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Communication

On the little-known hyporheic biodiversity of India, with annotated checklist of copepods and bathynellaceans (Crustacea) and a note on the disastrous implications of indiscriminate sand mining

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Abstract: The vast and ecologically diversified hyporheic realm and the adjacent riparian areas of India have received scant attention from the standpoint of biodiversity studies. Analysis of about 2500 samples collected from the alluvial sediments of certain rivers and streams, besides some bores in the riparian zone, mainly in the coastal deltaic belt of the rivers Krishna and Godavari in Andhra Pradesh State during 2000–2012 yielded 41 copepod and bathynellacean species. Of these, 31 new species have been formally described during the ongoing studies whereas the remainder are previously known ones. An annotated checklist of all these taxa is presented, giving the type locality and other localities of occurrence, methods of sampling, chief references, and also some taxonomic and/or ecological remarks wherever necessary. The harpacticoid copepod family Parastenocarididae and the eumalacostracan order Bathynellacea are two significant, major groups of stygofauna that have been recorded for the first time from India. Both these groups and also some cyclopoid copepods have clear-cut Gondwanan lineages, representing the remnants of unique ancient fauna that require urgent attention from conservationists in order that the overall evolutionary history of the Indian biota is preserved. A note is also added on the devastating influence of the ongoing rampant sand mining activity on the hyporheic biodiversity.

Keywords: Bathynellacea, checklist, Copepoda, hyporheic ecosystem, riparian bores, sand mining impacts.

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INTRODUCTION

To save the earth's fast-depleting biodiversity, which is due primarily to habitat loss and impairment, has become a matter of increasing concern for scientists and governments all over the world. What is even more disconcerting today is that certain unique and as-yet unexplored habitats are imperiled even before the study of their biodiversity and functions has begun in right earnest. One such greatly threatened habitat is the hyporheic habitat present within the sandy banks of rivers and streams. In India, scant attention, if any, has been paid to the study of hyporheic ecosystems. This paper gives, after briefly referring to the general biodiversity and functions of the hyporheic zone, an annotated checklist of the hyporheic copepod and bathynellacean crustaceans (size c. 1mm). This checklist is based on the taxonomic and biogeographic studies carried out during the last decade or so, mostly in the coastal deltaic belt of the rivers Krishna and Godavari in Andhra Pradesh State. Stringent legislative measures are suggested for protecting these precious sand-dwellers and their home, now under the devastating impact of excessive sand extraction. Incidentally, the stray hypogean copepod and bathynellacean species encountered in the riparian bores and two caves are also included in the checklist.

The term *hyporheic,* derived from Greek roots—*hypo*, meaning under or beneath, and *rheos*, meaning a stream, was first used by the Romanian hydrologist Orghidan (1959). It originally refers to the alluvial sediments that extend vertically and laterally from the river channel, giving rise to 'a rich and unique ecosystem'. Demonstrating the double influence of groundwater and stream properties on this ecosystem, Orghidan distinguished it from other groundwater habitats. And the subsequent pioneering work by Stanford & Ward (1993) proposes to integrate the stream channel and hyporheic systems into a river continuum concept—the hyporheic corridor. Essentially, the hyporheic zone constitutes 'a spatially and temporally dynamic ecotone' (Feris et al. 2003), sandwiched between the surface water and groundwater ecosystems. This 'critical interface' extends from the substrate surface to a depth of about 50cm, below which lies the phreatic or groundwater regime (Pennak 1940). Its functional role is governed by such properties as its elasticity, permeability, biodiversity, and connectivity (Gibert et al. 1990; Vervier et al. 1992) in close interaction with the geomorphology, geohydrology, landscape use and the buffering ecosystems along the river corridor. It is in this zone that hydrological, ecological and biogeochemical processes interact, influencing key ecosystem processes such as primary productivity and nutrient cycling (Mulholland & Webster 2010). Hence, the findings concerning the functional significance of the hyporheic zone are of crucial importance in floodplain management and restoration (Boulton et al. 2010). Overall, the hyporheic science, which is a vital facet of groundwater ecology and 'a topic of great practical relevance' to regulators and policy makers, has been recognized in the West as a fascinating, multidisciplinary field that combines methods, concepts and data from hydrogeology, geochemistry, microbiology and aquatic ecology (Larned 2012). Besides being the home of rich biodiversity, the hyporheic zone endows us with a number of 'ecological goods and services' such as the following: offers a spawning ground and refuge for certain fishes (salmon, etc.) and rooting zone for aquatic plants; controls the flux and location of water exchange between streams and subsurface; acts as a buffer zone for the attenuation of certain pollutants by biodegradation, sorption and mixing; provides an important zone for biogeochemical cycling of carbon, energy and nutrients; forms a functional sink/source for fine organic detritus and other sediments; and moderates water temperature against heat and freezing (Environment Agency 2009).

