe	*Podiceps cristatus* (Linnaeus, 1758)	WM
3	Black-necked Grebe	*Podiceps nigricollis* Brehm, 1831	LC/WM
	Pelicans	Family PELICANIDAE	
4	Great White Pelican	*Pelecanus onocrotalus* Linnaeus, 1758	R/WM
5	Spot-billed Pelican	*Pelecanus philippensis* Gmelin, 1789	R/NT
6	Dalmatian Pelican	*Pelecanus crispus* Bruch, 1832	V/WM
	Cormorants/Shags	Family PHALACROCORACIDAE	
7	Little Cormorant	*Phalacrocorax niger* (Vieillot, 1817)	LC/R

Sl. No.	Common Name	Scientific Name	Status Resident/ Abundance
8	Indian Cormorant	*Phalacrocorax fuscicollis* Stephens, 1826	LC/R
9	Great Cormorant	*Phalacrocorax carbo* (Linnaeus, 1758)	LC/R
	Darters	Family ANHINGIDAE	
10	Darter	*Anhinga melanogaster* Pennant, 1769	R
	Herons, Egrets & Bitterns	Family ARDEIDAE	
11	Little Egret	*Egretta garzetta* (Linnaeus, 1766)	LC/R
12	Western Reef Egret	*Egretta gularis* (Bose, 1792)	LC/R
13	Pacific Reef Egret	*Egretta sacra* (Gmelin, 1789)	LC/R
14	Grey Heron	*Ardea cinerea* Linnaeus, 1758	LC/R
15	White-bellied Heron	*Ardea insignis* Hume, 1878	CR/R
16	Goliath Heron	*Ardea goliath* Cretzschmar, 1827	LC/Un
17	Purple Heron	*Ardea purpurea* Linnaeus, 1766	LC/R
18	Great Egret	*Casmerodius albus* (Linnaeus, 1758)	LC/R
19	Intermediate Egret	*Mesophoyx intermedia* (Wagler, 1829)	LC/R
20	Cattle Egret	*Bubulcus ibis* (Linnaeus, 1758)	LC/R
21	Indian Pond Heron	*Ardeola grayii* (Sykes, 1832)	LC/R
22	Chinese Pond Heron	*Ardeola bacchus* (Bonaparte, 1855)	LC/R
23	Striated Heron	*Butroides striatus* (Linnaeus, 1758)	LC/R
24	Malayan Night Heron	*Gorsachius melanolophus* (Raffles, 1822)	LC/R
25	Black-crowned Night Heron	*Nycticorax nycticorax* (Linnaeus, 1758)	LC/R
26	Little Bittern	*Ixobrychus minutus* (Linnaeus, 1766)	LC/R
27	Yellow Bittern	*Ixobrychus sinensis* (Gmelin, 1789)	LC/R
28	Cinnamon Bittern	*Ixobrychus cinnamomeus* (Gmelin, 1789)	LC/R
29	Black Bittern	Dupetor flavicollis (Latham, 1790)	LC/R
30	Great Bittern	Botaurus stellaris (Linnaeus, 1758)	LC/WM
	Storks	Family CICONIIDAE	
31	Painted Stork	Mycteria leucocephala (Pennant, 1769)	NT/R
32	Asian Openbill-Stork	Anastomus osciatans (Boddaert, 1783)	LC/R
33	Black Stork	Ciconia nigra (Linnaeus, 1758)	LC/WM
34	Asian Woollyneck	Ciconia episcopus (Boddaert, 1783)	LC/WM
35	White Stork	Ciconia ciconia (Linnaeus, 1758)	LC/WM
36	Black- necked Stork	Ephippiorhyncus asiaticus (Latham, 1790)	NT/R
37	Lesser Adjutant	Leptoptilys javanicus (Horsfield, 1821)	Vu/R
38	Greater Adjutant	Leptoptilos dubius (Gmelin, 1789)	En/R

Sl. No.	Common Name	Scientific Name	Status Resident/ Abundance
	Ibises & Spoonbills	Family THRESKIORNITHIDAE	
39	Black-headed Ibis	Threskiornis melanocephalus (Latham, 1790)	NT/R
40	Red-naped Ibis	Pseudibis papillosa (Temrninck, 1824)	LC/R
41	Glossy Ibis	Plegadis falcinellus (Linnaeus, 1766)	LC/R
42	Eurasian Spoonbill	Platalea leucorodia Linnaeus, 1758	LC/R
	Flamingos	Family PHOENICOPTERIDAE	
43	Greater Flamingo	Phoenicopterus roseus Linnaeus, 1758	LC/R
44	Lesser Flamingo	Phoenicopterus minor (Geoffroy, 1798)	NT/R
	Swans, Geese & Ducks	Family ANATIDAE	
45	Fulvous Whistling-Duck	Dendrocygna bicolor (Vieillot, 1816)	LC/R
46	Lesser Whistling-Duck	Dendrocygna javanica (Horsfield, 1821)	LC/R
47	Greylag Goose	Anser anser (Linnaeus, 1758)	LC/WM
48	Greater White-fronted Goose	Anser albifrons (Scopoli, 1769)	LC/WM
49	Lesser White-fronted goose	Anser erythropus (Linnaeus, 1758)	Vu/WM
50	Bar-headed Goose	Anser indicus (Latham, 1790)	LC/WM
51	Knob-billed Duck	Sarkidiornis melanotos (Pennant, 1769)	LC/R
52	Common Shelduck	Tadoma tadoma (Linnaeus, 1758)	LC/WM
53	Ruddy Shelduck	Tadorna feruginea (Pallas, 1764)	LC/WM
54	White-winged Duck	Asarcomis scutulata (S. Mulier, 1842)	EN/R
55	Cotton Pygmy Goose	Nettapus coromandelianus (Gmelin, 1789)	LC/R
56	Gadwall	Anas strepera Linnaeus, 1758	LC/WM
57	Falcated Duck	*Anas falcate* Georgi, 1775	NT/WM
58	Eurasian Wigeon	*Anas Penelope* Linnaeus, 1758	LC/WM
59	Mallard	*Anas platyrhynchos* Linnaeus, 1758	LC/WM
60	Indian Spot-billed Duck	*Anas poecilorhyncha* J .R. Forester, 1781	LC/R
61	Eastern Spot-billed Duck	*Anas zonorhyncha* Linnaeus, 1758	LC/WM
62	Northern Shoveller	*Anas clypeata* Linnaeus, 1758	LC/WM
63	Andaman Teal	*Anas albogularis* (Muller, 1842)	Vu/R
64	Northern Pintail	*Anas acuta* Linnaeus, 1758	LC/WM
65	Garganey	*Anas querquedula* Linnaeus, 1758	LC/WM
66	Baikal Teal	*Anas Formosa* Georgi, 1775	LC/WM
67	Common Teal	*Anas crecca* Linnaeus, 1758	LC/WM
68	Marbled Duck	*Marmaronetta angustirostris* (Menetries, 1832)	Vu/WM

