possible that the populations of this species in Thangu and Chugya areas were not visited by subsequent collectors leading to the unavailability of specimens from these areas. The collection reported here indicates that it continues to survive in Kuari Pass area since the last 130 years (1885–2015). The species is not endemic to India and fulfils the criteria B2a, B2biv and D1 of section B and D of the 'Vulnerable' category at regional level according to IUCN[18].

A. thangoensis W.W.Sm. has been rediscovered from Kuari Pass area district Chamoli, Uttarakhand. A new distributional record is made here from Western Himalaya based on Duthie's collection after a lapse of 130 years and our own collection in 2015 after 106 years of type collection from Sikkim. Interestingly, the specimen collected from Chugya (Tibet, China) by Rohmoo Lepcha (285, CAL) as mentioned in Singh and Diwakar[19], also makes it a new record to the flora of China. It is a threatened species assessed as 'Vulnerable'[3,4] and based on our field observations, its 'Vulnerable' status is tentatively supported. However, the continued existence (1885–2015) of this species in Kuari Pass area proves that it survives on inaccessible rocky slopes despite anthropogenic pressures and calls for a survey of all known localities and similar habitats, both in India and China for correct assessment of its global threat status.

1. Mabberley, D. J., *Mabberley's Plant-Book: A Portable Dictionary of Plants, their Classifications, and Uses*, Cambridge University Press, Cambridge, 2008, p. 1021.
2. Majumdar, N. C., In *Flora of India, Volume 2* (eds Sharma, B. D. and Balakrishnan, N. P.), Botanical Survey of India, Kolkata, 1993, pp. 503–595.
3. Rao, C. K., Geetha, B. L. and Geetha, S., *Red List of Threatened Vascular Plant Species in India*, Botanical Survey of India, Howrah, 2003, p. 28.
4. Nayar, M. P. and Sastry, A. R. K., *Red Data Book of Indian Plants*, *Volume 1*, Botanical Survey of India, Kolkata, 1987, p. 367.
5. Rawat, D. S. and Rana, C. S., *Curr. Sci.*, 2007, **92**(11), 1486–1488.
6. Smith, W. W. and Cave, G. H., *Rec. Bot. Surv. India*, 1911, **4**, 141–260.
7. Srivastava, S. K., Lakshminarasimhan, P., Arisdason, W. and Sardesai, M. M., *J. Threat. Taxa*, 2015, **7**(8), 7465–7470.
8. Uniyal, B. P., Sharma, J. R., Choudhery, U. and Singh, D. K., *Flowering Plants of Uttarakhand (A Check List)*, Bishen Singh Mahendra Pal Singh, Dehradun, 2007, p. 404.
9. Grierson, A. J. C., In *Flora of Bhutan* (eds Grierson, A. J. C. and Long, D. G.), Royal Botanical Garden Edinburgh, UK, 1984, vol. 1, pp. 205–209.
10. Press, J. R., Shrestha, K. K. and Sutton, D. A., Annotated checklist of the flowering plants of Nepal. Natural History Museum Publications, London, 2000; http://www.efloras.org (accessed on 23 March 2016).
11. Chowdhery, H. J. and Wadhwa, B. M., *Flora of Himachal Pradesh, Volume 1*, Botanical Survey of India, Howrah, 1984, pp. 85–108.
12. Majumdar, S. C., In *Flora of Jammu and Kashmir, Volume 1* (eds Singh, N. P., Singh, D. K. and Uniyal, B. P.), Botanical Survey of India, Kolkata, 2002, pp. 633–690.
13. Hajra, P. K., Verma, D. M. and Giri, G. S., *Material for the Flora of Arunachal Pradesh, Volume 1*, Botanical Survey of India, Howrah, 1996, p. 655.
14. Zhengyi, W., Lihua, Z. and Wagner, W. L., In *Flora of China (Caryophyllaceae through Lardizabalaceae), Volume 6* (eds Wu, Z. and Raven, P. H.), Missouri Botanical Garden Press, St. Louis, USA, 2001; www.efloras.org (accessed on 23 March 2016).
15. Srivastava, R. C., *Flora of Sikkim (Ranunculaceae to Moringaceae)*, Oriental Enterprises, Dehradun, 1998.
16. Naithani, B. D., *Flora of Chamoli District, Volume 1*, Botanical Survey of India, Howrah, 1984.
17. Gaur, R. D., Rawat, D. S. and Dangwal, L. R., *J. Econ. Taxon. Bot.*, 1995, **19**, 9–26.
18. IUCN Red List Categories and Criteria: Version 3.1, IUCN Species Survival Commission, IUCN, Gland, Switzerland, 2013, p. 32.
19. Singh, R. K. and Diwakar, P. G., *Indian J. For.*, 2010, **33**(3), 429–436.