As to the biodiversity, the hyporheic zone supports a heterotrophic assemblage of both interstitial and benthic community (hyporheos) of diverse groups of organisms including some ancient and rare relictual Gondwanan lineages that are now absent from the surface waters. The hyporheic biodiversity is generally composed of Protista (Ciliophora, Sarcomastigophora), Gastrotricha, Tardigrada, Oligochaeta (Aelosomatidae), Annelida (Potamodrilidae), Insecta (Collembola, Ephemeroptera, Odonata, Plecoptera, Trichoptera, Coleoptera, Diptera), Rotifera, Acari, Crustacea (Copepoda, Ostracoda, Amphipoda, Isopoda, Cladocera, Syncarida, Thermosbaenacea), Mollusca (Aplacophora, Bivalvia, Gastropoda), Platyhelminthes (Turbellaria) and Nematoda (Hakenkamp & Palmer 1999). The obligate interstitial animals (stygobites) are small, elongated and vermiform, blind, unpigmented, and have reduced limbs and/or elongated sonsorial structures, which compensate for the lack of vision, and produce but a few eggs and develop slowly (Danielopol et al. 1994). Based on their body size, the hyporheic organisms are often grouped into three categories: micro- (<50µm), meio- (50–1000 µm), and macro- (>1000µm) elements. Given the well-known 'ecotone edge effects' (Odum 1971), the hyporheic systems can support extremely large densities of meiofauna (although low densities and high diversity is the general rule), which eventually may equal or even exceed those in marine systems (Palmer 1990; Borchardt & Bott 1995), and provide a vital trophic link between bacteria, meiofauna and macrofauna. The meiofauna feed on benthic bacteria and algae, influencing the microbial and algal community, as well as biofilm and particulate organic matter dynamics (Hakenkamp et al. 2002). Their selective feeding on bacteria and algae could as well influence stoichiometry (e.g., C, N, and P ratios) of stream sediments (Elser et al. 1996; Hessen 1997). The fauna, in turn, constitute an important part of the diet of many freshwater fishes (Williams 1981; McNicol et al. 1985; Brown et al. 1989; Schmid-Araya & Schmid 2000; Ranga Reddy 2001) and predaceous invertebrates (Benke & Wallace 1980; Schmith & Smock 1992; Schmid-Araya & Schmid 2000). The usefulness of hyporheic fauna as indicators (biosensors) of anthropogenic impacts such as pollution has also been documented for certain groups (Notenboom et al. 1994; Boulton 2000a,b). Furthermore, the very ancient crustaceans such as bathynellaceans have long been recognized as suitable objects for understanding the history of the earth's crust and biological speciation (Schminke 1974; Schram 1977, 2008) (see Discussion).

MATERIALS AND METHODS

About 2500 core samples collected mainly from the alluvial sediments mostly in the coastal deltaic belt of the rivers Krishna and Godavari and also from the riparian/phreatic bores in Andhra Pradesh State (exceptions: only a single sample each from the river Sutlej in Himachal Pradesh State and River Muvattupuzha in Kerala State, and two samples from cave pools) during 2000-2012 by adopting the following methods:

(1) Karaman & Chappuis method (Chappuis 1942): This method, the most frequently used one, entails 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 seeping into the pits. Each time the sample was filtered through bolting-silk plankton net (mesh size 70µm), and the filtrate fixed in 5% formaldehyde in plastic vials.

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

(3) Direct filtration of water from farm bores in the riparian zone: Specimens were collected by filtering the water when it was pumped out of farm bores (depth c. 10m) adjacent to rivers. Filtering was done manually by holding a bolting-silk plankton net (mesh size 70µm) against the water current for 20–30 minutes at each time of sampling. The filtrate was fixed as before.

In the laboratory, the specimens studied were sorted into 70% alcohol and later transferred into glycerol; their morphology was studied using the general methods of microscopy in vogue. For the sake of completeness of the checklist of the species that are essentially hypogean, three cavernicolous species, collected by Coring and filtration method, are also included. Abbreviations used: AP = Andhra Pradesh State; EGD = East Godavari District; R. = River.

RESULTS

Phylum Arthropoda
Subphylum Crustacea Brűnich, 1772
Class Maxillopoda Dahl, 1956
Subclass Copepoda Milne-Edwards, 1840
Order Cyclopoida Burmeister, 1834
Subfamily Cyclopinidae Dana, 1846
Genus *Allocyclopina* Kiefer, 1954

1. *Allocyclopina inopinata* Defaye & Ranga Reddy, 2008

Type locality: R. Godavari at Kotipalli Village ($18^0$85'N & $82^0$02'E; 10m) near Ramachandrapuram Town, EGD., AP.

Other localities: None.

Sampling methods: Karaman & Chappuis method, and direct filtration method.

Reference: Defaye & Ranga Reddy 2008: 1119–1141.

Remark: Tolerates brackish conditions.

Family Cyclopidae Rafinesque, 1815
Subfamily Eucyclopinae Kiefer, 1927
Genus *Paracyclops* Claus, 1893

2. *Paracyclops fimbratus* (Fischer, 1853)

Type locality: P. Dudegofka, St. Petersburg ($59^0$53'39"N & $30^0$15'51"E; 5m), Russia.

Other localities: Europe and Asia extending eastwards to include Turkey, Palestine, China, Japan and India and widely distributed throughout the Palaearctic region (Karaytug 1999). Found but rarely in the interstitial samples of R. Krishna at Vijayawada city ($16^0$31'8.50"N & $80^0$37'17.38"E; 88m), AP.