Sl. No.	Common Name	Scientific Name	Status Resident/ Abundance
69	Red-crested Pochard	*Netta rufina* (Pallas, 1773)	LC/WM
70	Common Pochard	*Aythya ferina* (Linnaeus, 1758)	LC/WM
71	Baer's Pochard	*Aythya baeri* (Radde, 1863)	CR/WM
72	Ferruginous Duck	*Aythya nyroca* (Gulden stadt, 1770)	NT/WM
73	Tufted Duck	*Aythya fuligula* (Linnaeus, 1758)	LC/WM
74	Greater Scaup	*Aythya marila* (Linnaeus, 1761)	LC/WM
75	Common Goldeye	*Bucephala clangula* (Linnaeus, 1758)	LC/WM
76	Smew	*Mergellus albellus* Linnaeus, 1758	LC/WM
77	Goosander	*Mergus merganser* Linnaeus, 1758	LC/WM
78	White-headed Duck	*Oxyura leucocephala* (Scopoli, 1769)	En/WM
	Cranes	Family GRUIDAE	
79	Demosielle Crane	*Antthropoides virgo* (Linnaeus, 1758)	LC/WM
80	Sarus crane	*Grus Antigone* (Linnaeus, 1758)	Vu/R
81	Common Crane	*Grus grus* (Linnaeus, 1758)	LC/WM
82	Black-necked Crane	*Grus nigricollis* Przevalski, 1876	Vu/SUv
	Rails, Crakes, Moorhens, Coots	Family RALLIDAE	
83	Andaman Crake	*Rallina canningi* (BIyth, 1863)	NT/R
84	Slaty-headed Crake	*Rallina eurizonoides* (Lafresnaye, 1845)	LC/R
85	Slaty-breasted Rail	*Gallirallus striatus* Linnaeus, 1766	LC/R
86	Water Rail	*Rallus aquaticus* Linnaeus, 1758	LC/WM
87	Brown-cheeked Rail	*Rallus indicus* Linnaeus, 1758	LC/WM
88	Brown Crake	*Amauronis akool* (Sykes, 1832)	LC/R
89	White –breasted Waterhen	*Amaurornis phoenicurus* (Pennant, J 1769)	LC/R
90	Black-tailed Crake	*Porzana bicolor* (Walden, 1872)	LC/R
91	Bailon's Crake	*Porzona pusilla* (Pallas, 1776)	LC/WM
92	Spotted Crake	*Porzona porzona* (Linnaeus, 1766)	LC/WM
93	Ruddy-breasted Creake	*Porzana fusca* (Linnaeus, 1766)	LC/R
94	Watercock	*Gallicrex cinerea* (Gmelin, 1789)	LC/R
95	Purple Swamphen	*Porphyrio porphyrio* (Linnaeus, 1758)	LC/R
96	Common Moorhen	*Gallinula chloropus* (Linnaeus, 1758)	LC/R
97	Eurasian Coot	*Fulica atra* Linnaeus, 1758	LC/R
	Finfoots	Family HELIORNITHIDAE	
98	Masked Finfoot	*Heliopais personatus* (G.R. Gray, 1849)	En/R
	Jacanas	Family JACANIDAE	
99	Pheasant tailed Jacana	*Hydrophasianus chirurgus (Scopoli, 1786)*	LC/R

Sl. No.	Common Name	Scientific Name	Status Resident/ Abundance
100	Bronze-winged Jacana	*Metopidius indicus* (Latham, 1790)	LC/R
	Painted-Snipes	Family ROSTRATULIDAE	
101	Greater Painted Snipe	*Rostratula benghalensis* (Linnaeus, 1758)	LC/R
	Oystercatcher	Family HAEMATOPODIDAE	
102	Eurasian Oystercatcher	*Haematopus ostralegus* Linnaeus, 1758	LC/WM
	Plovers, Dotterels, Lapwings	Family CHARADRIIDAE	
103	Northern Lapwing	*Vanellus vanellus* (Linnaeus, 1758)	LC/WM
104	River Lapwing	*Vanellus duvaucelii* (Lesson, 1826)	NT/R
105	Grey-headed Lapwing	*Vanellus cinereus* (Linnaeus, 1758)	WM
106	Sociable Lapwing	*Vanellus gregarious* (Pallas, 1771)	Cr/WM
107	Red-wattled Lapwing	*Vanellus indicus* (Boddaert, 1783)	LC/R
108	White-tailed Lapwing	*Vanellus leucurus* (Lichtenstein, 1823)	LC/WM
109	Pacific Golden Plover	*Pluvialis fulva* (Gmelin, 1789)	LC/WM
110	Grey Plover	*Pluvialis squatarola* (Linnaeus, 1758)	LC/WM
111	Common Ringed Plover	*Charadrius hiaticula* Linnaeus, 1758	LC/WM
112	Long-billed Plover	*Charadrius placidus* J.E. Gray, 1863	LC/WM
113	Little ringed plover	*Charadrius dubius* Scopoli, 1786	LC/R
114	Kentlsh Plover	*Charadrius alexandrines* Linnaeus, 1758	LC/R
115	Lesser Sand Plover	*Charadrius mongolus* Pallas, 1776	LC/WM
116	Greater Sand Plover	*Charadrius leschenaultia* Lesson, 1826	LC/WM
117	Caspian Plover	*Charadrius asiaticus* Pallas, 1773	LC/WM
	Sandpipers, Stints, Snipes, Godwits & Curlews	Family SCOLOPACIDAE	
118	Jack Snipe	*Lymnocryptes minimus* (Briinnich, 1764)	LC/WM
119	Solitary Snipe	*Gallinago salitaria* Hodgson, 1831	R
120	Wood Snipe	*Gallinago nemoricola* Hodgson, 1836	Vu/WM
121	Pin-tail Snipe	*Gallinago stenura* (Bonaparte, 1830)	LC/WM
122	Swinhoe's Snipe	*Gallinago megala* Swinhoe, 1861	LC/WM
123	Common Snipe	*Gallinago gallinago* (Linnaeus, 1758)	WM
124	Asian Dowitcher	*Limnodromus semipalmatus* (Blyth, 1848)	NT/WM
125	Black-tailed Godwit	*Limosa limosa* (Linnaeus, 1758)	NT/WM
126	Bar-tailed Godwit	*Limosa lapponica* (Linnaeus, 1758)	LC/WM
127	Whimbrel	*Numenius phaeopus* (Linnaeus, 1758)	LC/WM
128	Eurasian Curlew	*Numenius arquata* (Linnaeus, 1758)	NT/WM

