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ORIGINAL ARTICLE

Species richness of Cladocera (Crustacea: Branchiopoda) in the Western Ghats of Maharashtra and Goa (India), with biogeographical comments

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ABSTRACT

We assessed the species richness of Cladocera of the Western Ghats and surrounding areas of Maharashtra and Goa. Data of 230 samples from about 80 localities collected between 2009 and 2013 revealed 51 species in six families. Non-parametric estimators of species richness, Chao 2 and Jackknife 2, estimated the real total at 58 and 63 species, suggesting a coverage of 80% of the total species of the area. This fauna was compared with that of other countries from the Oriental region and found to be relatively species-poor, which is not in line with the biodiversity rich area status of the Western Ghats. Reasons for this are unclear. Complementarity among the cladoceran faunas of different countries belonging to the Oriental region increased with latitude and altitude. Along with the complementarity index, a comparison of family and generic occurrences of Cladocera revealed that family-level representation was similar between countries but species occurrences (like Daphnia *species) varied. The subgenus* Daphnia *was reported only from Nepal while* Ctenodaphnia *was common in all countries of the Indian region. Biogeographically, the fauna was mainly composed of wide-ranging tropical species, mixed with some rare Palaearctic elements. Only two species were endemic to India. Of another one, the closest relative lives in Yucatan, Mexico, and thus has a tropical Amphi-Pacific distribution.*

Key words: Biodiversity, Cladocera, India, Daphnia, Alona, Chydorus.

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INTRODUCTION

Data on the Cladocera of Asia are improving as more studies are being conducted on regional scales, leading to new discoveries. The fauna of Thailand, with over 100 species on record, is particularly well known (Maiphae *et al.,* 2005, 2008). A recent study of Laos also has resulted in the discovery of more than 70 species (Kotov *et al.,* 2013). In contrast, advance in documenting the Cladocera of India has been slow. Of the ca. 700 species known globally (Kotov, 2011), the number living in India is actually unknown. Fernando and Kanduru (1984) listed 130 species, of which Michael and Sharma (1988) described only 89. One hundred thirty species have been recently listed by Chatterjee *et al.* (2013), but many records remain doubtful because Indian literature abounds with checklists riddled with identification errors. Within India, the cladoceran fauna of the North East is the best known (Sharma and Sharma, 1990, 2007, 2008, 2009, 2011), with over 60 species documented.

Comprehensive species richness data of Cladocera from the Western Ghats, a biodiversity-rich region (Myers *et al.,* 2000; Mittermeier *et al*., 2005), are not available. The situation here is similar, with most studies focusing on faunal inventories and little attention to correct identification and nomenclature. There are a number of faunistic checklists of Cladocera from single localities from Maharashtra state (nearly 1/3 of Western Ghats lies in Maharashtra) (Rane, 2002, 2009; Patil GP *et al.,* 2008; Patil SS *et al.,* 2008; Vanjare *et al.,* 2010; Rane, 2013). Countless nomenclatural errors in these works render them useless and have only artificially inflated the species richness. Hence, our primary objective was to derive a first ever species richness estimate for the northern region of the Western Ghats (region lying in Maharashtra and Goa; referred henceforth as NWG). We also compared the fauna from NWG with some well-studied South and South East Asian regions, with special attention for the genus *Daphnia*. We also comment on the biogeography of selected species.

METHODS

Study region

The Western Ghats are a chain of hills spread over 1600 km across six different Indian states, with a few gaps in between (Mani, 1974) (Fig. 1A). The hills have an altitudinal range of 600-1000 m reaching 2000 m in the southern regions. The Western Ghats receive most of their rainfall during Monsoon (June-October). This amount varies with region (the southern region receives more than the north) (Mani, 1974). The sampling region for our study consisted of Western Ghats and adjoining areas in the states of Maharashtra and Goa (Fig. 1).

Sampling

Sampling was performed from January 2009 to November 2013. Two hundred and thirty samples were collected from about 80 different habitats located between 495 and 1309 m asl covering the complete altitudinal range of NWG. Different types of habitats (from rock-pools to large water reservoirs) were sampled and an attempt was made to sample habitats more than once. Plankton tow-net and hand-net with mesh size of 52 µm and 150 µm were used for collections. The tow-net consisted of an iron ring 10 cm in diameter, attached to about 300 cm of long nylon rope, fitted with a 10 cm (diameter) net of plankton mesh and provided with a 125-mL plastic receptacle at the tail end. Hand net consisted of a circular plastic frame (r=7.5 cm, h=6 cm) having a net with a mesh size of 150 µm with an extension to hold it. This net was particularly used for littoral samples. Samples were collected in plastic containers (100 mL) on the field itself and immediately fixed by using 5% formaldehyde or 70% ethanol.

Identification

Cladocerans were separated and dissected under a Stereomicroscope (Magnus MS 24; Lawrence & Mayo Pvt. Ltd., Bangalore, India). Final examination of specimens was carried out under a compound microscope (Ch20i and CX41; Olympus, Tokio, Japan).Identifications were done using keys by Korovchinsky (1992) for Sididae, Benzie (2005) for *Daphnia*, Dumont and Pensaert (1983) for *Scapholeberis*, Orlova-Bienkowskaja (2001) for *Simocephalus*, Berner (1986) for *Ceriodaphnia*, Goulden (1968) for Moinidae, Smirnov (1992) for Macrothrichidae, Kotov and Štifter (2006) for Ilyocryptidae, Smirnov (1971, 1996) for