Sampling method: Coring and filtration method.

References: Karaytug & Boxshall 1998: 563–602; Karaytug 1999: 30–43.

Remark: Morphologically highly variable species; generally epibenthic.

Subfamily Cyclopinae Kiefer, 1927

Genus *Haplocyclops* Kiefer, 1952

Subgenus *Kiefercyclops* Karanovic & Ranga Reddy, 2005

3. *Haplocyclops (Kiefercyclops) fiersi* Karanovic & Ranga Reddy, 2005.

Type locality: Bore well on Acharya Nagarjuna University campus ($16^0$22'41''N & $80^0$31'39.4''E; 19.8m), 13km from Guntur Town, in the riparian zone of Nambur canal of R. Krishna, AP.

Other localities: None.

Sampling method: Direct filtration method.

Reference: Karanovic & Ranga Reddy 2005: 83–92.

Remark: Most reduced free-living cyclopoid; generally confined to riparian bore wells.

Genus *Rybocyclops,* 1982

4. *Rybocyclops dussarti* Ranga Reddy & Defaye, 2008

Type locality: Agriculture bore, in the riparian zone of Gundlakamma R., at Chollaveedu village ($15^0$31'39''N $78^0$56'56''E; 231m), Racharla Mandal of Prakasam District, AP.

Other locality: Bore well, in the riparian/phreatic zone of Gundlakamma R., at Araveetikota Village (15^o34'49''N 78^o55'56''E; 235m) of Racharla Mandal of Prakasam District, AP.

Sampling method: Direct filtration method.

Reference: Ranga Reddy & Defaye 2008: 41–49.

Remark: Has clear-cut Gondwanan affinities with the Madagascan congener, *Rybocyclops pauliani* (Lindberg 1954) (see Ranga Reddy 2011b).

Order Harpacticoida Sars, 1903

Family Phyllognathopodidae Gurney, 1932

Genus *Phyllognathopus* Mrazek, 1893

5. *Phyllognathopus viguieri* (Maupas, 1892)

Type locality: Not known.

Other localities: Cosmopolitan species; present record from the hyporheic habitat of R. Godavari at Rajahmundry ($16^0$59'N & $81^0$47'E; 14m), EGD, AP.

Sampling method: Coring and filtration method.

References: Karanovic & Ranga Reddy 2004a: 122-131; Galassi et al. 2011: 4-17.

Remark: Morphologically highly variable species; possibly a cryptic morphospecies (Wells 2011).

Genus *Neophyllognathopus* Galassi & De Laurentiis, 2011

6. *Neophyllognathopus bassoti* (Rouch, 1972)

Type locality: Interstitial of Lake Wisdom ($50^0$19'55"S & $147^0$7'6"E; 400m) on Long Island, Papua New Guinea.

Other localities: Wells on Bantayan Island ($11^0$13'15"N & $123^0$44'45"E; 30m) of the Philippines; present records from bore wells in Brindavan Gardens ($16^0$18'N & $80^0$29'E; 33m) of Guntur Town in Guntur District, and Kandukur Town ($15^0$15'N & $79^0$47'E; 632m) in Prakasam District, AP.

Sampling method: Direct filtration method.

References: Rouch 1972: 148-155; Bruno & Cottarelli, 1999: 521–528; Karanovic & Ranga Reddy 2004b: 247–259; Galassi et al. 2011: 32–43.

Family Ameiridae Boeck, 1865

Subfamily Ameirinae Boeck, 1865

Genus *Nitokra* Boeck, 1865

7. *Nitokra ?lacustris* (Schmankevitch, 1895)

Type locality: Not available.

Other localities: Widely distributed in the world (see Dussart & Defaye 1990); present record from R. Krishna at Vijayawada City ($16^0$31'8.50"N & $80^0$37'17.38"E; 11.88m), AP.

Reference: Lang 1948: 812–14.

Sampling method: Coring and filtration method.

Remark: The morphology shows certain characters that are suggestive of a new subspecies rather than the typical form (Ranga Reddy unpubl.). Rare in the interstitial.

Family Canthocamptidae Brady, 1880

Subfamily Canthocamptiinae Brady, 1880

Genus *Elaphoidella* Chappuis, 1928

8. *Elaphoidella crassa* Chappuis, 1954

Type locality: Mawsmai Cave near Cherrapunji ($25^0$18'N & $91^0$42'E / 25.30^0N & 91.70^0E; 1,484m), Meghalaya State.

Other localities: None.

Sampling method: Not known.

Reference: Chappuis 1954: 218–220.

Remark. First cavernicolous copepod species from India.

Genus *Mesochra* Boeck, 1865

9. *Mesochra wolskii* Jakubisiak, 1933

Type locality: Lagoon Matanzas ($23^0$03'4"N &

81°34'31"W; 20m), Cuba.

Other localities: Different localities in North and South Atlantic, Pacific, and Indian Oceans. Present record from R. Krishna at Vijayawada City (16°31'8.50"N & 80°37'17.38"E; 11.88m), AP.

Sampling method: Coring and filtration method.

Reference: Fiers & Rutledge 1990: 108–111.