Sl. No.	Common Name	Scientific Name	Status Resident/ Abundance
129	Spotted Redshank	*Tringa erythropus* (Pallas, 1764)	LC/WM
130	Common Redshank	*Tringa tetanus* (Linnaeus, 1758)	LC/WM
131	Marsh Sandpiper	*Tringa stagnatilis* (Bechstein, 1803)	LC/WM
132	Common Greenshank	*Tringa nebularia* (Gunner, 1767)	LC/WM
133	Green Sandpiper	*Tringa ochropus* Linnaeus, 1758	LC/WM
134	Wood Sandpiper	*Tringa glareola* Linnaeus, 1758	LC/WM
135	Terek Sandpiper	*Xenus cinereus* (Guldenstadt, 1774)	LC/WM
136	Common Sandpiper	*Actitis hypoleucos* Linnaeus, 1758	LC/WM
137	Great Knot	*Calidris tenuirostris* (Horsfield, 1821)	Vu/WM
138	Red Knot	*Calidris canutus* (Linnaeus, 1758)	LC/WM
139	Red-necked Stint	*Calidris ruficollis* (Pallas, 1776)	LC/WM
140	Little Stint	*Calidris minuta* (Leisler, 1812)	LC/WM
141	Temminck's Stint	*Calidris temminckii* (Leister, 1812)	LC/WM
142	Long-toed Stint	*Calidris subminuta* (Middendorff, 1853)	LC/WM
143	Curlew Sandpiper	*Calidris ferruginea* (Pontoppidan, 1813)	LC/WM
144	Dunlin	*Calidris alpina* (Pallas, 1764)	LC/WM
145	Spoon-billed Sandpiper	*Eurynorhynochus pygmeus* (Linnaeus, 1758)	CR/WM
146	Ruff	*Philomachus pugnax* (Linnaeus, 1758)	LC/WM
147	Red-necked Phalarope	*Phalaropus lobatus* (Linnaeus, 1758)	LC/WM
148	Sanderling	Calidris alba (Pallas, 1764)	LC/WM
149	Broad-billed Sandpiper	Limicola falcinellus (Pontoppidan, 1763)	LC/WM
	Avocets & Stilts	Family RECURVIROSTRIDAE	
150	Black-winged Stilt	Himantopus himantopus (Linnaeus, 1758)	LC/R
151	Pied Avocet	Recurvirostra avosetta Linnaeus, 1758	LC/WM
	Ibisbill	Family IBIDORHYNCHIDAE	
152	Ibisbill	Ibidrhyncha struthersii Vigors, 1832	LC/R
	Crab-Plovers	Family DROMADIDAE	
153	Crab-Plover	Dromas ardeola Paykull,, 1805	LC/WM
	Stone-Curlew & Stone-Plovers/Thick-knees	Family BURHINIDAE	
154	Beach Thick-knee	Esacus neglwctus (Vieillot, 1818)	NT/R
155	Great Thick-knee	Esacus recurvirostris (Cuvier, 1829)	NT/R
156	Indian Thick-knee	Burhinus oedicnemus indicus (Linnaeus, 1766)	LC/R

