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Cover: Stripe-necked Mongoose *Urva vitticolla* in poster colours, adapted from photograph by Ashni Dhawale, by Pooja Ramdas Patil.

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COMMUNICATION

Faunistic overview of the freshwater zooplankton from the urban riverine habitats of Pune, India

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Abstract: Urbanization modifies the physical, chemical, and biological nature of all ecosystems including rivers. Such changes negatively impact all aquatic biodiversity including the freshwater zooplankton. Given the fast pace of urbanization in all the major cities across India, the aim is to provide a faunistic overview of Rotifera, Cladocera, and Ostracoda from two polluted rivers flowing through Pune, one of the rapidly growing cities in the state of Maharashtra, India. A one-year survey of three localities on the rivers Mula & Mutha and data from published literature on another locality revealed the presence of 73 species which includes 47 rotifers, 15 cladocerans, and 11 ostracods. A higher species number of rotifers was seen at lesser polluted localities while cladocerans and ostracods occurred even in the most urbanized sampling locality. Many of the species found were commonly observed species from the region. Epizoic associations of cladocerans and rotifers and red coloration in the former group were observed during a low dissolved oxygen phase in both rivers. Such observations underscore the potential bioindicator value of these small animals to the impacts of urbanization.

Keywords: Biodiversity, Cladocera, Epizoic, Mula-Mutha river, Ostracoda, pollution, Rotifera, urbanization.

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INTRODUCTION

Urbanization refers to the mass migration of human populations from rural to urban settings (Kuddus et al. 2020). More than half the world's population (~4.3 billion) lives in urban areas which may increase to six billion by the year 2041 (Ritchie & Roser 2018; UNDESA 2018). Thus, urban areas, especially in developing countries like India, are expanding at an exponential rate assisted by the ever-increasing population (Henderson 2002; Cohen 2006; Onda et al. 2019; Kuddus et al. 2020). Such rapid urbanization can have adverse effects on different ecosystems by way of native species loss and/or an increase in the number of non-native species (McMichael 2000; McKinney 2002, 2006).

Rivers are an important component of many urban centres providing water, power, and means of transport besides harbouring high biodiversity (McMichael 2000; Everard & Moggridge 2012; Tran Khac et al. 2018). Many studies have shown that anthropogenic activities like modification of the river channel/bank and untreated waste disposal impact riverine biodiversity in multiple ways which include cultural eutrophication and biotic homogenization to name a few (Blair 2001; Ouyang et al. 2002; Dudgeon et al. 2006; Schindler 2012; Braghin et al. 2018; Du et al. 2023).

Freshwater zooplankton is a well-represented group of invertebrates in rivers and forms an important component of aquatic food chains (Dumont & Negrea 2002; Liu et al. 2020). Zooplankton communities respond to physical and chemical changes in the riverine habitats by displaying variations in their growth, community composition, density, diversity, and distribution (Bērziņš & Pejler 1987, 1989; Duggan et al. 2001; Nogrady et al. 1993; Hulyal & Kaliwal 2008; Jeppesen et al. 2011; Adamczuk et al. 2015; Du et al. 2023).

Literature exists on the different limnological aspects of lotic and lentic habitats in India, though, several of them, especially in the case of zooplankton, have issues like species misidentifications (Sharma & Sharma 2021). Data from reliable studies point to species losses occurring in response to changes in environmental variables like nutrients (phosphorus and nitrogen), dissolved oxygen, turbidity and water flow (Padmavati & Goswami 1996; Arora & Mehra 2003; Rajaram & Das 2008; Padhye & Dahanukar 2015).

Pune is a rapidly growing city in India where its population has grown exponentially within the last 70 years from 3.75 lakhs (1941) to 5 million (2011) and is expected to be >9 million by 2035 (see Butsch et al. 2017; UNDESA 2018). Mula & Mutha, the two rivers that provide water to this urban centre are highly polluted within the city limits due to various anthropogenic activities (Wagh & Ghate 2008; Padhye 2020). Existing faunal literature on these rivers suggests decreasing species numbers across animal groups like odonates, molluscs, fish and birds due to this urbanization effects (Gole 1983; Kharat et al. 2001, 2003; Wagh & Ghate 2008; Kulkarni & Subramanian 2013; Kulkarni et al. 2021). Studies on zooplankton from a single locality on the Mula River have also shown a similar trend (Vanjare et al. 2010; Padhye 2020).