Remark: A predominantly marine taxon; well established in R. Krishna at Vijayawada City; rare in the interstitial.

Genus *Cletocamptus* Schmankevitsch, 1875

10. *Cletocamptus deitersi* (Richard, 1887)

Type locality: Naposta Grande R., Argentina.

Other localities: R. Krishna at Vijayawada City (16°31'8.50"N & 80°37'17.38"E; 88m) (Ranga Reddy 2001); Lake Kolleru (16°39'N & 81°13'E; 3.26m) (Ranga Reddy & Radhakrishna 1979), AP; widely distributed in the world (Dussart & Defaye 1990).

Sampling method: Coring and filtration method.

References: Lang 1948: 1278–1280; Hamond 1973: 414–417.

Remarks: Currently considered as a *species inquirenda* (Gómez et al. 2004); a highly euryhaline species.

Family Diosaccidae Sars, 1906

Genus *Neomiscegenus* Karanovic & Ranga Reddy, 2004

11. *Neomiscegenus indicus* Karanovic & Ranga Reddy, 2004

Type locality: Groundwater runoff on the southern bank of R. Krishna at Vijayawada City (16°31'8.50"N, 80°37'17.38"E; 11.88m) in AP.

Other localities: None.

Sampling method: Direct filtration method.

Reference. Karanovic & Ranga Reddy 2004b: 246-260; Wells 2007: 531.

Remark: Seems to prefer the aquifers in the riparian zone.

Family Ectinosomatidae Sars, 1903

Genus *Rangabradya* Karanovic & Pesce, 2001

12. *Rangabradya indica* Karanovic & Pesce, 2001

Type locality: Freshwater bore well in Brindavan Gardens (16°18'N & 80°29'E; 33m) of Guntur Town in Guntur District, AP.

Other localities: None.

Sampling method: Direct filtration method.

Reference: Karanovic & Pesce 2001: 282–290; Wells 2011: 382, 388.

Family Miraciidae Dana, 1846

Subfamily Steheliinae Brady, 1880

Genus *Delavalia* Brady, 1880

13. *Delavalia madrasensis* (Wells, 1971)

Type locality: Estuarine beaches of the Vellar R. near Porto Novo (6°29'47"N & 2°36'12"E; 40m), Tamilnadu (erstwhile Madras State).

Other localities: Rambha Bay, Chilka Lake (19°41'39"N & 85°18'24"E / 19.69417°N & 85.30667°E; 8m), Odisha State, and intertidal sand on Long Island, Middle Andaman Islands (Wells & Rao 1987); present record from R. Krishna at Vijayawada (16°31'8.50"N & 80°37'17.38"E; 11.88m), AP.

Sampling method: Coring and sampling method.

References: Wells 1971: 509-510 (female only as *Stenhelia madrasensis*); Radhakrishna & Ranga Reddy 1978: 152–158 (both sexes under the synonym *Stenhelia krishnensis*); Wells 2007: 548.

Remarks.: A highly euryhaline species, well established in R. Krishna.

Family Laophontidae T. Scott, 1905

Subfamily Laophontinae T. Scott, 1905

Genus *Folioquinpes* Fiers & Rutledge, 1990

14. *Folioquinpes chathamensis* (Sars, 1905)

Type locality: Chatham Islands (44°02'S & 176°26'W / 44.033°S & 176.433°W; 294m), an archipelago in the Pacific Ocean.

Other localities: Cape Town (33°55'31"S & 18°25'26"E; 1,590.4m), Africa; Chilka Lake (19°41'39"N & 85°18'24"E / 19.69417°N & 85.30667°E; 8m), India; New Zealand (Dussart & Defaye 1990); present record from R. Krishna at Vijayawada City (16°31'8.50"N & 80°37'17.38"E; 11.88m).

Sampling method: Coring and filtration method.

References: Lang 1948: 1119; Sewell 1924: 830–832, pl. 57, fig. 2; Wells 2011: 431, 440, 460.

Remarks: Mostly a brackish form, but occurring in the purely freshwater condition of R. Krishna.

Family Parastenocarididae Chappuis, 1940

Genus *Parastenocaris* Chappuis, 1940

15. *Parastenocaris curvispinus* Enckell, 1970

Type locality: "W. Prov., Kalutara [6°34'59"N & 79°57'33"E; 3m], 25 miles, S. Colombo. Long sandbank in the estuary of the river".

Other localities. R. Krishna at Vijayawada (16°31'8.50"N & 80°37'17.38"E; 11.88m), R. Godavari at Rajahmundry (16°59'N & 81°47'E; 14m), and R. Pennar at Chennur Village (14.14733°N & 79.847712°E; 115m) near Kadapa Town in Andhra Pradesh State; R.

Mahanadi at Rajim Town (20°57’57” N, 81°52’51” E; 281 m), R. Yamuna at Champaran, and R. Indravati at Chitrakoot Waterfalls in Chhattisgarh State; R. Periyar at Kalady Village (10^{0}10’N & 76^{0}26’E), R. Bharatpuzha at Cheruthuruthi (10^{0}44’N & 76^{0}17’E), and R. Muvattupuzha at Muvattupuzha (9^{0}96’70”N & 76^{0}58’30”E; 28m) in Kerala State.