Sl. No.	Common Name	Scientific Name	Status Resident/ Abundance
	Coursers & Pratincoles	Family GLAREOLIDAE	
157	Collared Pratincole	Glareola pratincola (Linnaeus, 1766)	LC/WM
158	Oriental Pranticole	Glareola maldivarum J .R. Forster, 1795	LC/R
159	Small Pratincole	Glareola lacteal Temminck, 1820	LC/R
	Skimmers	Family RYNCHOPIDAE	
160	Indian Skimmer	Rynchops albicollis Swainson, 1838	Vu/R
	Gulls, Terns & Noddies	Family LARIDAE	
161	Slender-billed Gull	Chroicocephalus genei Breme, 1839	LC/WM
162	Brown-headed Gull	Chroicocephalus brunnicephalus Jerdon, 1840	LC/WM
163	Black-headed Gull	Chroicocephalus ridibundus Linnaeus, 1766	LC/WM
164	Palla's Gull	Ichthyaetus ichthyaetus Pallas, 1773	LC/WM
165	Heuglin's Gull	Larus fuscus heuglini Bree, 1876	LC/WM
166	Steppe Gull	Larus fuscus barabensis Bruch, 1853	LC/WM
167	Mew Gull	Larus canus Linnaeus, 1758	LC/WM
168	Gull-billed Tern	Gelochelidon nilotica (Gmelin, 1789)	LC/WM
169	Caspian Tern	Hydroprogne caspia Pallas, 1770	LC/WM
170	Little Tern	Sternula albifrons Pallas, 1764	LC/R
171	Bridled Tern	Sterna anaethetus Scopoli, 1786	LC/R
172	River Tern	*Sterna aurantia* J.E. Gray, 1831	NT/R
173	Common Tern	*Sterna. hirundo* Linnaeus, 1758	LC/WM
174	Black-bellied Tern	*Sterna. acuticauda* J .E. Gray, 1831	En/R
175	Whiskered Tern	*Chlidonias hybrid* (Pallas, 1811)	LC/R
176	White-winged Tern	*Chlidonias leucopterus* (Temminck, 1815)	LC/WM
177	Brown Noddy	*Anous stolidus* (Linnaeus, 1758)	LC/WM
178	White Tern	*Gygis alba* Linnaeus, 1766	LC/Visi
179	Greater Crested Tern	*Thalasseus bergii* Lichtenstein, 1823	LC/R
180	Lesser Crested Tern	*Thalasseus bengalensis* Lesson, 1831	LC/R
181	Sandwich Tern	*Thalasseus sandiensis* Latham, 1787	LC/V
182	Roseate Tern	*Sterna dougallii* Montagu, 1813	LC/R
183	Black-napped Tern	*Sterna sumatrana* Raffles,1822	LC/R
184	White-cheeked Tern	*Sterna repressa* Hartert, 1916	LC/R
185	Saunder's Tern	*Sternula saundersi* Hurne, 1877	LC/V
186	Sooty Tern	*Onychoprion fuscatus* Linnaeus, 1766	LC/R

Table 2. Wetland dependant and associated birds

Sl. No.	Common Name	Scientific Name	Status Resident/ Abundance
	Hawks, Eagles, Buzzards, Kites, Harriers	**Family ACCIPITRIDAE**	
1	Brahminy Kite	*Haliastur indus* (Boddaert, 1783)	LC/R
2	Greater Spooted Eagle	*Aquila clanga* Pallas, 1811	VU/WM
3	Indian Spooted Eagle	*Aquila hastata* Pallas, 1811	VU/R
4	White-bellied Sea eagle	*Haliaeetus leucogaster* (Gmelin, 1788)	LC/R
5	Palla's Fish agle	*Haliaeetus leucoryphus* (Pallas, 1771)	VU/R
6	White-tailed Eagle	*Haliaeetus albicilla* Linnaeus, 1758	LC/WM
7	Lesser Eish eagle	*Ichthyophaga humilis* (S. Muller & Schlegel, 1841)	NT/R
8	Grey-headed Fish eagle	*Ichthyophaga ichthyaetus* (Horsfield, 1821)	NT/R
9	Eurasian Marsh Harrier	*Circus aeruginosus* (Linnaeus, 1758)	LC/WM
	Osprey	**Family PANDIONIDAE**	
10	Osprey	*Pandion haliaetus* (Linnaeus, 1758)	LC/WM
	Pheasants, Patridges, Quails	**Family PHASIANIDAE**	
11	Swamp Francolin	*Francolinus gularis* (Temminck, 1815)	VU/R
	Owls	**Family STRIGIDAE**	
12	Brown Fish-Owl	*Ketupa zeylonenesis* (Gmelin,1788)	LC/R
13	Tawny Fish Owl	*Ketupa flavipes* (Hodgson, 1836)	LC/R
14	Buffy Fish owl	*Ketupa ketupu* (Horsefield, 1821)	LC/R
	Kingfishers	**Family ALCEDINIDAE**	
15	Stork-billed Kingfisher	*Pelargopsis capensis* (Linnaeus, 1758)	LC/R
16	Brown-winged Kingfisher	*Pelargopsis amauroptera* Pearson, 1841	NT/R
17	Ruddy Kingfisher	*Halcyon coromanda* (Latham, 1790)	LC/R
18	Black-capped Kingfisher	*Helcyon pileata* (Boddaert, 1783)	LC/WM
19	Collared Kingfisher	*Todiramphus chloris* (Boddaert, 1783)	LC/R
20	Oriental Dwarf Kingfisher	*Ceyx erithaca* (Linnaeus, 1758)	LC/SM
21	Blue-eared Kingfisher	*Alcedo meninting* Horsfield, 1821	LC/R
22	Common Kingfisher	*Alcedo althis* (Linnaeus, 1758)	LC/R
23	Blyth's Kingfisher	*Alcedo hercules* Laubmann, 1917	NT/R