The present study aims to provide a faunistic overview of Rotifera, Cladocera, and Ostracoda of Mula & Mutha rivers passing through the urban part of Pune, Maharashtra. Additionally, peculiar observations and habits of some of the species found in the study are also commented upon.

MATERIALS AND METHODS

Site

Mula & Mutha are tributaries of the Bhima River (Pune, Maharashtra) and are heavily polluted within the city limits, receiving large amounts of untreated waste. Both rivers originate in the Western Ghats, meet in Pune and then join the Bhima River outside the city limits. Floating vegetation (*Pistia* sp., *Eichhornia* sp., and *Lemna* sp.) is observed here frequently and in high densities, after post-monsoon in the urban regions while submerged (*Hydrilla* sp.) and emergent vegetation (*Typha* sp.) is also seen at many places.

Two sampling sites were selected along the Mula River (Ram-Mula confluence & Aundh Bridge) and Mutha River (Vitthalwadi & Garware College) within Pune City for the study (Figure 1). Urbanization around Ram-Mula confluence and Vitthalwadi is comparatively lower than Aundh Bridge and Garware College sites (authors pers. obs. 19 November 2017).

Field and laboratory work

Qualitative sampling was carried out at Ram-Mula confluence, Vitthalwadi, and Garware College between post monsoon and winter season in 2017–18. Sample aliquots were taken (~3–4) from a stretch of ~100 m at each site and concentrated in a single container (100 ml). Effort was made to collect the sample once in each season. A plankton net of 53-micron and hand net of 100-micron mesh size was used for the collection. The sediment was gently disturbed, and water was filtered subsequently with the hand net for better

