Distribution and assemblages of large branchiopods (Crustacea: Branchiopoda) of northern Western Ghats, India

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ABSTRACT

The present study is a report on the distribution and assemblages of large branchiopods from the Western Ghats of Maharashtra. Different types of water bodies were sampled including pools on lateritic outcrops. Eight species of large branchiopods were found in 72 samples collected over a period of 4 years. We found 7 large branchiopod species in rock pools, while the cyclosteriid Cyclasteria hislopi was observed only in rivers and water reservoirs. In twenty-five percent of the samples multiple species co-occurred with a maximum of 4 species in a single sample. Streptocephalus dichotomus was the most commonly observed species while Streptocephalus sahyadriensis was noted only in rock pools. Altitude and aquatic vegetation were identified as important factors for the distribution of large branchiopods in the studied area. Triops granarius was the species most commonly found to be co-occurring with other species, followed by S. sahyadriensis. Cyclasteria hislopi and Eulimnadia indocylindrova always occurred alone.

Key words: Temporary water bodies, Rocky outcrops, Streptocephalus, Triops, Eulimnadia.

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INTRODUCTION

Large branchiopods are a group of freshwater crustaceans found mostly in seasonal water bodies throughout the world (Brendonck et al., 2008). These animals are found in characteristic assemblages with representatives of a few or mostly all orders co-habiting a single habitat with up to 10 species found in a single site (Thiéry, 1991; Maeda-Martínez et al., 1997). Many factors are known to influence branchiopod assemblages including habitat type, size of the water body, hydroperiod, pH, salinity and temperature and biotic conditions such as vegetation presence, competition and predation (Thiéry, 1991; Maeda-Martínez et al., 1997 and references therein; Boven et al., 2008). Various aspects of such assemblages have been investigated from the temperate regions of the old world and the new (Hamer and Appleton, 1991a; Thiéry, 1991; Maeda-Martínez et al., 1997; Petrov and Cvetković, 1997; Eder et al., 1997; Hamer and Martens, 1998; Thiéry and Puente, 2002; Marrone et al., 2006; Boven et al., 2008; Waterkeyn et al., 2009). However, limited information is available from the Oriental biogeographical region, including India. Studies on the large branchiopods of India are scattered and have mainly focused on taxonomical and/or faunistic records (Bond, 1934; Nayar and Nair, 1968; Raj, 1971; Battish, 1983; Belk and Esparza, 1995; Durga Prasad and Simhachalam, 2009; Simhachalam and Timms, 2012; Padhye et al., 2015). Other studies have been addressed on biology, phylogeny and/or applied aspects of selected species (Bernice, 1972; Paul and Nayar, 1977; Munuswamy, 1988; Prasath et al., 1994; Radhika et al., 1998; John et al., 2004; Vikas et al., 2012).

India is considered to be one of the megadiversity countries of the world (Mittermeier et al., 1998) and includes areas such as the Western Ghats known to have several endemic species of plants and animals (Mittermeier et al., 2005). Some parts of the Western Ghats of Maharashtra possess unique and interesting habitats in the form of rocky outcrops (Widdowson and Cox, 1996; Jog et al., 2002) which are generally known to host rich large branchiopod fauna (Pinder et al., 2000; Timms 2006; Brendonck et al., 2010; Jocque et al., 2010). Despite these facts, ecological and distributional studies on the large branchiopod in these parts of Ghats and surrounding areas are rare to the best of our knowledge, with only a few published reports (Pai, 1958; Karande and Inamdar, 1959, 1960, 1964; Padhye et al., 2011a, 2011b, 2015).

The large branchiopod fauna of the Western Maharaashtra (India) has recently been compiled (Padhye et al., 2015, and reference therein). In the present work we investigate the distributional patterns and the coexistence of the large branchiopod assemblages observed in the region. We report the observations on the frequency of associations between the species and evaluate the relative
importance of selected environmental variables in explaining the distributional patterns of the large branchiopod species considered in this study.

METHODS

Study area

The Western Ghats are a steep western edge of an elevated Plateau (Prasad et al., 2009) running for almost 1600 km and covering six states of India, namely Gujarat, Maharashtra, Goa, Karnataka, Tamil Nadu and Kerala (Mani, 1974). The northern region of the Western Ghats considered for this study lies in the states of Maharashtra and Goa. This region of the Ghats has been the center of the Deccan volcanism event and is made up mostly of basaltic rock (Jog et al., 2002). Some parts of the Ghats show peculiar rocky outcrop formations (either basaltic or lateritic) on hilltops (Widdowson and Cox, 1996) known to have unique fauna and flora (Porembski and Watve, 2005; Watve, 2013). This region of the Ghats gets a majority of its rainfall in the Monsoon season (June - September/October) and has a prolonged dry season lasting from 5 to 8 months (Mani, 1974).