Sl. No.	Common Name	Scientific Name	Status Resident/ Abundance
24	Crested Kingfisher	*Megaceryle lugubris* (Temminck, 1834)	LC/R
25	Pied Kingfisher	*Ceryle rudis* (Linnaeus. 1758)	LC/R
	Swallows & Martins	**Family HIRUNDINIDAE**	
26	Sand Martin	*Riparia riparia* (Linnaeus, 1758)	LC/Unk
27	Plain Martin	*Riparia paludicola* (Vieillot, 1817)	LC/R
28	Pale Martin	*Riparia diluta* (Sharpe & Wyatt, 1893)	LC/R
29	Barn Swallow	*Hirundo rustica* Linnaeus, 1758	LC/R
30	Pacific Swallow	*Hirundo tahitica* Linnaeus, 1771	LC/R
31	Red-rumped Swallow	*Hirundo daurica* Linnaeus, 1771	LC/R
32	Wire-tailed Swallow	*Hirundo smithi* Leach, 1818	LC/R
33	Streak throated Swallow	*Petrochelidon fluvicola* Blyth, 1855	LC/R
	Wagtails & Pipits	**Family MOTACILLIDAE**	
34	Forest Wagtail	*Dendronanthus indicus* (Gmelin, 1789)	LC/WM
35	White Wagtail	*Motacilla alba* Linnaeus, 1758	LC/R
36	Citrine Wagtail	*Motacilla citreola* Pallas, 1776	LC/R
37	Yellow Wagtail	*Motacilla flava* Linnaeus, 1758	LC/WM
38	Grey Wagtail	*Motacilla cinerea* Tunstall, 1771	LC/R
39	White-browed Wagtail	*Motacilla maderaspatensis* Gmelin, 1789	LC/R
40	Rosy Pipit	*Anthus roseatus* Blyth, 1847	LC/R
41	Red-throated Pipit	*Anthus cervinus* (Pallas, 1811)	LC/WM
42	Buf-bellied Pipit	*Anthus rubescens* (Tunstall, 1771)	LC/WM
43	Water Pipit	*Anthus spinoletta* (Linnaeus, 1758)	LC/WM
44	Richards's Pipit	*Anthus richardi* Vieillot, 1818	LC/WM
	Dippers	**Family CINCLIDAE**	
45	White-throated Dipper	*Cinclus cinclus* (Linnaeus, 1758)	LC/R
46	Brown Dipper	*Cinclus pallasii* Temminck, 1820	LC/R
	Thrushes, Shortwings, Robinds, Forktails, Wheaters	**Family MUSCICAPIDAE**	
47	Plumbeous Water Redstart	*Rhyacornis fuliginosa* (Vigors, 1831)	LC/R
48	White-capped Redstart	*Chaimarrornis leucocephalus* (Vigors, 1831)	LC/R
49	Little Forktail	*Enicurus scouleri* Vigors, 1832	LC/R
50	Black-backed Forktail	*Enicurus immaculatus* (Hodgson, 1836)	LC/R

Sl. No.	Common Name	Scientific Name	Status Resident/ Abundance
51	Slaty-backed Forktail	*Enicurus schistaceus* (Hodgson, 1836)	LC/R
52	White-crowned Forktail	*Enicurus leschenaultia* (Vieilloot, 1818)	LC/R
53	Spotted Forktail	*Enicurus maculatus* Vigors, 1831	LC/R
	Prinias	**Family CISTICOLIDAE**	
54	Swamp Prinia	*Prinia cinerascens* (Moore, 1854)	LC/R
	Buntings	**Family EMBERIZIDAE**	
55	Chestnut-eared Bunting	*Emberiza fucata* Pallas, 1776	LC/R
56	Black-faced Bunting	*Emberiza spoddocephala* Pallas, 1776	LC/WV
57	Common Reed Bunting	*Emberiza schoeniclus* (Linnaeus, 1758)	LC/WV

CR – Critically Endangered, Vu – Vulnerable, En – Endangered, NT – Near threatened, R - Rare, R – Resident, WM – Winter migrant, LC – Locally Common

Out of 310 Indian wetland birds, seven species are endemic, three fall in the Restricted Range Species category and one comes under data deficient category; 11 are Biome-Restricted Species of which five species are from Eurasian High Mountain (Biome 05), three from Sino-Himalayan Subtropical Forest (Biome 08), one from Indo-Chinese Tropical Moist Forest (Biome 09), and two from Indo-Malayan Tropical Dry Zone (Biome 11) (Jhunjhunwala *et al*., 2001).

Table 3. Occurrence of Waterbirds Familywise

Sl. No.	Family	World	Asia	India
1	Podicipedidae	22	6	3
2	Pelecanidae	8	4	3
3	Phalacrocoracidae	37	11	3
4	Anhingidae	4	3	1
5	Ardeidae	62	30	20
6	Ciconiidae	19	11	8
7	Threskiornithidae	35	9	4
8	Phoenicopteridae	5	2	2
9	Anatidae	160	62	35
10	Gruidae	15	9	4
11	Rallidae	146	34	15
12	Heliornithidae	3	1	1
13	Jacanidae	8	3	2
14	Rostratulidae	2	1	1

Sl. No.	Family	World	Asia	India
15	Haematopodidae	11	2	1
16	Charadriidae	67	22	15
17	Scolopacidae	90	60	32
18	Recurvirostridae	9	3	2
19	Ibidorhynchidae	18	4	1
20	Dromadidae	1	1	1
21	Burhinidae	9	3	3
22	Glareolidae	18	4	3
23	Laridae	91	45	26
	Total	840	330	186

Threats

The main pressure on Asian waterbirds is wetland drainage and conversion, including the infilling (or 'reclamation') of intertidal coastal wetlands, principally for agriculture and aquaculture. Dams and irrigation projects are also negatively affecting wetlands. Clearance, conversion and degradation of natural forests, grassland and wetlands are the most far reaching causes of endangerment in Asia, affecting nearly all species classified a Critical, Endangered, and Vulnerable. Exploitation for human use is the second most common category of threat, affecting more than 50% of all threatened bird species; of these, c. 70% are hunted for food and sport and c. 30% are captured for the wild bird trade.

Suggestions for conservation

With the ever increasing developments, change in the patterns of land use and resource use, the conservation of our limited natural resources has gained greater significance. The causes by environmental damages can be controlled only by the implementation of serious conservation measures. Illegal poaching and hunting should be completely banned. Felling of trees for cultivation and expansion of settlement areas should be discouraged. Biodiversity awareness campaigning for local settlers as well as the tourists should be initiated and this could prove very useful in the protection of the natural resources. A broad range of national policies on forestry, agriculture, wetlands and fisheries can have significant impacts on biodiversity conservation. By ensuring that policies and laws at local, provincial and national levels also take into account the principle of conservation, threats to species can be minimized.

Though many checklists are available on the avifauna of wetlands, but there is a lack on the various aspects of ecological studies. It is shown that there is still a lot of research that needs to be carried out to better understand the ecology, particularly the movements within the ecosystem and studies on different aspects on the ecology and habitat modeling of migratory birds with satellite tracking to be initiated in the wetlands of India. Information on phonological patterns of migratory birds and behavioural eco-physiology of migrating waterbirds also important in this region. Foraging ecology studies with the ultimate goal of understanding the consequences of habitat selection by wintering birds in terms of meeting energy demands is the need of the day. Specifically, the information on waterbirds diet, foraging rates among habitats and seasons, and food availability lack biogeographic zone wise.