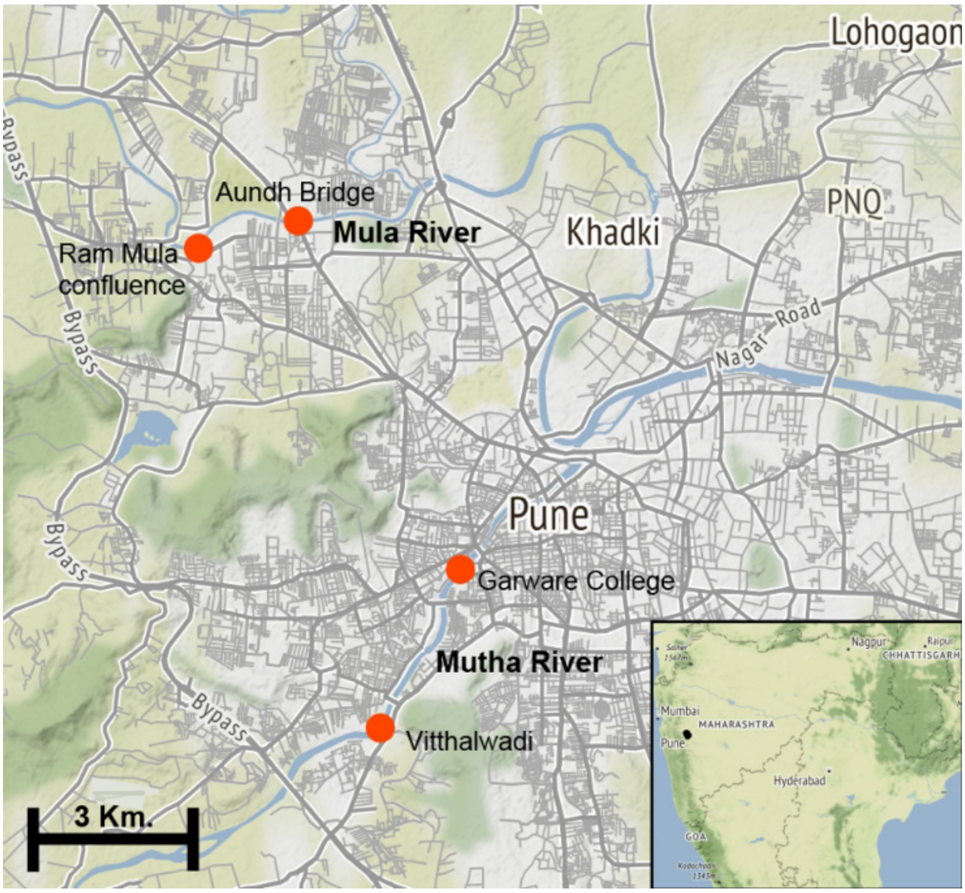

Figure 1. The collection localities along the Mula & Mutha rivers, Pune.

representation of meiobenthic species. The samples were preserved in 4% formalin. Dissolved Oxygen was taken using a DO probe (Hanna) and salinity, pH, water temperature were taken at each sampling station using a multiparameter probe (Eutech). Identifications were done under light microscope (Olympus CH20i) and stereo microscope (Magnus MS 24). Identification was done using standard literature available for the respective groups (Supplementary list 1). Zooplankton data for the Aundh Bridge site was taken from Vanjare et al. (2010) and Padhye & Dahanukar (2015) since the site was inaccessible during the sampling period. Urbanization extent was assessed qualitatively by visual inspection.

RESULTS AND DISCUSSION

Environmental data recorded during the study are shown in supplementary Table 1. The pH ranged from 7.12–8.6, dissolved oxygen from 0.25–11.8 mg/L, water temperature from 18.6–32°C and salinity from 105–386 ppm. No environmental data was collected for the Garware College site.

Seventy-three species of three different zooplankton groups were documented, of which rotifers being the most species rich with 47 species, followed by cladocerans—15 and ostracods—11, respectively (supplementary Table 2). Rotifers were reported from only three localities while cladocerans and ostracod species were observed at all the four sampling stations (Figure 2). Sampling stations having lesser urbanization had more species of rotifers (Ram Mula = 31 & Vitthalwadi = 34) with no species seen at the locality in the city centre (Garware College, Figure 1). Maximum species of cladocerans and ostracods were found at the Aundh Bridge (cladocerans = 11; ostracods = 7) though, representatives of these groups were also found at the Garware College site.

Among the 47 rotifer species, 41 were from the order Ploima, five from the order Flosculariaceae (subclass Monogononta) and one from the family Philodinidae within the subclass Bdelloidea. The Brachionidae family was the most species-rich with 13 species followed by Lecanidae with nine species while eight rotifer families were represented by a single species only. Rotifer genera *Brachionus* and *Lecane* (n = 9 each) were found in high numbers which is typical of these genera in tropical waters (Arora & Mehra 2002). Notable findings include rotifers with a restricted geographic distribution like *Brachionus durgae* (Ram Mula & Vitthalwadi), *Epiphanes brachionus spinosa* (all sites) and *Lecane stenroosi* (Vitthalwadi) were also seen in the study. Three predatory rotifers from the family Asplanchnidae, viz. *Asplanchnopus multiceps, Asplanchna brightwellii and Asplanchna priodonta* were also observed at three of the four sites (Image 2). Most of the recorded rotifer species are common and cosmopolitan in distribution.

Chydorids were the most species rich cladoceran group with five species followed by Daphniidae with three. Both the moinid species were observed in high densities at the site located on river Mutha in the most urbanized region of Pune city (Garware College). Some of the species such as *Simocephalus mixtus*, *Macrothrix spinosa*, and *Ilyocryptus spinifer* are known to occur seasonally at one of the sites on Mula River (Aundh Bridge). Most of these species are commonly known from the region with *Leydigia* (*Neoleydigia*) *ciliata* and *I. spinifer* being the most commonly occurring species in Pune (Padhye et al. 2023) (Image 2).