Sampling area and methods

Sampling was performed from November 2009 to September 2013 in a region lying in the Western Ghats of the state of Maharashtra between 15°N to 20°N (henceforth referred to as NWG) (Fig. 1). We also sampled a single locality in Goa (a water reservoir, located approximately 150 km south of Masai plateau, near the western coast of Goa, adjacent to the Western Ghats). A total of 72 samples were collected from 28 different localities in the studied area (Supplementary Tab. 1). In a given locality, samples collected from different sites were considered as separate samples. Similarly, samples collected from the same sites on different dates were considered as different samples in order to account for putative temporal variations. Samples were categorized into 4 types of habitats, i.e. pools, ponds, lakes (water reservoirs) and rivers according to Williams et al. (2004) and De Bie et al. (2008). The sampling sites (pools and ponds) were selected via chance encounter while walking in the respective localities. Sampling was performed during the monsoon season for the localities having temporary water bodies. Qualitative sampling was carried out by sweeping with a hand net with a circular plastic frame (r=7.5 cm) and a mesh size of 150 μm. An effort was made to sample representatively each microhabitat of the water-bodies during every collection. Only littoral samples were taken from riverine and reservoir localities. Samples were collected in plastic containers (100 mL) in the field and immediately fixed with 8% formalin. Animals were sorted, observed and/or dissected under Stereo Binocular Microscope and identified according to Velu and Munuswamy (2005) for Anostraca, Longhurst (1955) and Raj (1971) for Notostraca, Battish (1981), Martin and Belk (1988), Balaraman and Nayar (2004), Babu and Nandan (2010), Rabet (2010), Rogers et al. (2012) and Simhachalam and Timms (2012) for Laevicaudata and Spinicaudata.

In addition, the physical and chemical parameters of water like pH, Temperature and Salinity were checked on the field by using portable Multiparameter probe. Latitude and longitude were obtained either with a handheld GPS unit or from Google Earth for few localities. Altitude of the localities was also recorded by using the handheld GPS unit or were extracted via DIVA-GIS (v7.5) using BIOCLIM data (Hijmans et al. 2005, http://www.worldclim.org). Data for average annual precipitation were extracted using BIOCLIM data via DIVA-GIS (v7.5). Presence/absence of submerged and/or floating aquatic vegetation was recorded in the field itself.

Data analyses

Large branchiopod occurrence data obtained from the 72 samples were used for calculating the Fager’s index of affinity. This index is calculated as a measure of co-occurrence for the branchiopods observed in a species assemblage (Maeda-Martínez et al., 1997). The index is calculated by the formula:

$$IF = \frac{2(n_1+n_2)}{(n_1+n_2+2)}$$

(eq. 1)

where $n_1+2$ is the number of joint occurrences of species 1 and 2, $n_1$ is the total number of occurrences of species 1 and $n_2$ is the total number of occurrences of species 2.

Large branchiopod assemblage pattern table format was adopted from Maeda-Martínez et al. (1997). Mapping was carried out using DIVA-GIS (v7.5) freeware (www.diva-gis.org). The distribution of the large branchiopod species was investigated in relation to local environmental and spatial characteristics using canonical correspondence analysis (CCA) based on the large branchiopod occurrence data for the 72 samples. Environmental variables used for the analysis were pH, Temperature, Salinity, Average Annual precipitation, Altitude and Aquatic vegetation. The significance of the analysis was tested using Monte Carlo permutations (n=999). Dummy coding was applied for presence/absence of aquatic vegetation. CCA analysis was performed using PAST (v 2.17c) (Hammer et al., 2001).

RESULTS

Species richness and faunistic notes

A total of 8 species belonging to all the 5 orders of large branchiopods were found from 72 samples (pools,
53; ponds, 15; reservoir, 3; rivers, 1) from NWG (Tab. 1; Fig. 1). Nineteen of the 28 localities had only one species. Alandi road 1 locality hosted the maximum number of species (5) followed by Tableland (4) and Masai (4) (Supplementary Tab. 1). Eighteen of the 72 (25%) samples hosted more than one species (Tab. 2). Five of these 18 samples had 3 or more co-occurring species. Seven species were present in pools, 4 in ponds, while water reservoirs and rivers hosted only Cyclestheria hislopi. Anostracans were the most commonly occurring group of large branchiopods (they occurred in 43 out of 72 samples) with Streptocephalus dichotomus being more frequent (27 out of the 72 samples) than S. sahyadriensis (16 out of the 72 samples).