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WETLAND BIRDS


Anastomus osciatanus
Asian Openbill -Stork


Mycteria leucocephala
Painted Stork


Phalacrocorax niger
Little Cormorant


Numenius arquata Eurasian Curlew


Actitis hypoleucos Common sandpiper


Chroicocephalus brunicephalus
Brown-headed Gull


Charadrius dubias Little ringed Plover


Tringa taotanus Common Redshank

Chapter 37

MAMMALIA

M. KAMALAKANNAN, C. VENKATRAMAN AND GOPAL SHARMA*

ABSTRACT

A total of 428 species of Mammals have been recorded from India, of which six species are considered as freshwater mammals in India. Threats include habitat degradation due to developmental activities, river pollution, prey decline in their habitat and poaching.

Key words: Mammals, habitat degradation, loss of wetland.

INTRODUCTION

Mammals are found in all types of habitat, ranging from snowy heights of the Himalaya to sea coast, and show all types of adaptation, viz. – terrestrial, arboreal, fossorial, volant, aquatic etc. There are about 5,416 species of mammals belonging to 154 families and 29 orders have been reported from the world. Of which, 428 species of Mammals have been recorded from India, which is about 7.9% of the global mammalian species, representing 48 families and 14 orders. Unlike the marine mammals (enormous and lives in the different marine ecosystem), the freshwater mammals are few in numbers and live either in an aquatic and semiaquatic condition (Wilson and Reeder, 2005). Six species namely, Gangetic Dolphin *Platanista gangetica* (Roxburgh, 1801), Oriental small-clawed otter *Aonyx cinerea* (Illiger, 1815), European otter *Lutra lutra* (Linnaeus, 1758), Smooth-coated otter *Lutrogale perspicillata* (I.Geoffroy Saint-Hilaire, 1826), Himalayan water shrew *Chimarrogale himalayica* (Gray, 1842) and Elegant water shrew *Nectogale elegans* Milne-Edwards, 1870 are considered as freshwater mammals in India.

Gangetic Dolphin

Two subspecies namely, Ganges river dolphin *Platanista gangetica gangetica* (Roxburgh, 1801) and Indus river dolphin *Platanista gangetica minor* Owen, 1853 have been recognised in India. The Ganges river dolphins are virtually identical in physical appearance. They are readily identified by their elongated snout, which can reach lengths of 20% of total body length. They are well developed for aquatic life, have long flippers that can be up to 18% of total body length. It is distributed in Brahmaputra, Ganges, Hoogly, Karnaphuli, Meghna and their tributaries and Indian seas while *Platanista gangetica minor are* distributed only in Punjab, inhabiting the Ganges and Indus river systems and their many tributaries,

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streams, and connecting lakes. The auditory senses are very well developed; navigates and captures food with the help of echolocation. The South-Asian river dolphin is declared as the National Aquatic Animal of India by the Government of India.

There are many studies on Gangetic Dolphin especially the population status and conservation measures [Smith (1993), Sinha (2002), Sinha and Sharma (2003) and Braulik (2006)]. The ecology of the species were studied by the Pilleri and Zbinden (1973), Singh and Sharma (1985) and the threats were studied by Mohan (1995), Bairagi,(1999), Kannan *et al* (1997) and Senthilkumar *et al.* (1999).

The distribution of *Platanista* in the Ganges River is, between longitudes 77°E and 89°E, from mouth of the river in Bay of Bengal to as far up as the river navigable near the foothill of Himalayas (Anderson 1879). He stated that, in the Brahmaputra River, *Platanista* was present "throughout all the main rivers, as far eastwards as longitude 95°E by latitude 27°30´N, frequenting all its larger tributaries." Outside the Ganges–Brahmaputra–Meghna river systems, Gangetic Dophin were present in the Karnaphuli River (Anderson 1879) and possibly the Sangu River in eastern Bangladesh (Haque 1976).

Kasuya and Haque (1972) recorded Gangetic Dophin in Dioghat on the Narayani River in Nepal, 250 MSL and approximately 100 km farther upstream than Anderson recorded in 1879. Shreshtha (1989) reported dolphins in the four main river systems of Nepal: the Mahakali, Karnali, Narayani, and Kosi Rivers. Susus ascend the Meghna river systems in Bangladesh at least to Sunamganj (Jones 1982). Nine susus were also sighted in the Barak River in 2006 at Silchar in Assam. (pers. comm. Pawlen Singha). Jones (1982) stated that the broad plume of freshwater created by the Ganges outflow in the Bay of Bengal may facilitate the dispersal of susus to rivers outside the Ganges–Brahmaputra–Meghna systems. In 2006, one susu entered the Burhabalang River in the state of Orissa, which discharges into the Bay of Bengal almost 300 km southwest of the mouth of the Ganges. This river has never been connected with the Ganges system. In the recent years, the dolphin's range in substantial portions of the Ganges system, especially in upstream areas.

The Gangetic Dolphin is endemic to the Indian sub-continent and has fairly extensive distribution range. Due to a continued decline in its population, the IUCN changed its status from 'Vulnerable' to 'Endangered' in 1996 and is listed Schedule-I of the Indian Wildlife (Protection) Act, 1972

Threats

Directed Intentional killing

The killing of dolphin for meat and oil is thought to have declined. But it still occurs in the middle Ganges near Patna, in the Kalni-Kushiyara River of Bangladesh, and in the upper reaches of the Brahmaputra. In India and Bangladesh, dolphin oil and body parts are used to lure prey, and Ganges River dolphins are used to this end. Efforts have been made in India to test shark liver, sardine oil and fish scrape to find an alternative for dolphin oil (used as fish attractant). The fish scrape are being used as the alternative of dolphin oil. The results are positive and promising.