Only one species from the ostracod genus, *Ilyocypris* sp., was seen at all the four sampling points while the oriental endemics like *Stenocypris derupta* Vávra, *Plesiocypridopsis* cf. *dispar* (Hartmann, 1964) and *Chrissia formosa* (Klie, 1938) were seen at the Ram-Mula confluence only. *Heterocypris incongruens* (Ramdohr, 1808) reported from Garware college is a cosmopolitan species known to tolerate high levels of pollution (Karakaş-Sarı & Külköylüoğlu 2008). *Plesiocypridopsis* cf *dispar* and *Stenocypris* sp. were seen near a natural spring pouring into the Mutha River at the Vitthalwadi site (Image 1).

Seventy-three species of rotifers, cladocerans, and ostarcods from just four locations in Pune City is a good number as compared to riverine fauna documented from some other urban zones of India. Arora & Mehra (2003) documented 89 rotifers from river Yamuna in Delhi, Hulyal & Kaliwal (2007) found 10 rotifers and six cladocerans in Almatti Reservoir of Bijapur, while Kamboj & Kamboj (2020) observed 10 rotifers and eight cladocerans in the Ganga River, Uttarakhand, and Rao (2001) reported 17 rotifers and six cladocerans from the river Ganga between Rishikesh and Kanpur, Uttar Pradesh. Reliable faunistic studies providing species numbers of ostracods from such habitats are not available. The variation observed in the species numbers between these studies could be explained by many possible differences in the geomorphological and geochemical features of the rivers, the local environmental conditions and biotic conditions such as predation pressure. Still, the trend in species numbers concerning the specific taxonomical groups was consistent with other studies, i.e., rotifers having the most number of species as

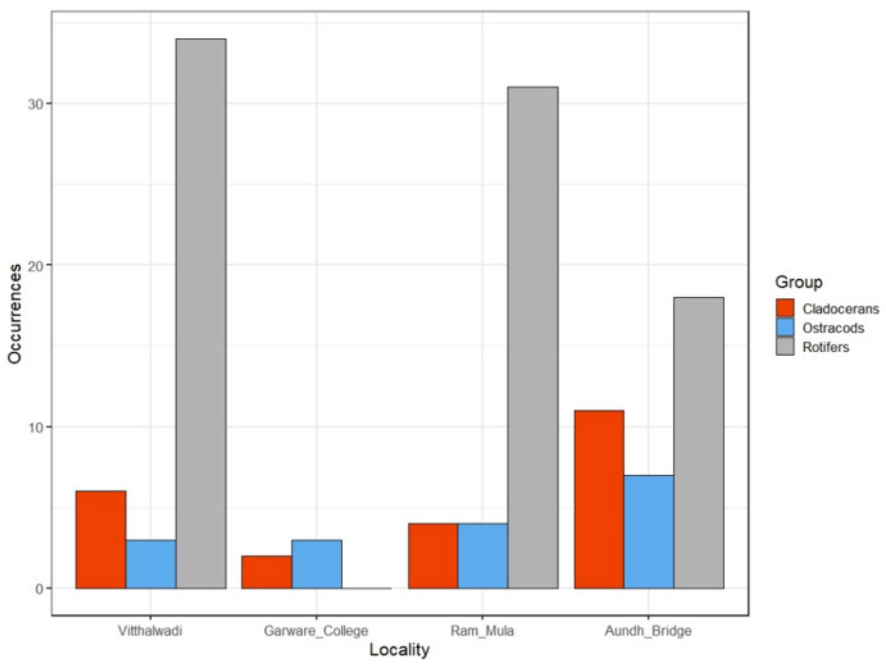

Figure 2. Number of species occurring at each of the study sites.