ACKNOWLEDGEMENTS. We thank the curators of the Central National Herbarium, Howrah and the Forest Research Institute, Dehradun for permission to consult specimens.

Received 5 April 2016; revised accepted 29 November 2016

SATISH CHANDRA
D. S. RAWAT*

Department of Biological Sciences,
College of Basic Sciences and Humanities,
G.B. Pant University of Agriculture and Technology,
Pantnagar 263 145, India
**For correspondence.*
e-mail: drds_rawat@yahoo.com

Species richness estimate of freshwater rotifers (Animalia: Rotifera) of western Maharashtra, India with comments on their distribution

Of the 2031 Rotifera species described so far, the Oriental region harbours 78 monogonont genera with 486 species and 9 bdelloid genera with 58 species[1]. Only a small fraction (~19%) of that total rotifer diversity is known from the Indian region when compared with the Southeast Asian countries[2]. Given the complex geography and geology of the Indian subcontinent, with estimates ranging from 360 to 492, it is difficult to predict the actual number of valid rotifer species present in India[3–7]. Comprehensive work has been carried out in the North East (NE) Indian states with valid reports of 238 species[6], while only some reliable faunistic information is available from other regions of the country[8,9]. The same state exists for the rotifer fauna of Maharashtra as well[10–13]. The literature though abounds with faunistic inventories from single localities having numerous nomenclatural errors. In this regard, we present a species richness estimate and a comprehensive faunistic report of freshwater monogonont rotifers from part of western Maharashtra. We also present faunal comparison between our study area and NE India (henceforth referred to as NEI) with special attention to families Brachionidae and Lecanidae.

The region selected for the study was between 18°–19°N and 73°–75°E. The region broadly consists of the Western Ghats on the western side and Deccan plateau on the eastern side (henceforth

referred to as WM). Sampling for rotifers was done from 35 different localities within the study region from 2012 to 2014, and a total of 77 samples were collected. Efforts were made to sample from different types of water bodies. Qualitative sampling was done using a 53 µm mesh plankton tow net and samples were preserved in 4–5% formalin. The specimens were observed and identified under a trinocular compound microscope. Taxonomic identifications were done using available keys and publication from various taxonomists[14]. Locality maps were prepared using DIVA-GIS (v 7.5)[15]. Species richness was estimated using nonparametric (distribution-free) methods to evaluate true species richness from the samples[16,17]. Chao 2, Jackknife2 and Bootstrap indices were calculated for our data to estimate the true species number. EsimtateS (v 9.1) was used to generate the species richness estimation indices[18]. Five hundred randomizations per sample were carried out to get the standard deviation estimate around each data point. Species were categorized into 'rare', 'average' and 'common' based on their occurrences in the total collected samples and converted into percentages. Grouping was done as follows; rare (less than 10%), average (10–30%) and common (more than 30%)[19]. Complementarity index[17,20,21] was used to compare faunas between WM and NEI[6]. The complementarity index is given by the formula

$$C_{jk} = U_{jk}/S_{jk},$$

where $S_{jk} = S_j + S_k - 2V_{jk}$ and S_j is the species richness of habitat j, S_k the species richness of habitat k, S_{jk} the sum of species richness of habitats j and k; $2V_{jk}$ the species number shared between habitats j and k; U_{jk} is the number of species unique to habitats j and k. Two habitats with identical faunas would have $C = 0$, while habitats with totally different faunas would have $C = 100$ (ref. 17).

Eighty-nine rotifer species belonging to 21 families and 43 genera were recorded from 30 different localities in the study (Table 1). The median number of species per locality was 10 (range = 1–33). Of the monogonont orders, Ploima was the richest (32 genera, 67 species) which included interesting species such as *Ascomorphella volvocicola* (Plate, 1886), an intracellular parasitic rotifer of *Volvox*, and *Brachionus rubens* (Ehrenberg, 1838), an epizoic rotifer on many invertebrates[10], followed by Floscullariaceae (10 genera, 17 species) which includes the free-swimming colonial species from genera *Sinantherina* and *Lacinularia* also seen for the first time from Indian freshwaters. The genus *Collotheca*, of order Collothecaceae (four species) includes all new records to Maharashtra (Table 1).