Accidental Killing

Entanglement of Gangetic Dolphins in fishing nets causes significant damage to the local population. Accidental killing is a severe problem throughout most of their range. The primary cause is believed to be entanglement in fishing gear such as nylon gillnets because their preferred habitat is often in the same location as primary fishing grounds. The problem of accidental killing is expected to worsen with increasing fishing intensity.

Bycatch (in fishing gear)

Monofilament gill net: When a gill net is set in the bottom is weighted to the column of the river water and the top is held up by floats creating a wall of net. These nets are difficult for the dolphin to see or detect with echolocation. So, they frequently run in to them when swimming or feeding and become entangled in the net. Gillnets are responsible for the by-catch related deaths of most dolphin and porpoise species.

Kapda jal

The sustained and heavy exploitation of small fishes of rivers by the wide spread use of the mosquito nets in river may affect the prey base of the Gangetic Dolphin. While the rate of renewal of this resource is remarkable, very few studies have been conducted in a small segment of the river on prey abundance estimates (Choudhay *et al*., 2006; Kelkar *et al*., 2010) and further research is required to quantify this threat in larger areas.

Chemical Pollution

The riverine ecosystem is close proximity to human activities and, therefore, is an ultimate sink for the discharge of sewage and industrial wastewater that emanates from human activities. The Ganges River basin is the most densely populated basin in the world and is heavily polluted by fertilizers, pesticides, industrial chemicals, and domestic effluents. Exposure of dolphins to toxic chemicals can affect their reproduction and survival. In the food chain, the dolphins, are apex predator, have been shown to accumulate high levels of persistent and toxic chemicals in their tissues. Several studies conducted about elevated levels of DDT in the blubber of Ganges dolphins (Kannan *et al.,* 1994; Senthilkumar *et al*., 1999). Notable levels of immunotoxic chemicals, such as butyltins and perfluorinated chemicals, have been found in the tissues of Ganges dolphins (Kannan *et al*., 1997, 2005; Yeung *et al.,* 2009). Heavy metals, including cadmium and lead, have been measured in the livers of Ganges dolphins (Kannan *et al*., 1993).

Gaps in research

The DNA sequencing of Gangetic Dolphin, survey in all distributional range and the acoustic behaviour are some of the gap areas in the Dolphin research in India.

Small-clawed otter

The small clawed Otter is commonly known as Asian Small-clawed Otter, Small-clawed Otter, Oriental Small-clawed Otter. This species is native to Bangladesh, Bhutan, Brunei Darussalam, Cambodia, China, India (Arunachal

Pradesh, Assam, Himachal Pradesh, Karnataka, Kerala, Tamil Nadu, West Bengal) Indonesia, Lao People's Democratic Republic, Malaysia, Myanmar, Nepal, Philippines, Singapore, Taiwan, Province of China, Thailand, Viet Nam.

The Small-clawed Otters occur in freshwater and peat swamp forests, rice fields, lakes, streams, reservoirs, canals, mangrove and along the coast. In Malaysia and Indonesia they occur in coastal wetlands, and along the banks of paddy fields. The Small-clawed Otters have a high climatic and trophic adaptability in south and south-east Asian tropics, occurring from coastal wetlands up to mountain streams (Melisch *et al.*1996).

The ecology, status and conservation of all three Indian otter species have well documented by Nagulu *et al* (1999), Hussain and Choudhury (1997) Hussain (1999, 2000) and Choudhury (1999). The *Aonyx cinerea concolor* and *Aonyx cinerea nirnai* are the two Indian subspecies of the small-clawed otter. It is the smallest otter in India and similar to Eurasian otter. As its name implies, the small claws of otter are rudimentary and not projecting beyond the tips of the toes and are webbed between the digits. Its sleek coat is greyish brown and the underside is light brown to the yellow and whitish throat.

In India, *Aonyx cinerea concolor* is distributed in Himalayan terai to North-eastern states and Sundarbans in West Bengal and *Aonyx cinerea nirnai* in South India. It is aquatic and, diurnal in behaviour; social animal lives in rivers, creeks, estuaries and coastal areas. The groups consist four to six to 18 individuals and spends more time in the land than the water, dig their own dens near the riverside. The Small-clawed Otter is adapted to feed on invertebrates as evident from the last two upper teeth (pm4 and m3) which are larger in size for crushing the exoskeleton of crabs and other hard shelled prey. The Small-clawed Otter feeds mainly on crabs, snails and other molluscs, insects and small fish such as gouramis and catfish (Pocock 1941, Wayre 1978). They supplement their diet with rodents, snakes and amphibians too.

Threats

Threats include habitat degradation due to developmental activities, river pollution, prey decline in their habitat and poaching. In many parts of Asia, the habitats have been reduced due to reclamation of peat swamp forests and mangroves, aquaculture activities along the intertidal wetlands and loss of hill streams. In India the primary threats are loss of habitats due to tea and coffee plantations along the hills, in the coastal areas loss of mangroves due to aquaculture and increased human settlements and siltation of smaller hill streams due to deforestation. Increased influx of pesticides into the streams from the plantations reduces the quality of the habitats. The threat posed by poaching is still very significant in many parts of India, and SE Asia and will certainly count as a major threat that needs to be constantly monitored. Poaching for pelt has been reported from across the Western Ghats in south India (Prakash *et al*., 2012). It is listed as Schedule-I species under the Indian Wildlife (Protection) Act, 1972, as Vulnerable and Appendix-II species of the IUCN Red List category and CITES, respectively.

Conservation action

Since 1977, The Small-clawed Otter has been listed on CITES Appendix II which indicates that the species is not necessarily threatened with extinction, but the trade on its pelt must be controlled in order to avoid utilization incompatible with their survival. However, most countries are not able to control the clandestine trade leading to extensive poaching. Nevertheless, it is a protected species in almost all the range countries which prohibits its killing. Once the Asian Small-clawed Otter was common in the streams and wetlands of south and Southeast Asia but now it is restricted to few protected areas. Creation of networks of Protected Areas, identification of sites as wetlands of national and international importance under the Ramsar Convention halted the degradation of its habitat.