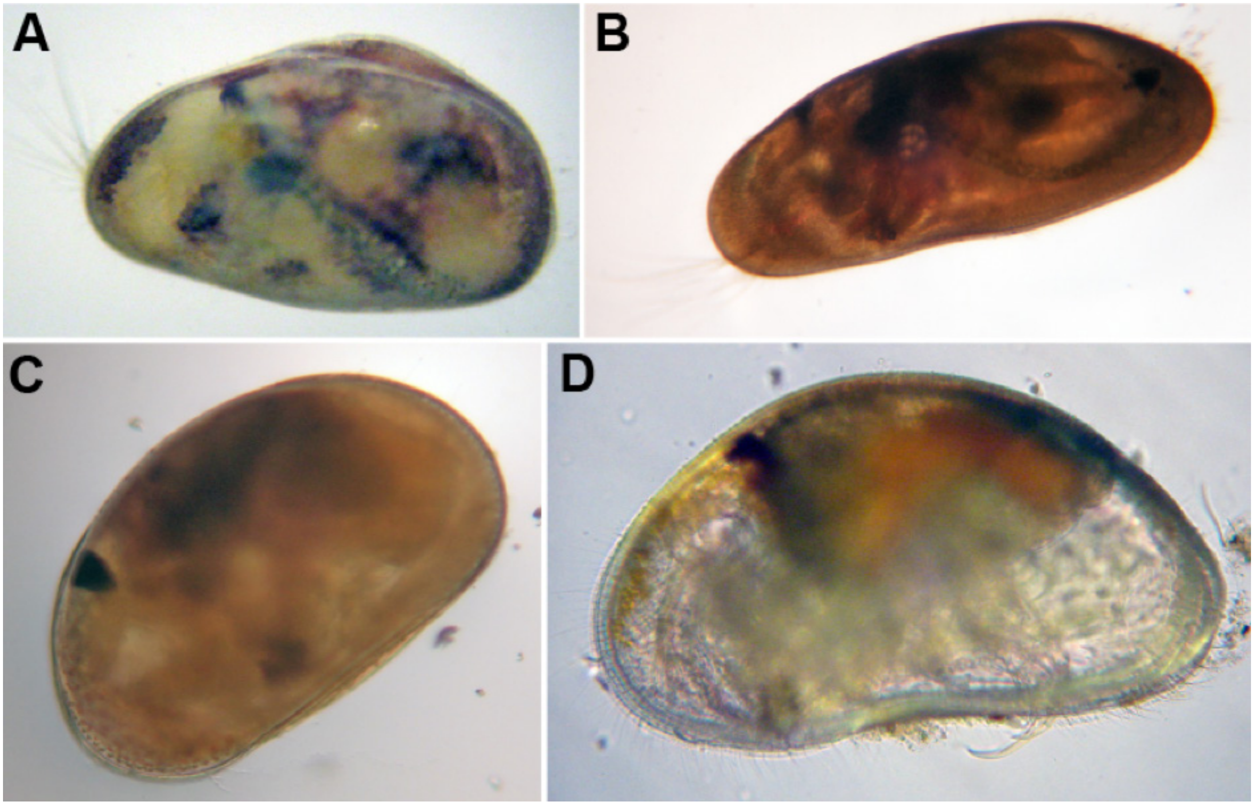

Image 1. Ostracods: A—*Cyprinotus cingalensis* Brady, 1886 | B—*Chrissia formosa* (Klie, 1938) | C—*Physocypria* sp. | D—*Plesiocypridopsis* cf. *dispar* (Hartmann, 1964). A–B images taken at 40x and C–D at 100x final magnification. © Yugandhar Shinde.

compared to cladocerans and ostracods (Sharma & Naik 1996; Arora & Mehra 2003; Sharma 2011). Similarly, the species number distribution between the order/families of each group was also in agreement with the studies available in India and other regions (Ploima being the most species-rich order in rotifers, Chydoridae being the most species-rich cladoceran family)

Occurrence of common species such as, *Moina micrura*, *Brachionus* spp., *Polyarthra* sp., and *Heterocypris incongruens* at such sites imply the ability of these organisms to tolerate a wide range of environmental conditions (Nogrady et al. 1993; Külköylüoğlu et al. 2018). Cultural eutrophication which can happen due to rapid urbanization (Dudgeon et al. 2006; Schindler 2006; Lodi et al. 2011) is known to affect zooplankton richness and increase the dominance of such common species in many cases (Nogrady et al. 1993; Dodson et al. 2000; Yuan & Pollard 2018; Kambhoj & Kambhoj 2020). Certain zooplankton species are known to evolve rapidly to cope with such environmental change to persist in unfavourable conditions like *Daphnia magna* adapting to an increased water temperature (Brans et al. 2017). The presence of such generalist species can lead to biotic homogenization, i.e., reduction in β diversity across space (Wang et al. 2021), which is a worldwide phenomenon noticed in disturbed ecosystems (Blair 2001; McKinney 2002, 2006, 2008; Liu et al. 2020). Kulkarni et al. (2021) showed that the species richness of aquatic gastropods decreased along an urbanization gradient including the rivers studied here with only invasive species reported in the most urbanized locality. This locality was very close to the Garware College site for which we recorded the lowest species numbers (Supplementary Table 1; Figure2).