Lecane was the most species-rich genus with 17 species, followed by *Brachionus* with 12 species. Twenty-nine genera were represented by single species only. Most frequently recorded rotifers include *Lecane bulla bulla*, *Polyarthra vulgaris* and *Euchlanis dilatata dilatata*. Ten species, i.e. *Ascomorpha* sp., *Lacinularia flosculosa*, *Lecane decipiens*, *Notommata* sp., *Proales* sp., *Ptygura tacita*, *Rotaria neptunia*, *Ptygura pedunculata*, *Taphrocampa* sp. and *Squatinella lamellaris* were seen only in a single sample, in very low numbers and even as a single individual at times.

More than 50% of the rotifer species were rare ($n = 48$), while only about 12% of species ($n = 11$) were common. Ten species were found only once in the collected samples. Many species were found in very low numbers, at times as single individuals. A small number of rotifer species (<10%) were common in most of the samples. Most frequently recorded rotifers include *L. bulla bulla* (53%), *P. vulgaris* (48%) and *E. dilatata dilatata* (43%).

Brachionus and *Lecane* species accounted for 26% of the total documented fauna. *Brachionus calyciflorus* and *Brachionus quadridentatus* were the most commonly occurring species from *Brachionus*, while *L. bulla bulla* and *Lecane luna* were the most common species in genus *Lecane*. With the given sample number, Chao 2 estimator gave an estimate of 92 (92.52) species, Jackknife 2 yielded 97 (97.08) species, while Bootstrap showed a value of about 95 (94.68) species. This indicates that the present work has covered about 90% of the fauna given the sample size (Figure 1 *b*).

The complementarity index between WM and NEI was quite high (0.77). Variation was mostly seen only in species number, especially for order Ploima while generic and family-level representation was similar for both compared regions (Figure 1 *c*–*e*). Twelve species, viz. *Ascomorphella volvocicola*, *Asplanchnopus hyalinus*, *Asplanchnopus*

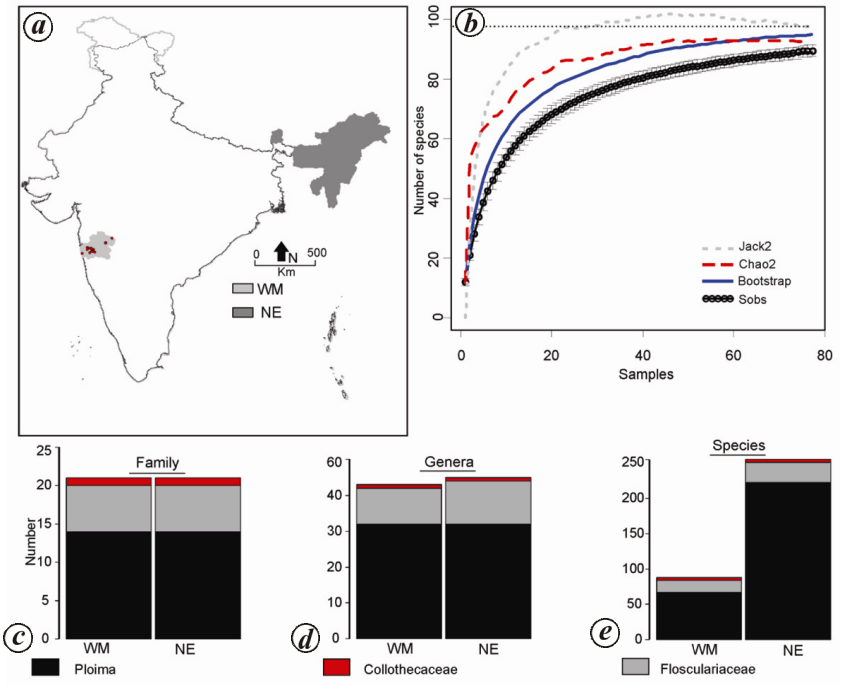

Figure 1. ***a***, Map showing the study area of western Maharashtra (WM) and North East Indian (NEI) region, fauna of which was used for comparative analysis. ***b***, Species estimation curves using sample-based incidence data (S_{obs}, species observed). Each point is the mean of 500 estimates based on 500 randomizations of sample accumulation order. ***c*–*e***, Comparison of family, genera and species number of the three rotifer orders between WM and NEI regions.