Over the years the IUCN SSC Otter Specialist Group has developed a cadre of biologists across Asia to conduct field surveys and to popularise otter conservation by promoting otters as ambassadors of the wetlands. However, concerted efforts to conserve this species are needed. For the long term survival of the species, policy based action, research on factors affecting its survival, habitat based action on creation and where required expansion of protected areas and communication and awareness building actions are needed.

Eurasian otter

The Eurasian Otter is spread across Europe, Africa and Asia and the IUCN has listed as Near Threatened. According to experts, the species has either gone extinct from several regions or it has been reduced to small isolated populations. Except for Europe, there is lack of data on population status and distribution of this species from the rest of the world.

A total of four subspecies of Eurasian otter are found in India namely, *Lutra lutra aurobrunneus* Hodgson, 1839, *Lutra lutra kutab* Schinz, 1844, *Lutra lutra monticolus* Hodgson, 1839 and *Lutra lutra nair* F.G. Cuvier, 1823. The Eurasian otter has a rough and grizzled coarse coat of dark olive brown colour and the under parts are lighter. Its outer nostrils are 'W' shaped, the lips and throat have yellow spots. There are many white vibrissae around the muzzle. The end of the tail is circular in section and is three-fourth of the head and body length. The webs extend to the last bone of each digit.

In India, *Lutra lutra aurobrunneus* is distributed in Uttarakhand and Himachal Pradesh; *Lutra lutra kutab* Jammu and Kashmir; *L. l. monticolus* Sikkim and North-eastern India and *Lutra lutra nair* Southern India. It is nocturnal and largely solitary in behaviour and lives in rivers, streams, marshes, swamp forests and coastal areas. They feed mainly fish, crab, snails, freshwater molluscs, fish, frogs, wetland birds, etc. They take shelter on land in the burrows. Threats include habitat degradation due to developmental activities, river pollution, pesticide use, prey decline in their habitat and poaching. It is listed in Schedule-II species under the Indian Wildlife (Protection) Act, 1972, and Appendix-I of the CITES.

Smooth-coated otter

In the Indian subcontinent they are adapted to live even in the semiarid region of north western India and Deccan plateau (Prater 1971). Generally, it uses large rivers and lakes, peat swamp forests, mangroves and estuaries, and rice fields for foraging (Foster-Turly, 1992). In South-east Asia rice fields appear to be one of the most suitable habitats in supporting its viable populations (Melisch *et al.,* 1996). However, they were more abundant in the mangroves of Kuala Gula, Malaysia as compared to the rain forest rivers (Shariff 1984).

Smooth-coated otter *Lutrogale perspicillata*

The *Lutrogale perspicillata perspicillata* is a recognised Indian subspecies. It is a common otter in India; possess a very smooth and sleek coat rather than a coarse coat. Its dorsal coat colour varies from blackish brown to lighter brown, or paler tawny or sandy brown, underside is lighter. The upper lip, cheeks, throat, and neck are whitish; muzzle is not spotted; nostrils 'V' shaped. The third digit is free from webbing. Tail length is more than half of the head and body length and distal part markedly flattened.

Distributed throughout the country except for high regions of Himalayas, and arid regions of Gujarat and Rajasthan. Sometimes during the dry season, these otters may become jungle hunters.

Major threats to Asian otter populations are loss of wetland habitats due to construction of large-scale hydroelectric projects, reclamation of wetlands for settlements and agriculture, reduction in prey biomass, poaching and contamination of waterways by pesticides. In south-east Asian countries, there does not seem to be any intentional otter trapping (Melisch *et al.,* 1996) though it is prevalent in India, Nepal and Bangladesh. It is listed in Schedule-II under the Indian Wildlife (Protection) Act, 1972, is Vulnerable and Appendix-II species of the IUCN Red List category and CITES, respectively.

Himalayan water shrew

Himalayan water shrew represents an important fauna of the Himalayan region. It can be diagnosed by its bluish grey speckled with white hair and paler at ventral parts. Eyes are small and the greatly reduced ears closed by a flap while diving. Its pelage is glossy and waterproof. The feet are well-developed and its toes are fringed with stiff long white bristle-hairs. The backs of the feet are light brown. Its tail is dark brown at all around, except the tip of the tail, where it is white below. They are usually associated with the clear, swift-flowing forest stream in mountainous region (Arai *et.al*., 1985). This species is reported to swim well underwater and have been observed running over stones in the bed of a stream and plunging freely into the water (Anderson 1879).

It is found in China, India, Japan, Laos, Myanmar, Taiwan, and Vietnam. In India, it is distributed in Himachal Pradesh, Uttarakhand, Sikkim and West Bengal. This is a semi-aquatic and nocturnal animal, swims well under the water. It is omnivorous in diet, feeds on insects, crustaceans and small fishes. Inhabits burrows on the banks or near streams and associated with clear streams in temperate evergreen forests. Hoffmann (1987), Lunde and Musser (2002), Hutterer (2005), and Smith and Xie (2008) have reported the systematics and ecology of the Himalayan water shrew and elegant water shrew along with other soricomorphs. Threats include habitat loss due to agriculture expansion, selective logging, harvesting for medical use, poisoning, pest control activities and decline of prey species. As per the IUCN Red List category, it is a Least Concern species.

Elegant water shrew

The Elegant water shrew is characterised by its slate grey upper parts and silver under parts. Its snout is long and the valvular ears are reduced. A unique tail with a long tuft of white hairs is modified for swimming. The webbed feet is brown in colour and fringed with short and stiff white hairs. In India, it is distributed in Sikkim. This is more aquatic adapted species than the Himalayan water shrew. Feeds on aquatic invertebrates and small fish. Inhabits montane forests with streams at altitudes of 900-3000 m. Little is known about its their ecology. Habitat loss is considered as threat to the species. As per the IUCN Red List category, it is a Least Concern species.

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