The presence or absence of certain species/groups like zooplankton can be applied to indicate environmental disturbances (Duggan et al. 2001; Hulyal & Kaliwal 2008; Du et al. 2023). Certain species from the genus *Brachionus* are indicators of eutrophic conditions of water (Mäemets 1983) and we found seven species in our collections especially *B. angularis*, *B. rubens*, *B. calyciflorus*). An epizoic association of the rotifer *Brachionus rubens* and cladoceran *Moina macrocopa* was observed at the Aundh Bridge site with over 40 individuals of *B. rubens* attached to a single individual of *M. macrocopa*. This association was seen during the peak summer months (April/May) when the DO level was very low (Vanjare et al. 2010) and not observed at any

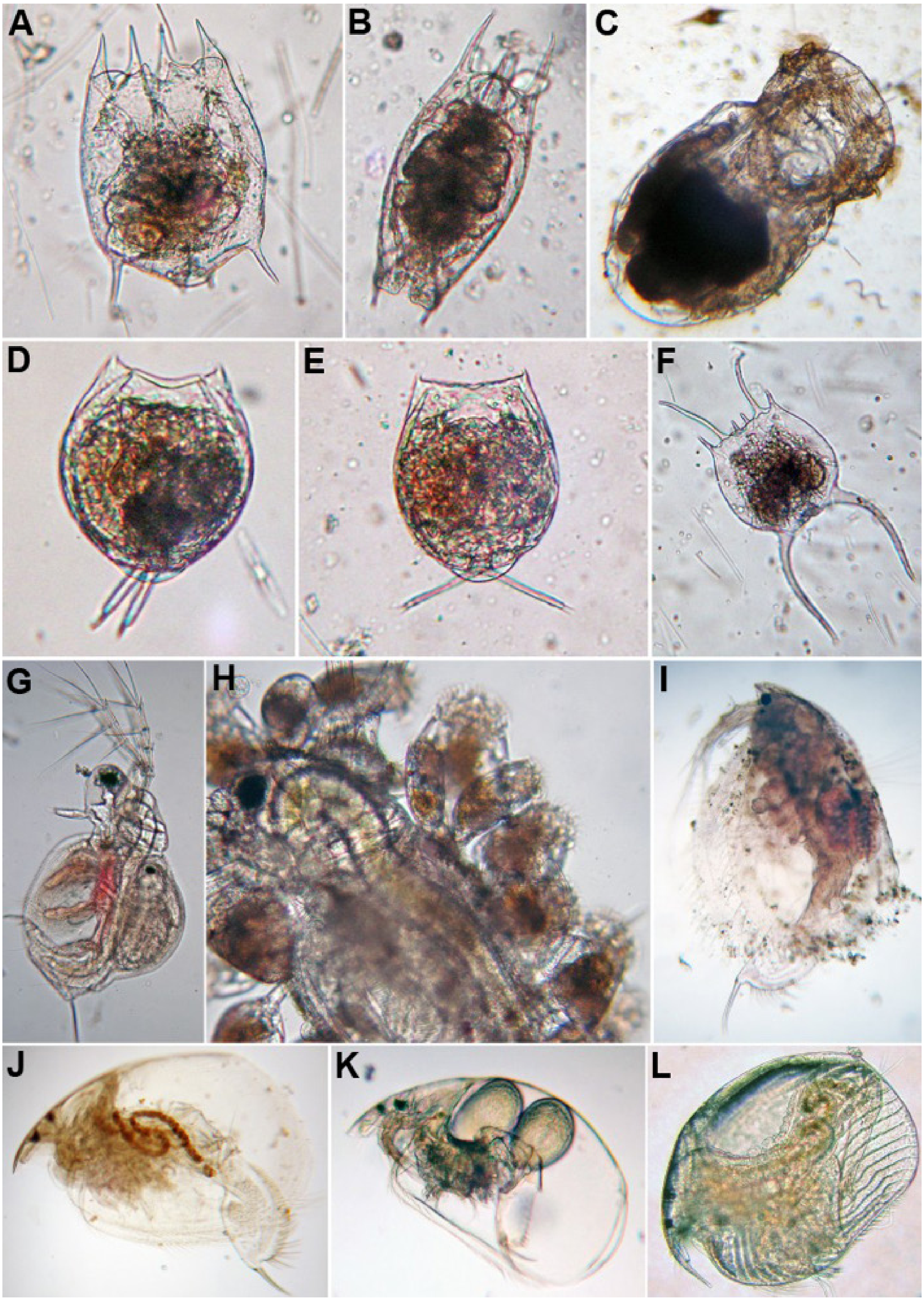

Image 2. Representative rotifers and cladocerans: A—*Brachionus calyciflorus* Pallas, 1766 | B—*Mytilina ventralis* (Ehrenberg, 1830) | C—*Asplanchnopus multiceps* (Schrank, 1793) | D—*Lecane luna* (Müller, 1776) | E—*Lecane curvicornis* (Murray, 1913) | F—*Brachionus falcatus* Zacharias, 1898 | G—*Moina micrura* Kurz, 1874 | H—Epizoic interaction of *Brachionus rubens* with *Moina macrocopa* (Straus, 1820) | I—*Ilyocryptus spinifer* Herrick, 1882 | J—*Leydigia ciliata* Gauthier, 1939 | F—*Ovalona cambouei* (Guerney et Richard, 1893) | L. *Kurzia longirostris* (Daday, 1898). H—image taken at 400x final magnification | A–G & I–L—images taken at 100x final magnification. © (A–F)—Avinash Vanjare, (G–L)—Sameer Padhye.