Table 1. Checklist of Rotifera recorded from the collection sites during the study

Anuraeopsis fissa Gosse, 1851[A]	*Brachionus forficula* Wierzejski, 1891[A]	*Filinia pejleri* Hutchinson, 1964*[R]	*Lecane luna* (Müller, 1776)*[A]	*Notommata* sp.[R]	*Tripleuchlanis plicata* (Levander, 1894)*[R]
Ascomorpha sp.[R]	*Brachionus quadridentatus* Hermann, 1783[C]	*Filinia terminalis* (Plate, 1886)[A]	*Lecane lunaris* (Ehrenberg, 1832)*[A]	*Plationus patulus patulus* (Müller, 1786)[C]	*Ptygura pedunculata* Edmondson, 1939[#R]
Ascomorphella volvocicola (Plate, 1886)[#R]	*Brachionus rubens* Ehrenberg, 1838[A]	*Hexarthra mira* (Hudson, 1871)[A]	*Lecane ohioensis* (Herrick, 1885)*[R]	*Platyias quadricornis quadricornis* (Ehrenberg, 1832)*[A]	*Ptygura tacita* Edmondson, 1940*[R]
Asplanchna brightwellii Gosse, 1850*[A]	*Cephalodella* sp.[R]	*Horaella brehmi* Donner, 1949*[R]	*Lecane papuana* (Murray, 1913)*[A]	*Polyarthra vulgaris* Carlin, 1943[C]	*Rotaria neptunia* (Ehrenberg, 1830)[R]
Asplanchna priodonta Gosse, 1850*[R]	*Collotheca ornata* (Ehrenberg, 1832)*[R]	*Keratella cochlearis* (Gosse, 1851)[A]	*Lecane pyriformis* (Daday, 1905)*[R]	*Pompholyx sulcata* Hudson, 1885*[A]	
Asplanchnopus hyalinus Harring, 1913*[R]	*Collotheca pelagica* (Rousselet, 1893)*[R]	*Keratella tropica* (Apstein, 1907)[C]	*Lecane quadridentata* (Ehrenberg, 1830)[A]	*Proales* sp.[R]	
Asplanchnopus multiceps (Schrank, 1793)*[A]	*Collotheca campanulata* (Dobie, 1849)*[R]	*Lacinularia elliptica* Shephard, 1897*[R]	*Lecane unguitata* (Fadeev, 1925)*[R]	*Sinantherina semibullata* (Thorpe, 1893)*[R]	
Beauchampiella eudactylota (Gosse, 1886)[A]	*Collotheca tenuilobata* (Anderson, 1889)*[R]	*Lacinularia flosculosa* (Müller, 1773)[R]	*Lecane ungulata* (Gosse, 1887)*[R]	*Sinantherina socialis* (Linnaeus, 1758)*[R]	
Brachionus angularis Gosse, 1851[C]	*Colurella* sp.[A]	*Lecane arcula* Harring, 1914*[A]	*Lepadella (Hetero-lepadella) ehrenbergii* (Perty, 1850)*[A]	*Sinantherina spinosa* (Thorpe, 1893)	
Brachionus bidentatus bidentatus Anderson, 1889[R]	*Conochilus (Conochiloides) dossuarius* Hudson, 1885[R]	*Lecane bulla bulla* (Gosse, 1851)[C]	*Lepadella (Lepadella) ovalis* (Müller, 1786)*[A]	*Squatinella lamellaris* (Müller, 1786)*[R]	
Brachionus budapestinensis Daday, 1885[R]	*Cyrtonia tuba* (Ehrenberg, 1834)[R]	*Lecane closterocerca* (Schmarda, 1859)[A]	*Limnias melicerta* Weisse, 1848*[R]	*Synchaeta pectinata* Ehrenberg, 1832[R]	
Brachionus calyciflorus Pallas, 1766[C]	*Dicranophorus* sp.[R]	*Lecane curvicornis* (Murray, 1913)[A]	*Lophocharis salpina* (Ehrenberg, 1834)*[R]	*Synchaeta stylata* Wierzejski, 1893*[R]	
Brachionus caudatus Barrois & Daday, 1894[C]	*Eosphora anthadis* Harring & Myers, 1922*[R]	*Lecane decipiens* (Murray, 1913)[R]	*Macrochaetus sericus* (Thorpe, 1893)[A]	*Taphrocampa* sp.[R]	
Brachionus dimidiatus Bryce, 1931[R]	*Epiphanes brachionus spinosa* (Rousselet, 1901)[#A]	*Lecane hamata* (Stokes, 1896)*[C]	*Monomatta* sp.[R]	*Testudinella patina* (Hermann, 1783)[C]	
Brachionus diversicornis (Daday, 1883)*[R]	*Euchlanis dilatata dilatata* Ehrenberg, 1832*[C]	*Lecane hornemanni* (Ehrenberg, 1834)*[A]	*Mytilina bisulcata* (Lucks, 1912)*[R]	*Trichocerca rattus* (Müller, 1776)*[R]	
Brachionus durgae Dhanapathi, 1974*[R]	*Filinia longiseta* (Ehrenberg, 1834)[A]	*Lecane leontina* (Turner, 1892)[A]	*Mytilina trigona* (Gosse, 1851)*[R]	*Trichocerca similis similis* (Wierzejski, 1893)[A]	
Brachionus falcatus Zacharias, 1898[A]	*Filinia opoliensis* (Zacharias, 1898)[R]	*Lecane ludwigii* (Eckstein, 1883)*[R]	*Mytilina ventralis ventralis* (Ehrenberg, 1830)[A]	*Trichotria tetractis* (Ehrenberg, 1830)[A]	