Sampling methods: Karaman & Chappuis method, and Coring and filtration method.

References: Enckell 1970: 553; Ranga Reddy & Defaye 2007: 9–17; Cottarelli et al. 2010: 488.

Remarks: A euryhaline species, most widespread and common in the hyporheic habitats of the peninsular India, the present range extending from south-western Sri Lanka to central India.

16. *Parastenocaris gayatri* Ranga Reddy, 2001

Type locality: Interstitial of R. Krishna at Vijayawada city (16^{0}31’8.50”N & 80^{0}37’17.38”E; 11.88m).

Other localities: River Krishna at Amaravati (16^{0}34’48”N & 80^{0}21’36”E; 14m) in Guntur District and R. Godavari at Rajahmundry, EGD, AP.

Sampling methods: Karaman & Chappuis method and Coring and filtration method.

Reference: Ranga Reddy 2001: 708–716; Karanovic 2005: 370; Cottarelli et al. 2010: 487; Schminke 2010: 350.

Remarks: A fairly common species in the R. Krishna and R. Godavari.

17. *Parastenocaris savita* Ranga Reddy, 2001

Type locality: Interstitial of R. Krishna at Vijayawada City (16^{0}31’8.50”N & 80^{0}37’17.38”E; 11.88m), A. P.

Other localities: R. Krishna at Amaravati (16^{0}34’48”N & 80^{0}21’36”E; 14m) in Guntur District and R. Godavari at Rajahmundry (16^{0}59’N & 81^{0}47’E; 14m), EGD.

Sampling methods: Karaman & Chappuis method, and Coring and filtration method.

References: Ranga Reddy 2001: 716–722; Ranga Reddy & Defaye 2007: 22–24. Schminke 2010: 350.

18. *Parastenocaris mahanadi* Ranga Reddy & Defaye, 2007

Type locality: R. Mahanadi at Rajim Town (20^{0}57’57”N & 81^{0}52’51” E; 281m), Chhattisgarh State.

Other locality: None.

Sampling method: Coring and filtration method.

References: Ranga Reddy & Defaye 2007: 2–9, 22–24; Schminke 2010: 350.

Remark: A rare species.

19. *Parastenocaris muvattupuzha* Ranga Reddy & Defaye, 2009

Type locality: R. Muvattupuzha at Muvattupuzha Town (9^{0}58’01”N & 76^{0}34’59”E; 15m), Kerala State.

Other localities. None.

Sampling method: Coring and filtration method.

Reference: Ranga Reddy & Defaye 2009: 32–43; Schminke 2010: 350; Cottarelli et al. 2010: 488.

20. *Parastenocaris kotumsarensis* Ranga Reddy & Defaye, 2009

Type locality: Kotumsar cave located on the bank of the R. Kanger, flowing through the Kanger Valley National Park (18^{0}52’09”N & 81^{0}56’05”E; 560m) near Jagdalpur Town, Chhattisgarh State.

Other localities: None.

Sampling methods: Coring and filtration method and Direct filtration method.

Reference: Ranga Reddy & Defaye 2009: 43–51.

Remark: First cavernicolous parastenocaridid species from India.

21. *Parastenocaris sutlej* Ranga Reddy, 2011

Type locality: R. Sutlej at Tattapani (31^{0}14’56’’N 77^{0}05’10’’E; 656m), Himachal Pradesh State.

Other localities: None.

Sampling method: Coring and filtration method.

Reference: Ranga Reddy 2011a: 464–473.

Remark: First parastenocaridid species from a Himalayan River.

22. *Parastenocaris gundlakamma* Ranga Reddy, 2011

Type locality: Gundlakamma River pond at Nemiligundla Sri Ranganayakaswamy Temple (15^{0}30.916’N & 78^{0}52.155’E; 289m) near Giddalur Town, Prakasam District, AP.

Other localities: None.

Sampling method: Coring and filtration method.

Reference: Ranga Reddy 2011a: 474-482.

23. *Parastenocaris tirupatiensis* Ranga Reddy, 2011

Type locality: Bore well at S.V. University campus (13^{0}37’44”N & 79^{0}23’58”E; 162m), Tirupati Town, phreatic/ perhaps the riparian zone of Swarnamukhi R.

Other localities: None.

Sampling method: Direct filtration method.

Reference: Ranga Reddy 2011c: 21–29.

Genus *Kinnecaris* Jakobi, 1972

24. *Kinnecaris godavari* Ranga Reddy & Schminke, 2009

Type locality: R. Godavari at Rajahmundry ($16^0$59'N & $81^0$47'E; 14m), EGD, AP.

Other localities: None.

Sampling method: Coring and filtration method.

Reference: Ranga Reddy & Schminke 2009a: 312–325; Schminke 2010: 350; Cottarelli et al. 2010: 488.

Genus *Siolicaris* Jakobi, 1972

25. *Siolicaris sandhya* (Ranga Reddy, 2001)

Synonym: *Parastenocaris sandhya* Ranga Reddy, 2001.

Type locality: Interstitial of R. Krishna at Vijayawada City ($16^0$31'8.50"N & $80^0$37'17.38" E; 11.88m), AP.