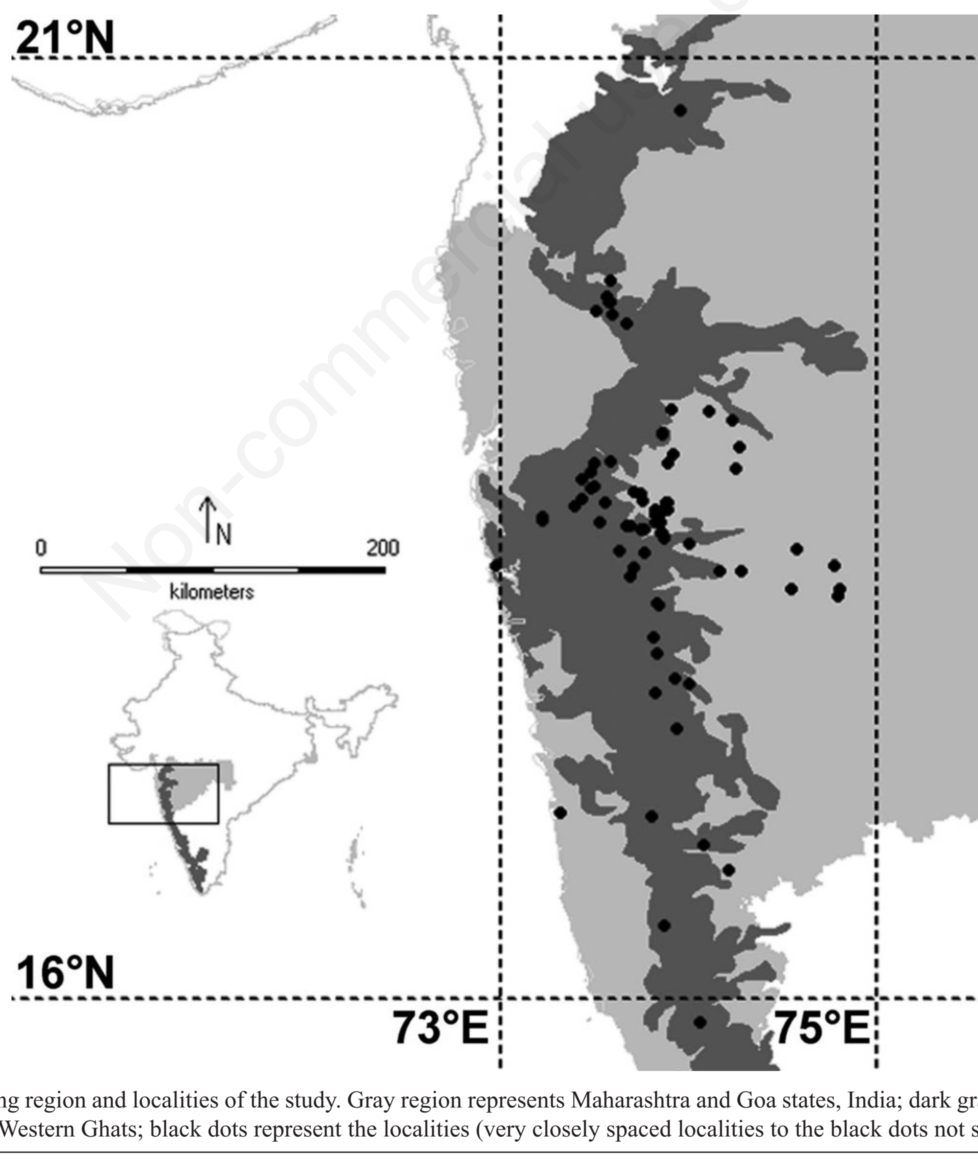

Fig. 1. Sampling region and localities of the study. Gray region represents Maharashtra and Goa states, India; dark gray shaded region represents the Western Ghats; black dots represent the localities (very closely spaced localities to the black dots not shown).

Chydoridae. We also referred to papers on particular species if recent taxonomical work had been carried out on them.

Species richness estimation

Species richness was estimated using nonparametric (distribution-free) methods to evaluate true species richness from samples (Chao, 1987; Colwell and Coddington, 1994). This method is based on the relationship between singleton and doubletons observed in samples. We selected Chao2 and Jackknife2 indices for our data to estimate the true species number. EsimtateS (v9.1) (Colwell, 2013; http://viceroy.eeb.uconn.edu/EstimateS) was used to generate the species richness estimation using Chao2, Jackknife2 indices. Estimation was carried out using bias-corrected Chao2 and Jackknife2 indices. Five hundred randomizations per sample were carried out to get the standard deviation estimate around each data point.

Complementarity index

The complementarity index is a measure of non-similarity which can be used to compare different faunas and can provide a good resolution between two faunas (Colwell and Coddington, 1994; Dumont and Segers, 1996; Maiphae *et al.,* 2005). It is given by the formula:

$$C_{jk}=U_k/S_{jk} \text{ where } S_{jk}=S_j + S_k - V_k \qquad \text{(eq. 1)}$$

where:
S_j, species richness of habitat j;
S_k, species richness of habitat k;
S_{jk}, sum of species richness of habitats j and k;
V_{ik}, species number shared between habitats j and k;
V_{ik}, $Sj + S_k - 2V_k$;
U_{ik}, number of species unique to habitats j and k.

It can be expressed as a percentage of non-similarity (=complementarity) between groups. Thus, two habitats with identical faunas would have C=0, while habitats with totally different faunas would have C=100 (Colwell and Coddington, 1994). Complementarity index was used to compare faunas between selected Asian countries. For comparisons between different geographical regions we used Maiphae *et al.,* (2005, 2008) for Thailand; Dumont and Van de Velde (1977), Swar and Fernando (1979) and Manca *et al.* (2006) for Nepal and Fernando (1980) for Sri Lanka. Data for comparison of numbers of Daphniidae were taken from the same literature used for complementarity analysis.

RESULTS

Fifty one species were found (Tab. 1). Chydoridae was the most speciose family with species numbers two to three times that of other families, while Ilyocryptidae was represented by only one species. Forty percent of the species found were *rare*, ten species were abundant. *Ilyocryptus spinifer* Herrick, 1882 was recorded in about 40 % of the sampled habitats followed by *Leydigia (Neoleydigia) ciliata* Gauthier, 1939 (36%) *and Simocephalus (Simocephalus) mixtus* Sars, 1903 (30%). Maximum species richness was in seen *Alona* Baird, 1843 and *Chydorus* Leach, 1816 with four species each, followed by subgenus *Ctenodaphnia* Dybowski & Grochowski, 1895 and genus *Macrothrix* Baird, 1843 (each with three species). Species such as *Dunhevedia serrata* Daday, 1898, *Kurzia (Kurzia) latissima* (Kurz, 1875), and *Moinodaphnia macleayi* (King, 1853) were found in single samples and with 1-2 specimens. *Daphnia* (*Ctenodaphnia*) *carinata* and *D.* (*C.*) *similoides* Hudec, 1991were restricted to temporary pools formed on outcrops in NWG. *D.* (*C.*) *lumholtzi* G.O. Sars, 1885 on the other hand, was common in all types of habitats. Amongst moinids, *Moina micrura* Kurz, 1874 and *Moina macrocopa* (Strauss, 1820) were abundant in eutrophic waters, a trait well known in these species. *Moinodaphnia macleayi* (King, 1853) and *Moina hemanti* were seen in a single locality. *Indialona ganapati* Petkovski, 1966 was restricted to the limnetic zone of large reservoirs, a trait also mentioned by Kotov (2000). *Camptocercus* cf. *vietnamensis* Sinev, 2012, *Notoalona globulosa* (Daday, 1898) and *Bosmina (Bosmina) longirostris* (O.F. Muller, 1776) were only seen in rivers and lakes. *Anthalona harti harti,* Van Damme, Sinev et Dumont, 2011 was mostly restricted to ephemeral waters. The highest number of species was seen in Pashan, a small reservoir with 30 species.