Relative occurrence categories in superscript: R, Rare; A, Average; C, Common; *New records for Maharashtra. [#]New records for India[11].

multiceps, *Brachionus dimidiatus*, *Collotheca campanulata*, *Conochilus (Conochiloides) dossuarius*, *Cyrtonia tuba*, *Eosphora anthadis*, *Limnias melicerta*, *Mytilina trigona*, *Ptygura pedunculata*, and *Synchaeta stylata* were distinct for WM and not reported from NEI.

The study area shows a rich and diverse rotifer fauna and is in accordance with the perception that tropical water bodies generally support a high number of rotifer species[3]. It is noteworthy that the results presented here are an effort of arbitrary sampling for a few years. Nearly 70% of the families known from the Indian region ($n = 29$) were found in this study. The species number recorded from the region was almost twice compared to all previous reports (from 3 to 45)[10–13,22], suggesting a tremendous hidden diversity of monogonont Rotifera in the study area. Comparison with most other rotifer studies from India and Maharashtra cannot be justified due to unreliability of identified material in most of the recent studies. This high species number could just be a result of (i) intensive sampling efforts from various aquatic habitats not surveyed before; (ii) correct taxonomical identification which is currently lacking for many freshwater invertebrates, including Rotifera, and (iii) ignorance of sessile and colonial Rotifera species. Record of 12 species of sessile and colonial rotifers is one the highest diversity of sessile and colonial rotifers from India.

Nearly 90% representation of the species further proves the sampling intensity of the study. Prospects of finding the remaining 10% undiscovered species could lie in sampling the 'exotic' environments like saline lakes, and hot water springs, where specialized rotifer fauna is known to be found. More than 50% representation of cosmopolitan and pantropical fauna conforms to the general pattern of richness observed in the Oriental tropics[23]. The dominance of genus *Lecane* in the present study can be contributed to its ability of surviving in varied habitats[23]. NEI harbours slightly low diversity of *Brachionus*, which may be attributed to the slightly acidic waters present there, since this genus prefers alkaline waters[24].

The apparent high disparity between the NEI and WM fauna could be due to differences in sampling area and inherent environment resulting from differences in altitude, rainfall and temperature[6], and more importantly, due to the degree of taxonomic expertise available in the region. High family and generic diversity are the special features of the study, and comparable to long-term studies undertaken in NEI. Of the ~250 species reported from NEI (seven states), we recorded 36% species diversity. The high species diversity of states like Assam can be contributed to the long-term efforts of workers there[6]. Fourteen per cent of the sampled rotifers were unique in their occurrence when compared to those documented from NEI.

Our emphasis on presenting comparative data was to highlight that given our small sampling region (Figure 1 *a*), we found a high diversity of rotifers with 21 families and 70% of the known Indian genera. The study also adds three new species to the Indian checklist and reveals a rich fauna with 41 new records to Maharashtra. Known for harbouring the northern Western Ghats and a wide range of environmental and geographical complexities, it would be worthwhile to take up detailed study of Rotifera from Maharashtra.