Other localities: R. Krishna at Amaravati ($16^0$34'48"N & $80^0$21'36"E; 14m) in Guntur District, and R. Godavari at Rajahmundry ($16^0$59'N & $81^0$47'E; 14m), EGD, AP.

Sampling methods: Karaman & Chappuis method and Coring and filtration method.

References: Ranga Reddy 2001: 723–730; Ranga Reddy & Defaye 2007: 22–24. Corgosinho et al. 2012: 59–65.

Remarks: This is a rare species and restricted to the R. Krishna and R. Godavari, AP.

Class Malacostraca Latreille, 1802
Subclass Eumalacostraca, 1892
Order Bathynellacea Chappuis, 1915
Family Bathynellidae Grobben, 1905
Genus *Serbanibathynella* Ranga Reddy & Schminke, 2005

26. *Serbanibathynella primaindica* Ranga Reddy & Schminke, 2005

Type locality: Farm bore at Tadepalli Village ($16^0$41'32''N & $82^0$02'24''E; 12.5m; water temperature 26^0C; pH 8.0), 3km from Vijayawada, in the riparian zone of R. Krishna, AP.

Other localities: Four other bores within a radius 2km from the type locality.

Sampling method: Direct filtration method.

References: Ranga Reddy & Schminke 2005b: 25–30; Camacho 2006: 19.

Remark: Mostly confined to riparian bore wells.

Genus *Indobathynella* Ranga Reddy & Totakura, 2012

27. *Indobathynella prehensilis* Ranga Reddy & Totakura, 2012

Type locality: Farm bore at Ravulapalem Village ($16^0$06'33.4"N & $81^0$46'49.9"E; 37m; depth c. 10m; water temperature 27^0C; pH 7.0), c. 30km from Rajahmundry, in the riparian zone of R. Godavari, EGD, AP.

Other localities: Farm bore, Chintalapudi Village ($16^0$02'23.8"N & $80^0$32'35.4"E; 36.5m), ~5km from Nidubrolu Town, Guntur District, farm bore, Peravaram Village ($16^0$53'42.0"N & $81^0$45'09.8"E; 17.7m; water temperature 26^0C; pH 7.0), ~20km from Rajahmundry, EGD, AP.

Sampling method: Direct filtration method.

Reference: Ranga Reddy & Totakura 2012a: 281–293.

Family Parabathynellidae Noodt, 1965
Genus *Atopobathynella* Schminke, 1973

28. *Atopobathynella operculata* Ranga Reddy, Drewes & Schminke, 2008

Type locality: R. Godavari at Rajahmundry Town ($16^0$59'N & $81^0$47'E; 14m), EGD, AP.

Other localities: None.

Sampling method: Coring and filtration method.

Reference: Ranga Reddy, Drewes & Schminke 2008: 52–60.

Genus *Chilibathynella* Noodt, 1964

29. *Chilibathynella kotumsarensis* Ranga Reddy, 2006

Type locality: Kutumsar cave located on the bank of the R. Kanger, flowing through the Kanger Valley National Park ($18^0$52'09"N & $81^0$56'05"E; 560m) near Jagdalpur Town, Chhattisgarh State.

Other localities: None.

Sampling methods: Coring and filtration method and Direct filtration method

References: Ranga Reddy 2006: 23–37; Camacho 2006: 25.

Remark: The first cavernicolous bathynellacean species from India.

Genus *Habrobathynella* Schminke, 1973

30. *Habrobathynella nagarjunai* Ranga Reddy, 2002

Type locality: Bore well on Acharya Nagarjuna University campus ($16^0$22'41''N & $80^0$31'39.4''E; 19.8m; water temperature 26^0C; pH 8.0), 13km from Guntur Town, in the riparian zone of Nambur canal of R. Krishna, AP.

Sampling method: Direct filtration method

References: Ranga Reddy 2002: 38–43; Camacho 2006: 28.

Remark: Mostly confined to riparian, phreatic bore wells.

31. *Habrobathynella schminkei* Ranga Reddy, 2004

Type locality: R. Pennar at Chennur ($14^0$34′00″N & $78^0$48′00″E; 115m), c. 15km from Kadapa Town, AP.

Other localities: River Godavari at Rajahmundry Town ($16^0$59′N & $81^0$47′E; 14m); some bore wells in the riparian zone of R. Godavari and R. Krishna, AP.

References: Ranga Reddy 2004: 277–284; Camacho 2006: 28; Ranga Reddy & Totakura 2010: 1–49.

32. *Habrobathynella indica* Ranga Reddy & Schminke, 2005

Type locality: River Krishna at Vijayawada city ($16^0$31′8.50′′N & $80^0$37′17.38′′E; 11.8m), close to southern end of Kanaka Durga Varadhi, a road-bridge.

Other localities: None.

Sampling method: Coring and filtration method.

References: Ranga Reddy & Schminke 2005a: 2217–2224; Camacho 2006: 28; Ranga Reddy & Totakura 2010: 40, 46–47.

Remark: This is a rare, typically hyporheic taxon, but has gone extinct at the type locality due to the increasing discharge of domestic effluents.