Factors affecting distribution

Besides C. hislopi, all species of large branchiopods lived in neutral or slightly basic pH (Tab. 3). Seven of the eight recorded species showed a wide altitudinal range with restriction seen in S. sahyadriensis only. S. sahyadriensis distribution was limited to rock pools of lateritic outcrops while its congener, S. dichotomus was spread quite uniformly throughout the sampled region (Fig. 2d). Cyzicus sp. was limited to only two, closely situated localities (Fig. 2a).

The first two CCA axes explained 77.2% variance (permutations=999; trace=0.84; P=0.001). Altitude and annual precipitation negatively correlated to the first axis (-0.63 and -0.41) while total number of species/sample weakly correlated with the second axis (0.41) (Fig. 3). Four of the eight species, i.e., Streptocephalus sahyadriensis, Triops granarius, Leptestheriella nobilis, and Lynceus alleppeyensis were mostly observed as assemblages on lateritic outcrops which were characterized by higher altitudes, little or no aquatic vegetation, and relatively lower salinity and pH (Fig. 3). Streptocephalus dichotomus was found in pools located at lower altitudes as well and also occurred as a single species in many habitats (Fig. 2).

Assemblages and species co-occurrences

Six of the eight species co-occurred in different combinations (Tab. 2). Triops granarius was the most represented species in all combinations of the species assemblage. The groups of S. sahyadriensis - L. nobilis and S. sahyadriensis - T. granarius - L. nobilis, both detected three times, were the most common combinations observed. Assemblages consisted of one representative of each order only. S. dichotomus along with L. nobilis showed the weakest Fager’s index (0.05). T. granarius co-occurred mostly with L. nobilis (0.41) followed by S. sahyadriensis and L. alleppeyensis (0.30 and 0.29, respectively). Occurrence of Cyzicus sp. was sporadic and it never occurred as a single species. Both of its occurrences were with L. alleppeyensis (Fager’s index of 0.44). Eulimnadia indocylinдра and C. hislopi occurred only as single species with the latter being more common of the former.

DISCUSSION

Faunistics, environmental variables and distributional patterns

The diversity of large branchiopods in India is poorly documented (Durga Prasad and Simhachalam, 2009), but presently, the number would roughly be 80 species (Raj, 1971; Battish, 1983; Belk and Esparza, 1995; Durga Prasad and Simhachalam, 2009). Eight species from this study thus represents about 10% of the known large branchiopod fauna of India. This species richness is less than the only other known comprehensive fauna from Oriental region (SE Asia) having 8 described and 3-4 undescribed species (Rogers et al., 2013). This difference in species number between NWG and SE Asia, may just be the result of limited sampling area and of the difference of geographical extent of the two regions rather than to be ascribed to true species deficiency in NWG.

Out of the eight species found, S. dichotomus is widespread in the Indian sub-continent and Myanmar (Belk

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Tab. 1. Species seen in the study along with the localities where they were found.

| Order       | Family            | Species                    | Code | Localities (observed) |
|-------------|-------------------|-----------------------------|------|----------------------|
| Anostraca   | Streptocephalidae | Streptocephalus dichotomus  | Stdi | Ju, Vi, Gh, De, Ar1, Ar2, Ko, Mi, Si, Aj, Ma, Ro |
|             |                   | S. sahyadriensis            | Stsa | Tb, Me, Mh, Ch       |
| Notostraca  | Triopsidae        | Triops granarius            | Tgra | Ar1, Tb, Me, Ya, Ja, Ch, Mh, Ma |
| Laevicaudata| Lynceidae         | Lynceus alleppeyensis       | Lall | Ar1, Ar2, Tb, Ya, Aj, Ma |
| Spinaudata  | Cylindridae       | Cylindra sp.                | Cyzi | Ar1, Ar2             |
| Spinaudata  | Eulimnadiidae     | Eulimnadia indocylinдра     | Euin | Bd, Ta, Ma           |
| Spinaudata  | Leptestheriidae   | Leptestheriella nobilis     | Lnob | Ar1, Up, Tb, Me, Ya, Aj, Ch |
| Cylindridae | Cyclestheridae    | Cyclestheria hislopi        | Chis | Di, Sh, Ga, Ps, La, Pu, My |

For locality names corresponding to the numbers, refer to Supplementary Tab. 1.
and Esparza, 1995; Rogers et al., 2013 and references therein). Three species, *S. sahyadriensis*, *E. indocylin-drova* and *L. nobilis* are Indian endemics. Distribution of *Triops granarius* has to be re-evaluated since this species seems to be paraphyletic with at least two distinct clades known to occur in India (Korn et al., 2013). A recent detailed phylogenetic study on *C. hislopi* has revealed that 3 distinct phylogenetic species occur on different continents, and that the populations from India and Southeast Asia form a separate clade (Schwentner et al., 2013).