The number of singletons (L) was 7 and doubletons (M) were 2 from the 230 samples. With those values, the Chao2 estimator produced an estimate of 57.8 (58) species while Jackknife2 yielded 62.87 (63) species (Fig. 2). Thus, about 80% of the fauna was covered by our study. Complementarity between regions ranged from 49% to 81% and increased with distance and latitude (Tab. 2). Of the countries included in the comparison, NWG was similar with Sri Lanka and most distinct from Nepal. Proportion of distribution was similar for Anomopoda across the regions. Values varied at family and generic level (Tab. 3). Few species such as *Diaphanosoma excisum* Sars, 1885, *Daphnia* (*Ctenodaphnia*) *lumholtzi*, *Moina micrura*, *Bosmina longirostris*, *Chydorus eurynotus* Sars, 1901and *Chydorus sphaericus* (O.F. Müller, 1776) s. lat. occurred in all compared regions. Three of the four compared regions (all except Nepal) shared many circumtropical species like *Latonopsis australis* Sars, 1888 s.lat., *Macrothrix spinosa* King, 1853, *Dunhevedia serrata*, *Kurzia (Rostrokurzia) longirostris* (Daday, 1898), *Ephemeroporus barroisi* (Richard 1894) and *Pseudochydorus globosus* (Baird, 1843) s. lat. At the same time spatially restricted elements were also reported, like *Moina hemanti* (*dumonti*-group) for NWG and *Macrothrix pholpunthini* Kotov, Maiphae & Sanoamuang, 2005 and *Armatalona macrocopa* Sars, 1895 for Thailand. Chydorids consistently represented more than 50% of the total cladoceran fauna in all the studied regions with *Alona* and *Chydorus* the best represented genera (Tab. 3).

Note on Daphniidae

The total number of daphniid species was similar for NWG, Sri Lanka and Thailand (Fig. 3). Five species of *Daphnia* were observed in Nepal, including the only report of the subgenus *Daphnia* namely*, Daphnia* (*Daphnia*) *longispina* (O.F. Muller, 1776). The number of species decreased with latitude with only one *Ctenodaphnia* in Thailand and two in Sri Lanka. *D.* (*C.*) *lumholtzi* was observed in all regions. On the other hand, Thailand had the maximum number from genus *Simocephalus* Schoedler, 1858 with six species while Nepal had only two representatives of that genus.

Tab. 1. Cladoceran species found in the study and their relative occurrence.

No.	Species	Relative occurrence
1	*Diaphanosoma excisum* Sars, 1885	A
2	*Diaphanosoma sarsi* Richard, 1895	C
3	*Latonopsis australis* Sars, 1888 s.lat.	A
4	*Pseudosida szalayi* (Daday, 1898)	R
5	*Ceriodaphnia* cf. *cornuta* Sars, 1885	Ab
6	*Ceriodaphnia quadrangula* (O. F. Müller, 1785)	A
7	*Daphnia* (*Ctenodaphnia*) *carinata* King, 1853 s.lat.	R
8	*Daphnia* (*Ctenodaphnia*) *similoides* Hudec, 1991	A
9	*Daphnia* (*Ctenodaphnia*) *lumholtzi* Sars, 1885	R
10	*Scapholeberis kingi* Sars, 1901	A
11	*Simocephalus (Simocephalus) mixtus* Sars, 1903	Ab
12	*Simocephalus* (*Coronocephalus*) *serrulatus* (Koch, 1841)	R
13	*Moina* n. sp.	R
14	*Moina micrura* Kurz, 1874	C
15	*Moina macrocopa* (Straus, 1820)	R
16	*Moinodaphnia macleayi* (King, 1853)	R
17	*Bosmina (Bosmina) longirostris* (O. F. Muller, 1776)	R
18	*Bosminopsis deitersi* Richard, 1895	R
19	*Macrothrix spinosa* King, 1853	Ab
20	*Macrothrix triserialis* (Brady, 1886)	Ab
21	*Macrothrix odiosa* Gurney, 1916	R
22	*Guernella* cf. *raphaelis* Richard, 1892	R
23	*Ilyocryptus spinifer* Herrick, 1882	Ab
24	*Alona affinis* (Leydig, 1860) s.lat.	R
25	*Alona cheni* Sinev, 2001	A
26	*Alona* cf. *cambouei* Guerney et Richard, 1893	A
27	*Alona quadrangularis* (O.F. Müller, 1776) s.lat.	R
28	*Anthalona harti harti,* Van Damme, Sinev et Dumont, 2011	A
29	*Coronatella* cf. *rectangula* Sars, 1862	A
30	*Camptocercus* cf. *vietnamensis* Sinev, 2012	R
31	*Notoalona globulosa* (Daday, 1898)	R
32	*Oxyurella singalensis* (Daday, 1862)	R
33	*Leberis punctatus* (Daday, 1898)	Ab
34	*Karualona* cf. *karua* (King, 1853)	Ab
35	*Kurzia (Kurzia) latissima* (Kurz, 1875) s. lat.	R
36	*Kurzia (Rostrokurzia) longirostris* (Daday, 1898)	Ab
37	*Leydigia (Neoleydigia) ciliata* Gauthier, 1939	Ab
38	*Euryalona orientalis* (Daday, 1898)	R
39	*Indialona ganapati* Petkovski, 1966	C
40	*Alonella* cf. *excisa* (Fischer, 1854)	A
41	*Chydorus eurynotus* Sars, 1901	Ab
42	*Chydorus parvus* Daday, 1898	C
43	*Chydorus sphaericus* (O.F. Müller, 1776) s.lat.	R
44	*Chydorus ventricosus* Daday, 1898	C
45	*Dadaya macrops* (Daday, 1898)	R
46	*Dunhevedia crassa* King, 1853	Ab
47	*Dunhevedia serrata* Daday, 1898	R
48	*Ephemeroporus barroisi* (Richard 1894)	C
49	*Picripleuroxus* sp.	A
50	*Pleuroxus aduncus* (Jurine, 1820) s.lat.	A
51	*Pseudochydorus globosus* (Baird, 1843) s. lat.	C

R, rare (1-10 samples); A, average (11-25 samples); C, common (26-40); Ab, abundant (above 40 samples).