other studied site. Dark red-coloured cladoceran species (*Moina micrura*, *M. macrocopa*, and *K. longirostris*) were spotted at the Aundh bridge site during the summer months when the DO was the lowest (Vanjare et al. 2010). We also observed a faint red coloration in the *Moina* species collected at the other localities in the winter samples. This colour change occurs due to haemoglobin production as a response to low dissolved oxygen in the water (Fox 1949).

Our study was based only on four sites on rivers Mula Mutha with no data available for upstream patches of both the rivers where the urbanization is relatively lower than the main city. Exhaustive sampling including more upstream localities would certainly increase the species number. Studying the environmental change indicator potential of these zooplankton groups along with long-term monitoring of their community dynamics will surely help us understand and devise ways of monitoring the impacts of urbanization. Conducting such studies is crucial in light of biodiversity loss happening as a consequence of increasing urbanization (Kharat et al. 2001, 2003).

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Supplementary Table 1. Environmental parameters at the site.

Site/ Parameter	Temperature (°C)	pH	Salinity (ppm)	DO (mg/L)	Remarks
Aundh Bridge	23.8–32.0	7.3–8.2	227–386	1.2–7.3	See Vanjare et al. 2010
Aundh Bridge	24–31.2	7.12–8.05	105–386	0.81–4.15	See Padhye & Dahanukar 2015
Ram-Mula	18.6–24.0	7.2–7.8	227–382	0.44–8.80	Current study
Vitthalwadi	22.0–30.1	7.2–8.6	129–356	0.25–11.8	Current study

Supplementary Table 2. List of species observed at the sites.