1. Segers, H., *Hydrobiologia*, 2008, **595**, 49–59.
2. Sa-Ardrit, P., Pholpunthin, P. and Segers, H., *J. Limnol.*, 2013, **72**(2), 361–375.
3. Arora, J. and Mehra, N., *Hydrobiologia*, 2003, **491**, 101–109.
4. Sinha, B., Annotated checklist of Indian Rotifera. Zoological Survey of India, Kolkata, 2014, p. 36.
5. Sharma, B. K. and Sharma, S., *Mitt. Mus. Nat.kd. Berl., Zool. Reihe*, 2005, **81**(1), 81–88.
6. Sharma, B. K. and Sharma, S., *Int. Rev. Hydrobiol.*, 2014, **99**, 1–18.
7. Mani, M. S., *Ecology and Biogeography in India*, Springer, The Netherlands, 1974, p. 647.
8. Segers, H., Sarma, S. S. S., Kakkassery, F. K. and Nayar, C. K. G., *Hydrobiologia*, 1994, **287**, 251–258.
9. Segers, H. and Babu, S., *Hydrobiologia*, 1999, **405**, 89–93.
10. Vanjare, A., Padhye, S. M. and Pai, K., *Opusc. Zool. (Budapest)*, 2010, **41**(1), 89–92.
11. Vanjare, A. and Pai, K., *Turk. J. Zool.*, 2010, **34**, 417–419.
12. Vanjare, A. and Pai, K., *Appl. Ecol. Environ. Res.*, 2013, **11**(4), 525–539.
13. Kulkarni, M. *et al.*, *J. Threat. Taxa*, 2015, **7**(6), 7196–7210.
14. Koste, W., Rotatoria. Die Ra dertiere-Mitteleuropas, begrundetvon Max Voigt. U berordnung Monogononta. Gebrüder Borntaeger Berlin, Stuttgart. I, 1978, p, 673.
15. Hijmans, R., Cameron, S. E., Parra, J. L., Jones, P. G. and Jarvis, A., *Int. J. Climatol.*, 2005, **25**, 1965–1978.
16. Chao, A., *Biometrics*, 1987, **43**, 783–791.
17. Colwell, R. K. and Coddington, J. A., *Philos. Trans. R. Soc. London, Ser. B*, 1994, **345**, 101–118.
18. Colwell, R. K., Estimate S: Statistical estimation of species richness and shared species from samples, ver. 9, 2013; http://purl.oclc.org/estimates
19. Chiambeng, G. Y. and Dumont, H. J., *J. Biogeogr.*, 2005, **32**, 1611–1620.
20. Dumont, H. J. and Segers, H., *Hydrobiologia*, 1996, **314**, 125–132.
21. Maiphae, S., Pholpunthin, P. and Dumont, H. J., *Hydrobiologia*, 2005, **637**, 147–156.
22. Arora, H. C., *Arch. Hydrobiol.*, 1963, **59**, 502–507.
23. Sharma, B. K., In *Faunal Diversity of India* (eds Alfred, J. R. B., Das, A. K. and Sanyal, A. K.), Zoological Survey of India, Kolkata, 1998, pp. 57–70.
24. Sharma, B. K. and Sharma, S., *Opusc. Zool. (Budapest),* 2014, **45**(2), 165–180.

ACKNOWLEDGEMENTS. A.I.V. and C.A.V. thank the Principal, Ahmednagar College, Ahmednagar for providing the necessary facilities and infrastructure. A.I.V. also thanks BCUD – Savitribai Phule Pune University, Pune for financial support (13SCI000001 2013–15). A.I.V. and S.M.P. thank Prof. Kalpana Pai, Savitribai Phule Pune University, Pune for providing laboratory facilities during initial sampling of rotifers. S.M.P. thanks Sanjay Molur, Wildlife Information Liaison Development Society, Coimbatore for support. We also thank Dr Yugandhar Shinde (Modern College, Shivajinagar, Pune) for help in rotifer collection.

Received 12 May 2016; revised accepted 1 November 2016

AVINASH ISAAC VANJARE[1]
CHITRA AVINASH VANJARE NEE PANIKAR[1]
SAMEER MUKUND PADHYE[2,3,*]

[1]*Department of Zoology, Ahmednagar College, Ahmednagar 414 001, India*
[2]*Wildlife Information Liaison Development Society, Coimbatore 641 035, India*
[3]*Department of Biodiversity, Abasaheb Garware College, Karve Road, Pune 411 004, India*
**For correspondence.*
e-mail: sameer.m.padhye@gmail.com