DISCUSSION

Credible faunal data are restricted to a few habitats which have a long history of observations (Dumont and Segers, 1996) and a stable taxonomy. However, many cladoceran taxa from the tropics have an uncertain identity (Kotov *et al.,* 2013). Southern Asia still trails in validly described cladoceran species when compared with other regions like Australia and Europe (Forró *et al.,* 2008), and even Southeast Asia (Maiphae *et al.,* 2005, 2008; Kotov *et al.,* 2013). Sharma and Sharma (2005) stated that the limnological surveys from India include poor species inventories due to the general lack of taxonomic expertise, a statement which is still valid (Chatterjee *et al.,* 2013). All this applies to almost all previous cladoceran studies from NWG region as well.

With ca. 130 species reported from India (an estimate yet again) (Chatterjee *et al.,* 2013), the 51 species from NWG represent roughly 40% of total species richness known. This number compares well with a recent inventory of Maharashtra by Rane (2013), finding 58 species (considering only the number and not the validity of species) but was distinctly lower than South Thailand (=72; Maiphae *et al.,* 2005), Laos (=70; Kotov *et al.,* 2013), and comparable to Cameroon (=61; Chiambeng and Dumont, 2005) in the impoverished African tropics. The number of species found can thus be said to be low for Asia, and certainly for a biodiversity rich area like the Western Ghats. The reasons for this lesser number might be due to incomplete or biased sampling and lack of systematic and/or repeated sampling of large water bodies, each of which should harbor about 50 cladoceran species at a time (Dumont and Segers, 1996). This low number could also reflect the fact that exotic environments like wet mosses and interstitial water, known to harbor unique taxa (Dumont, 1994), have not been included. Species living in such places could increase the expected species number. Endemic species may have a restricted distribution and hence are easy to be missed (Forró *et al.,* 2008). Our finding of *Moina hemanti* is one such example (Padhye and Dumont, 2014). Another problem in finding the true richness is that some widely distributed species may contain hidden diversity (cryptic species). Cosmopolitanism in Cladocera has been abandoned in favor of regional endemism (Dumont,

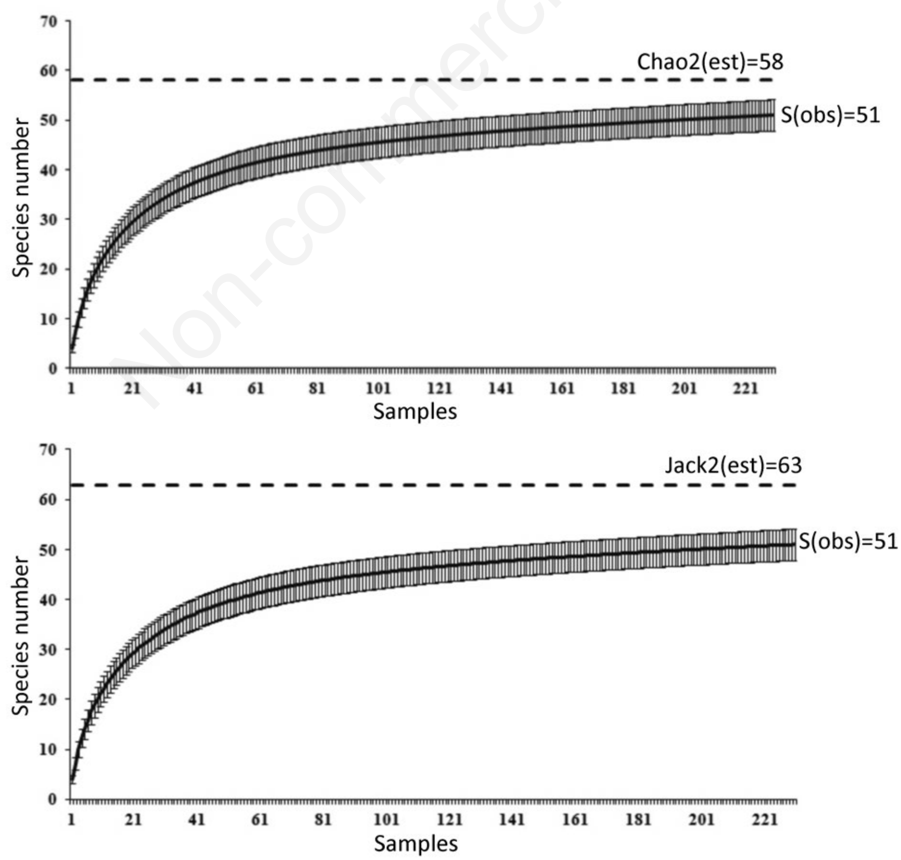

Fig. 2. Chao2 and Jackknife2 estimators of Cladocera species richness (black dashed line) against observed species richness (S (obs), black solid line). Each point is the mean of 500 estimates based on 500 randomizations of sample accumulation order.

1980; Frey, 1986, 1987; Hudec, 1991; Sinev, 1999, 2001, 2011, 2012; Van Damme and Dumont, 2008; Petrusek *et al.,* 2004; Belyaeva and Taylor, 2009; Kotov and Taylor, 2010; Van Damme *et al.,* 2011). We observed several such species complexes and labeled them as *cf.* or *s.lat.* as their identity is yet to be established. Examples include *Latonopsis australis*, *Moina micrura, Coronatella rectangula* and *Karualona karua*. Disentangling these will increase the species richness. At the same time, it can be said that sampling effort for our study was relatively efficient as 80% of the fauna was recovered and only an estimated 8-10 species were missed given the sample size (for values refer to Fig. 2). It has been shown that *Chao 2* and *Jackknife 2* estimators are efficient in assessment of cladoceran diversity with respect to incidence based data (Dumont and Segers, 1996; Maiphae *et al.,* 2005, 2008; Chiambeng and Dumont, 2005; Kotov *et al.,* 2013).