33. *Habrobathynella plenituda* Ranga Reddy & Schminke, 2009

Type locality: River Godavari at Rajahmundry town ($16^0$59′N & $81^0$47′E; 14m), EDG, AP.

Other localities: None.

Sampling method: Coring and filtration method.

Reference: Ranga Reddy & Schminke 2009b: 477–485.

34. *Habrobathynella krishna* Ranga Reddy & Totakura, 2010

Type locality: R. Krishna at Ramannapeta Village ($16^0$45′32′′N & $80^0$07′35′′E; 39m; water temperature 28^0C; pH 7.5), Guntur District, AP.

Other locality: R. Krishna at Madipadu Village ($16^0$48′50′′N & $80^0$04′22′′E, 40m), Guntur District, AP.

Sampling method: Coring and filtration method.

Reference: Ranga Reddy & Totakura 2010: 4–12.

35. *Habrobathynella vaitarini* Ranga Reddy & Totakura, 2010

Type locality: R. Krishna at Madipadu Village ($16^0$48′50′′N & $80^0$04′22′′E; 40m; water temperature 32^0C; pH 7.5), Guntur District, AP.

Other localities: R. Krishna at Pulichintala ($16^0$49′22′′N & $80^0$04′03′′E; 44m; water temperature 32^0C; pH 7.5) and Challagariga Village ($16^0$45′32′′N & $80^0$07′35′′E; 39m), Guntur District, AP.

Sampling method: Coring and filtration method.

Reference: Ranga Reddy & Totakura 2010: 13–20.

36. *Habrobathynella savitri* Ranga Reddy & Totakura, 2010

Type locality: River Godavari at Sundarapalli Village ($16^0$47′20′′N & $82^0$03′25′′E; 14m; water 30^0C; pH 7.5), EGD, AP.

Other localities: R. Godavari at Dhawaleswaram Town ($16^0$48′09′′N & $80^0$04′18′′E; 27m), and Kapileswarapuram Village ($16^0$41′26′′N & $82^0$02′24′′E; 23m), EGD, AP.

Sampling method: Coring and filtration method.

Reference: Ranga Reddy & Totakura 2010: 20–28.

37. *Habrobathynella vidua* Ranga Reddy & Totakura, 2010

Type locality: Farm bore at Tadepalli Village ($16^0$41′32′′N & $82^0$02′24′′E; 21m; water temperature 26^0C; pH 8.0) near Vijayawada City, A.P.

Other locality: Farm bore at Kunchanapalli Village ($16^0$23′42′′N & $80^0$32′28′′E; 26m; water temperature 27^0C; pH 7.5), 3km from the type locality.

Sampling method: Direct filtration method.

Reference: Ranga Reddy & Totakura 2010: 29–34.

Remark: So far known only from the farm bores of the riparian zone of River Krishna, AP.

38. *Habrobathynella borraensis* Ranga Reddy, Shabuddin & Totakura, 2014

Type locality: The Borra Caves ($18^0$16′49″N & $83^0$2′19″E; c. 705m) located on the East Coast of India, in the Ananthagiri Hills of the Araku Valley in the Visakhapatnam District of AP.

Other locality: None.

Sampling method: Coring and filtration method.

Reference: Ranga Reddy, Shabuddin & Totakura 2014: (online access).

Remark: A second cavernicolous bathynellacean from India.

Genus *Parvulobathynella* Schminke, 1973

39. *Parvulobathynella distincta* Ranga Reddy, Elia & Totakura, 2011

Type locality. R. Godavari at Kapileswarapuram ($16^0$47′28.5″N & $82^0$03′33.8″E; 34.3m; temperature 24^0C; pH 7.0), c. 35km from Rajahmundry town, EGD, AP.

Other localities: R. Godavari at Dhawaleswarapuram ($16^0$56′78.3″N & $81^0$46′70.2″E; 40.3m; temperature 27^0C; pH 7.5) and Atreyapuram ($16^0$50′2.97″N & $81^0$47′12.85″E), EGD, A P.

Sampling methods: Karaman & Chappuis method, and Coring and filtration method.

Reference: Ranga Reddy, Elia & Totakura 2011: 486–494.

40. *Parvulobathynella projectura* Ranga Reddy, Elia & Totakura, 2011

Type locality: River Godavari at Kotipalli Village ($16^0$41'33.5''N & $82^0$03'45.5"E; 10.8m; temperature 28^0C; pH 7.5), EGD, AP.

Other localities: None.

Sampling methods: Karaman & Chappuis method and Coring and filtration method.

Reference: Ranga Reddy, Elia & Totakura 2011: 494–500.

41. *Parvulobathynella macrodentata* Ranga Reddy & Totakura, 2012

Type locality: Farm bore at Peravaram village ($16^0$53'42.0"N & $81^0$45'09.8"E; 17.7m; water temperature 26^0C; pH 7.0), ca. 20km from Rajahmundry, in the riparian zone of River Godavari.

Other localities: Farm bore at Ravulapalem Village ($16^0$06'33.4"N & $81^0$46'49.9"E; 37m; depth c. 10m; water temperature 27^0C; pH 7.0), 20km from Rajahmundry, East Godavari District and also at Mamillapalli Village ($16^0$02'23.8"N & $80^0$32'35.4"E; 32m) near Nidubrolu town, Guntur District, AP.