Phylum Rotifera	
Asplanchnidae	*Asplanchna brightwellii* Gosse, 1850
	Asplanchna priodonta Gosse, 1850
	Asplanchnopus multiceps Schrank, 1793
Brachionidae	*Brachionus angularis* (Gosse, 1851)
	Brachionus bidentata (Anderson, 1889)
	Brachionus calyciflorus (Pallas, 1766)
	Brachionus caudatus (Barrois & Daday, 1894)
	Brachionus diversicornis Daday, 1883
	Brachionus durgae (Dhanapathi, 1974)
	Brachionus falcatus (Zacharias, 1898)
	Brachionus quadridentatus (Hermann, 1783)
	Brachionus rubens (Ehrenberg, 1838)
	Keratella cochlearis (Gosse, 1851)
	Keratella tropica (Apstein, 1907)
	Plationus patulus (Müller, 1786)
	Platyias quadricornis (Ehrenberg, 1832)
Epiphanidae	*Epiphanes brachionus spinosa* (Rousselet, 1901)
	Beauchampiella eudactylota (Gosse, 1886)
	Euchlanis dilatata (Ehrenberg, 1832)
Euchlanidae	*Tripleuchlanis plicata* (Levander, 1894)
Lecanidae	*Lecane bulla* (Gosse, 1851)
	Lecane closterocerca (Schmarda, 1859)
	Lecane hamata (Stokes, 1896)
	Lecane leontina (Turner, 1892)
	Lecane luna (Müller, 1776)
	Lecane lunaris (Ehrenberg, 1832)
	Lecane papuana (Murray, 1913)
	Lecane curvicornis (Murray, 1913)
	Lecane stenroosi (Meissner, 1908)
Lepadellidae	*Colurella obtusa* (Gosse, 1886)
	Lepadella (*Heterolepadella*) *ehrenbergii* (Perty, 1850)
	Lepadella (*Lepadella*) *ovalis* (Müller, 1786)
	Squatinella lamellaris (Müller, 1786)
Mytilinidae	*Mytilina bisulcata* (Lucks, 1912)
	Mytilina ventralis (Ehrenberg, 1830)
Notommatidae	*Cephalodella* sp.
	Monommata sp.
	Taphrocampa annulosa (Gosse, 1851)

Phylum Rotifera	
Scaridiidae	*Scaridium longicaudum* (Müller, 1786)
Synchaetidae	*Polyarthra vulgaris* (Carlin, 1943)
Trichocercidae	*Trichocerca cylindrica* (Imhof, 1891)
Hexarthridae	*Hexarthra mira* (Hudson, 1871)
Filiniidae	*Filinia longiseta* (Ehrenberg, 1834)
Testudinellidae	*Testudinella patina* (Hermann, 1783)
Flosculariidae	*Sinantherina semibullata* (Thorpe, 1893)
	Lacinularia elliptica Shephard, 1897
Philodinidae	*Rotaria neptunia* (Ehrenberg, 1830)
CLADOCERA	
Sididae	*Latonopsis australis* Sars, 1888 s.lat.
	Diaphanosoma sarsi (Richard, 1895)
Daphniidae	*Daphnia* (*Ctenodaphnia*) *lumholtzi* (Sars, 1885)
	Ceriodaphnia cornuta (Sars, 1885)
	Simocephalus (*Simocephalus*) *mixtus* (Sars, 1903)
Moinidae	*Moina macrocopa* (Straus, 1820)
	Moina micrura (Kurz, 1874)
Macrothricidae	*Macrothrix spinosa* (King, 1853)
	Macrothrix triserialis (Brady, 1886)
Ilyocryptidae	*Ilyocryptus spinifer* (Herrick, 1882)
Chydoridae	*Flavalona cheni* (Sinev, 2001)
	Ovalona cambouei (Guerney et Richard, 1893)
	Kurzia longirostris (Daday, 1898)
	Leydigia (*Neoleydigia*) *ciliata* (Gauthier, 1939)
	Chydorus eurynotus (Sars, 1901)
OSTRACODA	
Cyprididae	*Chrissia formosa* (Klie, 1938)
	Stenocypris hislopi (Ferguson, 1969)
	Stenocypris derupta (Vávra, 1906)
	Cypris granulata (Daday, 1898)
	Plesiocypridopsis cf *dispar* (Hartmann, 1964)
	Heterocypris incongruens (Ramdohr, 1808)
	Hemicypris pyxidata (Moniez, 1892)
	Hemicypris ovata Sars, 1903
	Cyprinotus cingalensis Brady, 1886
Candonidae	*Physocypria* sp.
Ilyocyprididae	*Ilyocypris* sp.

Supplementary List 1. List of references used for identification, classification and nomenclature used for identifying Rotifera, Claodocera, and Ostracoda.

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