NWG cladoceran species distribution varied from broadly distributed to point endemics. Of the species observed in the study, a large fraction was circumtropical with species such as *Latonopsis australis* s.lat., *Diaphanosoma sarsi* Richard, 1895, *Bosmina longirostris*, *Guernella raphaelis* Richard, 1892*, Macrothrix spinosa* King, 1853, *Macrothrix triserialis* (Brady, 1886), *Kurzia (Rostrokurzia)longirostris*, *Euryalona orientalis* (Daday, 1898), *Dadaya macrops* (Daday, 1898), *Chydorus parvus* Daday, 1898 and *Chydorus ventricosus* Daday, 1898. *Alona cheni* Sinev, 2001, *Camptocercus vietnamensis*, *Leberis punctatus* (Daday, 1898), *Indialona ganapati* and *Moina* n. sp. represented the Oriental fauna (Maiphae *et al.,* 2008; Sinev, 2012; Chatterjee *et al.,* 2013; Kotov *et al.,* 2005; Korovchinsky, 2013; Padhye and Dumont, 2014). *Moina* n. sp. is part of a group of species with a tropical Amphi-Pacific distribution (see Van Damme and Sinev, 2013) and its closest relative (*M. dumonti*) is found 10,000 km away in South America (Kotov *et al.,* 2005; Padhye and Dumont, 2014). Taxa known to be *species complexes* with a global distribution like *Chydorus sphaericus* s. lat., *Alona quadrangularis* (O.F. Müller, 1776) s. lat., *Alona affinis* (Leydig, 1860) s.lat. (Van Damme and Dumont, 2008; Belyaeva and Taylor, 2009; Van Damme *et al.,* 2010) were rarely seen. Regional forms of these species have a comparably limited distribution [*e.g*., *Alona kotovi* Sinev, 2012 from Vietnam is a Southeast Asian species from the *A. quadrangularis* species complex (Sinev, 2012)]. Also, chydorids like *Pleuroxus aduncus* (Jurine, 1820) s.lat., *Picripleuroxus* sp. and *Kurzia (Kurzia) latissima*, known from characteristic habitats (acid ponds and bogs) in the Palaearctic region (Chiambeng and Dumont, 2005), were uncommon in the collections, being seen in neutral ponds and riverine habitats only. Regional endemism could again perhaps help explain the occurrence of these species in NWG. Alternatively, the *ejected relicts* hypothesis of Korovchinsky (2006) states that many such cladoceran species are relicts of a Pre-Pleistocene continuous distribution. This hypoth-

Tab. 2. Complementarity values of the regions expressed in percentages.

	Northern Western Ghats	Sri Lanka	Thailand	Nepal
Northern Western Ghats	0	49	65	73
Sri Lanka	-	0	64	71
Thailand	-	-	0	81
Nepal	-	-	-	0

Tab. 3. Comparison of cladoceran fauna (in percentage) to other South and South East Asian regions w.r.t. order, family and genera (only most speciose families and genera given).

Richness (relative proportion to total species)	Northern Western Ghats	Sri Lanka	Nepal	Thailand
Order				
Anomopoda	92.16	91.67	94.87	91.35
Ctenopoda	7.84	8.33	5.13	8.65
Families				
Chydoridae	52.94	56.25	56.41	61.54
Daphniidae	15.69	14.58	28.21	6.7
Genera				
Alona	7.84	10.41	7.69	12.50
Chydorus	7.84	8.33	7.69	3.84
Daphnia	5.88	4.16	12.8	0.96
Total species	51	48	39	104

esis has also been put forth for the Palaearctic elements seen in Thailand (Maiphae *et al.,* 2008). Both these statements are conjectural for the moment and more studies are needed to confirm either of them.

Daphnia found in the study also have a varying distribution with species number changing latitudinally across regions, and follows a trend which has been analyzed in a recent study by Popova and Kotov (2013). *D.* (*C.*) *lumholtzi* is distributed in Africa, Asia and Australia but recently spread to North America (Benzie, 2005; Sorensen and Sterner, 1992) and South America (Kotov and Taylor, 2014). *D.* (*C.*) *similoides* extends from the Indian subcontinent to Central China (Hudec, 1991; Benzie, 2005) but recently it has been shown that China houses a distinct sub-species, *D.* (*C.*) *similoides sinensis* (Gu *et al.,* 2013). Therefore, it is likely that *D.* (*C.*) *similoides* s.str, is endemic to the Indian subcontinent. *Daphnia* (*Ctenodaphnia*) *carinata* is known from South Asia, Australasia and Africa (Benzie, 2005). Subgenus *Daphnia* is rare in the tropics but becomes speciose towards the subtropics (Fernando, 1980; Fernando *et al.,* 1987). Species from the subgenus *Daphnia* are found at lower latitudes but at higher altitudes (Dumont, 1994; Green, 1995; Kotov and Taylor, 2010; Van Damme and Eggermont, 2011). The absence of high altitudes in NWG and Sri Lanka is thus one of the reasons why *Daphnia* does not occur here. Nepal lies above 24°N with many Himalayan lakes at alpine altitudes over 4000 m. Presence of *Daphnia* here surely reflects both altitude and latitude. Other factors that may restrict *Daphnia* in the tropics are relentless fish predation (Burks *et al.,* 2000; Dumont, 1994; Green, 1995), invariably high temperatures (Allan and Goulden, 1980; Fernando, 1980; Dumont, 1994; Gillooly, 2000), and absence of a photoperiodic signal for sexual reproduction (Stross and Hill, 1968; Dumont, 1994; Kerfoot and Lynch, 1987; Chiambeng and Dumont, 2005).

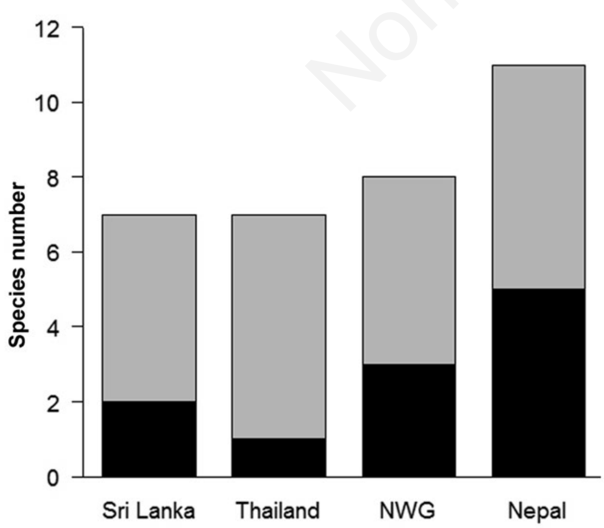

Fig. 3. Bargraph showing total Daphniid species for respective regions. Each bar represents total Daphniidae species; in black, number of *Daphnia* species; in gray, other members of the family.