Temperature, pH and salinity did not effectively explain the species distribution perhaps due to the overlapping pH, temperature and salinity ranges observed for all species (Tab. 2). Pools could be roughly categorized into pools with large branchiopod assemblages and pools with only single species (Fig. 3). Pools with assemblages were mostly found on lateritic rocky outcrops located at higher altitudes having little or no aquatic vegetation; conversely, pools with single species did not show any such specificity. Further sampling from additional localities (e.g., those given by Watve, 2013) would help in resolving these associations.

Distribution of both *Streptocephalus* species was distinct in the study area in spite of a high chance of dispersal owing to proximity of habitats (Fig. 2d). *Streptocephalus* species are usually considered generalists occurring in pools having a comparatively longer inundation period due to their slower maturation rate, though, exceptions are also known (De Roeck et al., 2010; Jocque et al., 2010). *Streptocephalus dichotomus* here could be considered as a generalist species on account of its wide distribution.

![Fig. 1. a) Sampled sites in the NWG. b) Studied area within India. Scale bar given for a).](image)
within the sampling region while \textit{S. sahyadriensis} could be considered as a more stenococous taxon, with a highly restricted distribution and a specificity for rock pools. The absence of \textit{C. hislopi} from higher altitude localities cannot be explained at this stage.

**Species assemblages and co-occurrences**

Twenty-five percent value of co-occurrence of species from all large branchiopod habitats sampled in NWG is comparable to 31\% from a study by Boven \textit{et al.} (2008) but was less than the value reported by other authors like Petrov and Cvetković (1997) (67\%) and Thiéry (1991) (90\%). The reason for such low co-occurrence ratio has been attributed to invertebrate predator density, availability of food and resource partitioning due to size disparity (Thiéry, 1991 and references therein; Simovich 1998; Hamer and Martens, 1998). This value could also be due to the low number of large branchiopod species found in NWG. Co-existence of 4 species of large branchiopods in a single sample is the highest level of coexistence documented from Western Ghats to date. A similar number of species of large branchiopods have been reported from

\textbf{Fig. 2.} Distribution of the large branchiopod species detected in the studied area. a) \textit{Cyzicus} sp. (black circle) and \textit{Lynceus alleppeyensis} (white square). b) \textit{Cyclostheria hislopi} (black circle) and \textit{Triops granarius} (white square) (locality of Goa for \textit{C. hislopi} not shown in the map). c) \textit{Eulimnadia indocylindrova} (black circle) and \textit{Leptestheriella nobilis} (white square). d) \textit{Streptocephalus dichotomus} (black circle) and \textit{Streptocephalus sahyadriensis} (white square).
Sambhar lake, Rajasthan in Central India with the co-occurrence of three fairy shrimps and a clam shrimp (Baid, 1968). All combinations of species of the three orders of large branchiopods were seen recurring over studied area, especially on rocky outcrops. Similar recurring assemblages of different orders have been reported from USA, Mexico and Africa (Hamer and Appleton, 1991b; Thiéry, 1991; Maeda-Martínez et al., 1997). Triops granarius, in the current study was observed only in assemblages, an observation also noted for the congeneric species T. cancriformis (Petrov and Cvetković, 1997; Boven et al., 2008; Waterkeyn et al., 2009). Congeneric appearances of anostracans are widespread (Daborn, 1977; Donald, 1983; Timms and Sanders, 2002) with co-occurrences of Streptocephalus species seen commonly (Moore, 1966; Mertens and Dumont, 1989; Hamer and Appleton, 1991a), but his was not observed in this study.

**CONCLUSIONS**

Many large branchiopod species exhibit endemism and are confined to small regions or their type localities (Dumont and Negrea, 2002; Brendonck et al., 2008; Durga Prasad and Simhachalam, 2009); conversely, other species have a wider distribution. These animals rely on banks of resting eggs as a buffer against environmental stresses (Brendonck, 1996). Hence, habitat loss caused by land conversion can destroy these egg banks threatening the diversity of large branchiopods. Such temporary water habitats are diminishing worldwide (Williams et al., 2004). Many species from Europe and North America are considered critically endangered and listed in the IUCN red list (www.iucnredlist.org). Baseline data about habitat destruction caused due to land conversion for activities like agriculture are not known for developing countries (Brendonck et al., 2008). Freshwater rock pools known to have high diversity of unique fauna are considered as untouched habitats (Brendonck et al., 2010; Jocque et al., 2010) and therefore are of conservational significance (Jocque et al., 2007; Watve, 2013 and references therein). The finding of 6 large branchiopod species, including the endemic Streptocephalus sahyadriensis, on lateritic outcrop localities emphasizes the need of a further comprehensive study focused specifically on these outcrops.