Sampling method: Direct filtration.

Reference: Ranga Reddy & Totakura 2012b: 871–882.

Remark: Mostly confined to the aquifers of the riparian areas.

DISCUSSION

In India, both the Himalayan and Peninsular River Systems present vast and ecologically diversified hyporheic realm and riparian areas, apparently harboring enormous biodiversity. However, as already mentioned in the Introduction, little is known about the Indian hyporheic biota. This is due to the minute size of most of the organisms, the difficulties involved in their sampling, the exacting microscopic study and drawing work, the lack of taxonomic expertise and funding support, etc.

The present faunistic survey covering only a fraction of the Indian hyporheic and riparian realm is indeed rewarding in that it has yielded 41 copepod and bathynellacean species, of which as many as 31 species are new to science and formally described and the remaining one are previously known in the literature; an additional 20 new species in the samples are yet to be named and described. The eumalacostracan order Bathynellacea and the harpacticoid copepod family Parastenocarididae are two significant, major groups of stygofauna that have been recorded for the first time from India. Both these groups are of much value in historical biogeography and phylogenetic studies. In particular, the Bathynellacea represents one of the oldest freshwater crustacean groups whose ancestors inhabited the seas in the Carboniferous or even earlier, now absent from the epigean realm. This group as a whole might have achieved its worldwide distribution prior to the breakup of Pangaea, and its present biogeography can be more convincingly explained by the vicariance model rather than by the classical dispersal model (Schminke 1974; Schram 1977, 2008). It is noteworthy that while all the Indian bathynellacean taxa are distinctly different from their Asian counterparts, they display spectacular Gondwanan heritage (Ranga Reddy 2011b). Of the two Indian endemic genera *Serbanibathynella* and *Indobathynella*, the latter is the most derived one in the family Bathynellidae. The parabathynellid genus *Habrobathynella* is remarkably speciose with as many as 12 Indian species (three new species present in the samples are yet to be named and described), nine of them inhabiting the sandy sediments of peninsular rivers. This genus is known outside India only by two species in Madagascar.

According to Noodt (1969), compared with the Bathynellacea, the Parastenocarididae is a much younger group, having originated possibly in the early Tertiary or even earlier. However, because parastenocaridids have no marine relatives or modern pathways between different continents (Boxshall & Jaume 2000), it has been postulated that they have a Pangaean origin (Karanovic 2006). The latter taxon is as yet known by 11 species in India. While eight species are distributed in alluvial sediments, one species each is restricted to a cave and two to riparian borewells. Two genera, viz., *Kinnecaris* and *Siolicaris*, have distinct Gondwanan affinities and so do three cyclopoid copepod genera, viz., *Haplocyclops*, *Rybocyclops* and *Allocyclopina* as well (Ranga Reddy 2011b). Since the Gondwanan lineages represent the remnants of unique ancient biota (Mani 1974; Roelants et al. 2004), they require urgent attention from conservationists in order that the overall evolutionary history of Indian biota is preserved (Karanth 2006). All in all, these tiny ancient crustaceans inhabiting the sandy sediments are no less important than the spectacular epigean vertebrates in understanding the evolutionary history of the earth's crust.

It is also worthy of note that amongst the other harpacticoid copepod species, *Delavalia madrasensis*, *Folioquinpes chathamensis*, *Neomiscegenus indicus*, and *Mesochra wolskii* belong to the almost exclusively marine families. Clearly, the occurrence of these species in the truly freshwater conditions of the hyporheic zone of the river Krishna near Vijayawada is indicative of their remarkable euryhaline adaptations.

CONSERVATION

Construction boom in the wake of rapid urbanization has fuelled increasing demand for river sand. As a result, all the Indian rivers without exception have been and are still literally plundered of their alluvium on a large scale. Sand miners are digging to a depth of about 15m with the help of machines, and even extracting the earth after touching the river floor. Besides the staggering and visible on-site and off-site ill-effects of uncontrolled sand extraction such as channel degradation and erosion, deepening of rivers and enlargement of river mouths, lowering of water tables in the nearby riparian areas plus occasional saline-water intrusion from the nearby seas, infrastructure damage like undermining of bridges and other structures, etc. (see Kondolf & Swanson 1993; Kondolf 1997; Mori et al. 2011), and sadly and more importantly, the highly fragile hyporheic habitats and their associated biota are gouged out along with their homes, as it were. In this connection, it is also noteworthy that the dubious 'eco-friendly' policy announced by certain state governments, providing for sand extraction up to 2m, is utterly myopic and disastrous to sand-associated life because most of the hyporheic life is confined to the upper one meter or so of the sediment. This fact must be taken cognizance of by the policy makers.

Considering the ecological importance of the hyporheic biodiversity in riverine ecosystem functioning, total ban must be imposed on sand mining activities. Should this be not feasible, 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. Simultaneously, 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. In view of the importance of hyporheic science as a multi-disciplinary area of specialization, funding agencies in the country will do well to play a pro-active role in encouraging research in this area, starting from the taxonomic characterization of species.

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