The disparity in complementarity seen between the studied regions is likely due to the combination of altitude, latitude (and resulting variation in environmental variables) and dearth of taxonomic expertise, as discussed earlier. Thus, the fauna of Nepal has distinct faunal elements owing to its altitude and this fauna will likely increase with a better taxonomical investigation. Many species found in north-eastern India (Sharma and Sharma, 1990, 2007, 2008 2009, 2011, 2014) can also be expected in the tropical parts of Nepal since they are known from countries such as Thailand and Laos (Maiphae *et al.,* 2008; Kotov *et al.,* 2013; Van Damme and Sinev, 2013). This in turn could affect the complementarity value. Complementarity index is known to be sensitive to the comprehensiveness of the underlying census. The more inclusive the inventory, the more robust is the complementarity index derived from it (Colwell and Coddington, 1994).

NWG is facing problems such as rampant land conversion, eutrophication and invasive fish species. Temporary water habitats are destroyed at an alarming rate by anthropogenic activities (Williams, 2002). Data on such loss of temporary water bodies due to land conversion are not known for developing countries (Brendonck *et al.,* 2008). Loss of small freshwater bodies could mean local extinction of species leading to a decrease in the regional diversity or even potential total extinction for endemic species (De Bie *et al.,* 2008; Forró *et al.,* 2008) like our *Moina hemanti* Ephemeral water bodies represented more than 50% of the total samples collected in the study (data available on request). Eutrophication leads to modification of the aquatic habitats and organization of zooplankton communities including Cladocera (Sampaio *et al.,* 2002). Many habitats in the hills of the Western Ghats were relatively free of eutrophication but habitats within city limits were highly eutrophicated and with peculiar cladoceran fauna (*C. cornuta* and *M. micrura* dominated the plankton). Destructive effect of introduced fish species like guppy (*Poecilia reticulata*) on native fauna has been documented by Ghate and Padhye (1988) and could be affecting cladocerans in a similar manner.

CONCLUSIONS

We found 51 species of Cladocera in six families, with maximum number of species in the Chydoridae. Chao2 and Jackknife 2 indices showed that only few species were missed: 80% of the estimated species were recovered in the study. This is somewhat surprising, as it does not confirm the NWG as a biodiversity hotspot for cladocerans. Comparison of NWG fauna with other regions showed that NWG was most similar to Sri Lanka and least to Nepal, suggesting a latitudinal as well as an altitudinal gradient. Cladoceran family representation was similar across the compared regions but varied at species level. The number of *Daphnia* species increased with latitude, with occurrence of sub genus *Daphnia* only in Nepal. Most of the species found were circumtropical with only two endemics and a few Palaearctic elements. One of the endemics belongs to the rare group of cladocerans with a Tropical Amphi-Pacific distribution.

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REFERENCES

Allan JD, Goulden CE, 1980. Some aspects of reproductive variation among freshwater zooplankton, p. 388-410. In: C.W. Kerfoot (ed.), Evolution and ecology of zooplankton communities. University Press of New England.

Belyaeva M, Taylor DJ, 2009. Cryptic species within the *Chydorus sphaericus* species complex (Crustacea: Cladocera) revealed by molecular markers and sexual stage morphology. Mol. Phylogenet. Evol. 50:534-546.

Benzie JAH, 2005. The genus *Daphnia* (including *Daphniopsis*) (Anomopoda: Daphniidae), p. 1-383. In: H.J. Dumont (ed.) Guides to the identification of the microinvertebrates of the continental waters of the world. SPB Academic Publishing.

Berner D, 1986. Taxonomy of *Ceriodaphnia* (Crustacea Cladocera) in U.S. Environmental Protection Agency Cultures, USEPA-600/4-86-032. Cincinnati, OH, USA.

Brendonck L, Rogers DC, Olesen J, Weeks S, Hoeh W R, 2008. Global diversity of large branchiopods (Crustacea: Branchiopoda) in freshwater. Hydrobiologia 595:167-176.

Burks RL, Jeppesen E, Lodge DM, 2000. Macrophyte and fish chemicals suppress *Daphnia* growth and alter life-history traits. Oikos 88:39-147.

Chao A, 1987. Estimating the population size for capture recapture data with unequal catchability. Biometrics 43:783-791.

Chatterjee T, Kotov AA, Van Damme K, Chandrasekhar SVA, Padhye S, 2013. An annotated checklist of the Cladocera (Crustacea: Branchiopoda) from India. Zootaxa 3667:1-89.

Chiambeng GY, Dumont HJ, 2005. The Branchiopoda (Crustacea: Anomopoda, Ctenopoda and Cyclestherida) of the rain forests of Cameroon, West Africa: low abundances, few endemics and a boreal-tropical disjunction. J. Biogeogr. 32:1611-1620.

Colwell RK, 2013. Estimate S: Statistical estimation of species richness and shared species from samples, ver. 9. Available from: http://purl.oclc.org/estimates.

Colwell RK, Coddington JA, 1994. Estimating terrestrial biodiversity through extrapolation. Philos. T.R. Soc. B 345:101-118.

De Bie T, Declerck S, Martens K, De Meester L, Brendonck L, 2008. A comparative analysis of cladoceran communities from different water body types: patterns in community composition and diversity. Hydrobiologia 597:19-27.

Dumont HJ, 1980. Zooplankton and the science of biogeography: the example of Africa, p. 685-696. In W.C. Kerfoot (ed.), Evolution and ecology of zooplankton communities. University Press of New England.

Dumont HJ, 1994. On the diversity of the Cladocera in the tropics. Hydrobiologia 272:27-38.

Dumont HJ, Pensaert J, 1983. A revision of the Scapholeberinae (Crustacea: Cladocera). Hydrobiologia 100:3-45.

Dumont HJ, Segers H, 1996. Estimating lacustrine zooplankton species richness and complementarity. Hydrobiologia 314:125-132.

Dumont HJ, Van de Velde I, 1977. Report on collection of Cladocera and Copepoda from Nepal. Hydrobiologia 53:55-65.

Fernando CH, 1980. The freshwater zooplankton of Sri-Lanka, with a discussion of tropical freshwater zooplankton composition. Int. Revue Ges. Hydrobiol. 65:85-125.

Fernando CH, Kanduru A, 1984. Some remarks on the latitudinal distribution of Cladocera on the Indian subcontinent. Hydrobiologia 113:69-76.