A detailed research of such temporary habitats is thus very much required especially in less studied regions such as the Western Ghats. Such studies will definitely help our understanding of large branchiopod diversity and ecology.

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**Tab. 2. Assemblage structures observed in the studied samples.**

| Number of species in an assemblage | Number of samples | Anostraca | Notostraca | Spinicaudata | Laevicaudata |
|-----------------------------------|------------------|----------|-----------|-------------|-------------|
| 2                                 | 12               | * Tgra   | Lnob      | *           |             |
| Stsa                              |                  | *        | Lnob      | *           |             |
| Stsa                              |                  | *        | Lnob      | *           |             |
| Stsa                              |                  | Tgra     | *         | *           |             |
| Stsa                              |                  | Tgra     | *         | *           |             |
| *                                 | Tgra             | Lnob     | *         |             |
| Stdi                              |                  | Tgra     | Lnob      | *           |             |
| Stdi                              |                  | Tgra     | *         | *           |             |
| Stdi                              |                  | *        | Lnob      | *           |             |
| Stsa                              |                  | *        | Lnob      | *           |             |
| 3                                 | 5                | Stdi     | * Cyzi    | Lall        |             |
| Stsa                              |                  | Tgra     | Lnob      | *           |             |
| Stsa                              |                  | Tgra     | Lnob      | *           |             |
| Stsa                              |                  | Tgra     | Lnob      | *           |             |
| Stsa                              |                  | Tgra     | Lnob      | *           |             |
| 4                                 | 1                | Stdi     | Tgra      | Cyzi        | Lall        |

*Stsa, S. sahyadriensis; Stdi, Streptocephalus dichotomus; Tgra, Triops granarius; Lnob, Leptestheriella nobilis; Cyzi, Cyzicus sp.; Lall, Lyneceus alleppeyensis.*
Distribution of large branchiopods in Western Ghats in the region and will hopefully lead to informed conservation measures.

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**Tab. 3.** Range of environmental variables for each species of large branchiopods with their number of occurrences and co-occurrences in 72 samples.

| Species | Total occurrence | Co-occurrence | Altitude (m asl) | Annual precipitation (range) (mm) | pH | Temperature (°C) | Salinity (mg/L) |
|---------|-----------------|---------------|-----------------|-----------------------------------|----|-----------------|----------------|
| *Streptocephalus dichotomus* Baird, 1860 | 27 | 6 | 587-1185 | 520-3693 | 6.5-8.8 | 20.2-30.8 | 15.5-383.0 |
| *S. sahyadriensis* Rogers & Padhye, 2014 | 16 | 8 | 1082-1289 | 2156-3977 | 7.1-8.8 | 20.3-33.0 | 24.0-38.0 |
| *Triops granarius* (Lucas, 1864) | 14 | 12 | 612-1289 | 754-3977 | 7.1-8.7 | 21.6-27.1 | 17.0-166.0 |
| *Lynceus alleppeyensis* Balaraman & Nayar, 2004 | 7 | 5 | 612-1289 | 754-3977 | 7.6-8.7 | 22.1-28.1 | 15.5-166.0 |
| *Leptestheriella nobilis* (Sars, 1900) | 15 | 10 | 578-1289 | 745-3977 | 7.4-8.8 | 21.6-29.8 | 22.6-383.0 |
| *Cyzicus* sp. | 2 | 2 | 587-612 | 754 | 8.2-8.7 | 26.0-27.0 | 147.0-166.0 |
| *Eulimnadia indocylindrova* Durga Prasad & Simhachalam, 2004 | 3 | 0 | 577-940 | 844-1859 | 8.0-8.2 | 20.9-29.9 | 17.0-157.0 |
| *Cyclestheria hislopi* (Baird, 1859) | 13 | 0 | 50-658 | 519-3414 | 7.1-9.0 | 23.7-30.0 | 39.0-310.0 |

**Fig. 3.** CCA ordination diagram showing the relationships between the large branchiopod species and the environmental variables for all the pool samples. Scree plot is shown in the inset. Species codes as in Tab. 2.
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