Fernando CH, Paggi JC, Rajapaksa R, 1987. *Daphnia* in tropical lowlands. In: R.H. Peters and R. de Bernardi (ed.), *Daphnia*. Mem. Ist. Ital. Idrobiol. 45:107-141.

Forró L, Korovchinsky NM, Kotov AA, Petrusek A, 2008. Global diversity of cladocerans (Cladocera; Crustacea) in freshwater. Hydrobiologia 595:177-184.

Frey DG, 1986. The non-cosmopolitanism of chydorid Cladocera: implications for biogeography and evolution, p. 237-256. In: R.H. Gore and K.L. Heck (eds.), Crustacean biogeography. A.A. Balkema.

Frey DG, 1987. The taxonomy and biogeography of the Cladocera. Hydrobiologia 145:5-17.

Ghate HV, Padhye AD, 1988. Predation of Microhyla tadpoles by Gambusia. J. Bombay Nat. Hist. Soc. 85:200-201.

Gillooly JF, 2000. Effect of body size and temperature on generation time in Zooplankton. J. Plankton Res. 22:241-251.

Goulden CE, 1968. The systematics and evolution of the Moinidae. Trans. Am. Phil. Soc. 58:1-101.

Green J, 1995. Altitudinal distribution of tropical planktonic Cladocera. Hydrobiologia 307:75-84.

Gu YL, Xu L, Li QQ, Dumont HJ, Han BP, 2013. A new subspecies of Daphnia: Daphnia similoides sinensis. Ecol. Sci. 32:308-312.

Hudec I, 1991. A comparison of populations from the *Daphnia similis* group (Cladocera: Daphniidae). Hydrobiologia 225:9-22.

Kerfoot WC, Lynch M, 1987. Branchiopod communities: association with planktivorous fish in space and time, p. 367-378. In: W.C. Kerfoot and A. Sih (eds.), Predation: direct and indirect impacts on aquatic communities. University Press of New England.

Korovchinsky NM, 1992. Sididae & Holopediidae, p. 1-82. In: H.J. Dumont (ed.), Guides to the identification of the microinvertebrates of the continental waters of the world. 3. SPB Academic Publ.

Korovchinsky NM, 2006. The Cladocera (Crustacea: Branchiopoda) as a relict group. Zool. J. Linn. Soc. 147:109-124.

Korovchinsky NM, 2013. Cladocera (Crustacea: Branchiopoda) of South East Asia: history of exploration, taxon richness and notes on zoogeography. J. Limnol. 72(Suppl.2):109-124.

Kotov AA, 2000. Re-description and assignment of the chydorid *Indialona ganapati* Petkovski, 1966 (Branchiopoda: Anomopoda: Aloninae) to Indialonini, new tribus. Hydrobiologia 439:161-178.

Kotov AA, 2011. Crustacea - Cladocera checklist. Available from: http://fada.biodiversity.be/ CheckLists/Crustacea - Cladocera.pdf

Kotov AA, Elias-Gutierrez M, Granados-Ramírez JG, 2005. *Moina dumonti* sp. nov. (Cladocera, Anomopoda, Moinidae) from southern Mexico and Cuba, with comments on moinid limbs. Crustaceana 78:41-57.

Kotov AA, Stifter P, 2006. Ilyocryptidae of the world, p. 1-172. In: H.J. Dumont (ed.), Guides to the identification of the microinvertebrates of the continental waters of the world, 22. Backhuys Publ.

Kotov AA, Taylor DJ, 2010. A new African lineage of the *Daphnia obtusa* group (Cladocera: Daphniidae) disrupts continental vicariance patterns. J. Plankton Res. 32:937-949.

Kotov AA, Taylor DJ, 2014. *Daphnia lumholtzi* Sars, 1885 (Cladocera: Daphniidae) invades Argentina. J. Limnol. 73:369-374.

Kotov AA, Van Damme K, Bekker EI, Siboualipha S, Silva-Briano M, Ortiz AA, De La Rosa RG, Sanoamuang L, 2013. Cladocera (Crustacea: Branchiopoda) of Vientiane province and municipality, Laos. J. Limnol. 72(Suppl.2):81-108.

Maiphae S, Pholpunthin P, Dumont HJ, 2005. Species richness of the Cladocera (Branchiopoda: Anomopoda and Ctenopoda) in southern Thailand, and its complementarity with neighboring regions. Hydrobiologia 637:147-156.

Maiphae S, Pholpunthin P, Dumont HJ, 2008. Taxon richness and biogeography of the Cladocera (Crustacea: Ctenopoda, Anomopoda) of Thailand. Int. J. Limnol. 44:33-43.

Mani MS, 1974. Ecology and biogeography in India. W. Junk Publ.: 647 pp.

Manca M, Martin P, Carolina DP, Benzie JAH, 2006. Re-description of *Daphnia* (*Ctenodaphnia*) from lakes in the Khumbu Region, Nepalese Himalayas, with the erection of a new species, *Daphnia himalaya*, and a note on an intersex individual. J. Limnol. 65:132-140.

Michael RG, Sharma BK, 1988. Fauna of India and adjacent countries, Indian Cladocera (Crustacea: Branchiopoda: Cladocera). Zoological Survey of India: 262 pp.

Mittermeier RA, Gil PR, Hoffman M, Pilgrim J, Brooks T, Brooks, Mittermeier CG, Lamoreux J, da Fonseca GAB, 2005. Hotspots revisited: Earth's biologically richest and most endangered terrestrial ecoregions. Cemex: 392pp.

Myers N, Mittermeier RA, Mittermeier CG, da Fonseca GAB, Kent J, 2000. Biodiversity hotspots for conservation priorities. Nature 403:853-858.

Orlova-Bienkowskaja MY, 2001. Daphniidae: genus *Simocephalus*, p. 1-130. In: H.J. Dumont (ed.), Guides to the identification of the microinvertebrates of the continental waters of the world, 17. Backhuys Publ.

Padhye SM, Dumont HJ, 2014. *Moina hemanti* n. sp., a new species of the genus *Moina* s.l. (Branchiopoda: Anomopoda) from Pune, India. Zootaxa 3860:561-570.

Patil GP, Kedar GT, Yeole SM, 2008. Zooplankton biodiversity study of two waterbodies in Washim district, Maharashtra. J. Aquat. Biol. 23:13-17.

Patil SS, Auti RG, Mokashe SS, 2008. Conservation and management of Salim Ali Lake, Aurangabad, p. 1614-1622. In: M. Sengupta and R. Dalwani (eds.), Proceedings of Taal 2007, 12th World Lake Conference.

Petrusek A, Černy M, Audenaert E, 2004. Large intercontinental differentiation of *Moina micrura* (Crustacea: Anomopoda): one less cosmopolitan cladoceran? Hydrobiologia 526:3-81.

Popova EY, Kotov AA, 2013. Latitudal patterns in the diversity of two subgenera of the genus *Daphnia* O.F. Müller (Crustacea: Cladocera: Daphniidae). Zootaxa 3736:59-174.

Rane P, 2002. Cladocera: crustacea zoological survey of India wetland ecosystem series. Fauna of Ujani 3:71-85.

Rane P, 2009. Zoological survey of India, Fauna of Bhimashankar wildlife sanctuary. Conservation Area Series 42:263-272.

Rane P, 2013. Cladocera, p. 1-673. In: Z.S.I. Kolkata (ed.), Fauna of Maharashtra. Zool. Survey of India, State Fauna Series.

Sampaio EV, Rocha O, Matsumura-Tundisi T, Tundisi JG, 2002. Composition and abundance of zooplankton in the limnetic zone of seven reservoirs of the Paranapanema River, Brazil. Braz. J. Biol. 62:525-545.

Sharma BK, Sharma S, 1990. On the taxonomic status of some cladoceran taxa (Crustacea: Cladocera) from Central India. Rev. Hydrobiol. Trop. 23:105-113.

Sharma BK, Sharma S, 2005. Faunal diversity of Rotifers (Rotifera: Eurotatoria) of Deepor Beel, Assam (N. E. India) - a Ramsar site. J. Bombay Nat. Hist. Soc. 102:69-175.

Sharma BK, Sharma S, 2007. New records of two interesting chydorid cladocerans (Branchiopoda: Cladocera: Chydoridae) from flood plain lakes of Assam, India. Zoos' Print J. 22:2799-2801.

Sharma BK, Sharma S, 2008. Zooplankton diversity in floodplain lakes of Assam. Rec. Zool. Surv. India 290:141-307.

Sharma BK, Sharma S, 2009. Faunal diversity of Cladocera (Crustacea: Branchiopoda) of Loktak Lake (a Ramsar site), Manipur (N.E. India). J. Bombay Nat. Hist. Soc. 106:156-161.

Sharma BK, Sharma S, 2011. Faunal diversity of Cladocera (Crustacea: Branchiopoda) of Nokrek Biosphere Reserve, Meghalaya, northeastern India. J. Threatened Taxa 3:2120-2127.

Sharma BK, Sharma S, 2014. Faunal diversity of Cladocera (Crustacea: Branchiopoda) in wetlands of Majuli (the largest river island), Assam, northeast India. Opusc. Zool. Budapest 45:1-9.

Sinev AY, 1999. *Alona costata* Sars, 1862 versus related palaeotropical species: the first example of close relations between species with a different number of main head pores among Chydoridae (Crustacea: Anomopoda). Arthropoda Selecta 8:131-148.

Sinev AY, 2001. Separation of *Alona cambouei* Guerne & Richard, 1893 from *Alona pulchella* King, 1853 (Branchiopoda, Anomopoda, Chydoridae). Arthropoda Selecta 10:5-18.

Sinev AY, 2011. Redescription of the rheophilous Cladocera *Camptocercus vietnamensis* Than, 1980 (Cladocera: Anomopoda: Chydoridae). Zootaxa 2934:53-60.

Sinev AY, 2012. *Alona kotovi* sp. nov., a new species of Aloninae (Cladocera: Anomopoda: Chydoridae) from South Vietnam. Zootaxa 3475:45-54.

Smirnov NN, 1971. [Chydoridae of the world fauna. Fauna SSSR].[Book in Russian] Rakoobraznie 1:1-531.

Smirnov NN, 1992. The Macrothricidae of the world, p. 1-143. In H.J. Dumont (ed.), Guides to the identification of the microinvertebrates of the continental waters of the world, 17. SPB Academic Publ.

Smirnov NN, 1996. Cladocera: the Chydorinae and Sayciinae (Chydoridae) of the world, p. 1-197. Guides to the identification of the microinvertebrates of the continental waters of the world, 17. SPB Academic Publ.

Sorensen KH, Sterner RW, 1992. Extreme cyclomorphosis in *Daphnia lumholtzi.* Freshwater Biol. 28:257-262.

Stross RG, Hill JC, 1968. Photoperiod control of winter diapause in the fresh-water Crustacean, Daphnia. Biol. Bull. 134:76-198.

Swar DB, Fernando CH, 1979. Cladocera from Pokhara Valley, Nepal with notes on distribution. Hydrobiologia 66:113-128.

Van Damme K, Dumont HJ, 2008. The 'true' genus *Alona* Baird, 1843 (Crustacea: Cladocera: Anomopoda): characters of the *A. quadrangularis*-group and description of a new species from Democratic Republic Congo. Zootaxa 1945:1-25.

Van Damme K, Eggermont H, 2011. The Afromontane Cladocera (Crustacea: Branchiopoda) of the Rwenzori (Uganda-D.R. Congo): ecology, biogeography and taxonomy including the description of *Alona sphagnophila* n. sp. Hydrobiologia 676:57-100.

Van Damme K, Kotov AA, Dumont HJ, 2010. A checklist of names in Alona Baird, 1843 (Crustacea: Cladocera: Chydoridae) and their current status: an analysis of the taxonomy of a lump genus. Zootaxa 2330:1-63.

Van Damme K, Sinev AY, 2013. Tropical amphi-pacific disjunctions in the Cladocera (Crustacea: Branchiopoda). J. Limnol. 72(Suppl.2):209-244.

Van Damme K, Sinev AY, Dumont HG, 2011. Separation of *Anthalona* gen.n. from *Alona* Baird, 1843 (Branchiopoda: Cladocera: Anomopoda): morphology and evolution of scraping stenothermic alonines. Zootaxa 2875:1- 64.

Vanjare AI, Padhye SM, Pai K, 2010. Zooplankton from a polluted river, Mula (India),with record of *Brachionus rubens* (Ehrenberg, 1838) epizoic on *Moina macrocopa* (Straus, 1820). Opusc. Zool. Budapest 41:89-92.

Williams DD, 2002. Temporary water crustaceans: biodiversity and habitat loss, p. 223-233. In: E. Escobar-Briones and F. Alvarez (eds.), Modern approaches to the study of Crustacea. Kluwer, Dordrecht.