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Research Article

Assessing the response of odonates (dragonflies and damselflies) to a tropical urbanization gradient

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Abstract

Understanding species responses to urbanization is important to realize their specific conservation needs. Odonates (dragonflies and damselflies) are freshwater insects perceived as good ecological indicators. To investigate responses of tropical odonates to an urbanization gradient, we sampled adult odonates along an urbanization gradient at six sites along the Mula River across Pune City, Maharashtra, India. For species–habitat analysis, we first performed a variable reduction using principal component analysis. we analyzed species–habitat data using redundancy analysis and canonical correspondence analysis. We documented 15 odonates across 6 sites. Our statistical analyses on patterns of odonate assemblages across sites and environmental variables did not return significant results. However, we detected site-exclusivity in a few species based on occurrence data and identified urban sensitive, urban tolerant and generalist species. We found that the odonate diversity was highest at a moderately urbanized site. We believe that increase in diversity due to moderate amounts of disturbance can be explained by the intermediate disturbance hypothesis. Based on our data, we suggest that for the conservation of odonates in the urban context, anthropogenic disturbance needs to be regulated. Here, we demonstrate that understanding species–habitat associations is the first step towards understanding their ecological and conservation requirements. To conserve odonates and rivers in metropolitan cities like Pune, restoring original river-side habitat and reducing the disturbance at highly urbanized sites to at least intermediate levels needs to be done on an urgent basis.

Key words: conservation, urbanization indicator, habitat ecology, species composition, urban wetlands

Introduction

In the wake of Ecological Armageddon (Pleasants et al. 2016; Hallmann et al. 2017) and planet's entry into the sixth mass extinction (Ceballos et al. 2015), mitigating environmental degradation through research and action is the need of the hour. Urbanization plays a major role in environmental degradation and disturbance in and around human-inhabited areas. Urbanization is the process of population concentration across space and time (Tisdale 1942), which leads to land-use changes and an increase in pollution. Urbanization is considered as one of the quickest long-lasting degradations resulting in frequent local extinctions (McDonnell et al. 1993, Platen and Kowarik 1995; McKinney 2002, 2008) as well as homogenization of biota (Aronson et al. 2014). Though the ill effects of urbanization are widely visible, there is still a general lack of knowledge on the impacts of urbanization on each ecosystem's structure, function and species composition, particularly in tropical Asia (Sun and Vose 2016). The intermediate disturbance hypothesis (IDH, Connell 1978) states that diversity is highest at sites with intermediate disturbances. Empirical evidence for IDH is abundant in sessile organisms like plants and macro-invertebrates as compared with free moving organisms (Wilkinson 1999). Low disturbance sites might have low diversity due to competitive exclusion. In contrast, high disturbance sites may not allow diversity due to rapid recolonization, making the sites with intermediate disturbance the most suitable to support diverse assemblages. Species responses to urbanization may depend on not only on their tolerance to environmental changes but to their ecological resource usage (Niemelä 2002; Kulkarni and Subramanian 2013). Habitat specialists are at a higher risk in fast-urbanizing environments, compared with generalists that may occupy a large number of habitats (Korkeamäki and Suhonen 2002). Generalists are thought to be tolerant of the effects of urbanization (Kark et al. 2007; MacGregor-Fors and Schondube 2011; Merckx and Van Dyck 2019). Massive negative impacts of urbanization on freshwater resources are of immediate concern (Chadwick et al. 2006; Elmore and Kaushal 2008), given the immense utility value of freshwater resources.

Urban wetlands and rivers play an essential role as freshwater ecosystems in the human-modified landscape. Riparian fauna includes a great variety of vertebrate and invertebrate species. The urban freshwater habitats, especially in and around cities, are under high anthropogenic pressure of degradation and modification. Therefore, studying such habitats provides an idea of the pace of urbanization and species losses. Many aquatic invertebrates play a role as bio-indicators, among which, odonates are widely studied as ecological indicators (Suhling et al. 2015).

Odonates are hemimetabolous insects, having a semi-aquatic life cycle (Corbet 1962; Stoks and Córdoba-Aguilar 2012). They depend on freshwater for reproduction. Their larval stages are aquatic, and adults are terrestrial and aerial. It is because of this dependence; odonates are widely used as aquatic as well as terrestrial habitat indicators (Monteiro-Júnior et al. 2014, Rocha-Ortega et al. 2019). Odonates, which are habitat specialists, are often endemic and threatened and are reported to be associated with primary forests and streams in the tropics (Villanueva and Mohagan 2010; Koparde et al. 2014, 2015). Moreover, dragonflies and damselflies have been observed to differ in their responses to habitat modifications, with damselflies reported to be more sensitive to micro-habitat changes (Koparde 2016). To date, there have been only a limited number of studies on responses of tropical odonates to rapidly urbanizing areas (Villalobos-Jiménez et al. 2016).

Here, we explored the species–habitat dynamics in a rapidly expanding metropolitan city situated on the edge of the western Ghats, a global biodiversity hotspot. Based on the information available (Willigalla and Fartmann 2012; Koparde 2016; Villalobos-Jiménez et al. 2016), we hypothesized a decrease in species richness from low to high urbanization. We also tested the degree of environmental tolerance of odonates based on frequency and sites of occurrence, and their habitat correlates. Based on regional knowledge, we recommend conservation action for the protection of urban wetlands and green spaces.

Methods

Study area

We used the land-use map (<https://bhuvan-app1.nrsc.gov.in/state/MH#> last accessed on 1 March 2020) to classify sites along an urbanization gradient (Fig. 1). We used high-resolution satellite images available from Google Inc. first to get the tentative location of the study sites along an urbanization gradient, and then after-ground reconnaissance selected the six sites (Supplementary Table S1). The Mula River originates in the western Ghats, and it is dammed at Mulshi village. From Mulshi, the river flows eastwards towards the Pune City. The degree of urbanization and land-use across Mulshi to Pune central area is in a gradient from low to high. Among the six sites, Mulshi is on the extreme of low urbanization gradient, whereas RTO (near Road Transport Office) is on the other extreme of high urbanization gradient as per the land-use around the sites (Fig. 1). Each study site was separated by a linear distance of 5 km, so as to avoid spatial autocorrelation.

Data collection

Odonata sampling

For each study site, we sampled 300 m distance using a newly devised Half Circle Point Count Method (Darshetkar et al. 2020 in review). In this method, we sampled odonates using point counts along the 300 m transect line. We placed six point counts spaced at 25 m starting from 0 m. The point count dimensions were 5 m radius facing the riverside (half circle) with an observation time of 5 min. We took multiple temporal replicates for each site during 2016–2017, ranging from six to nine visits per site (Table 2). We followed Subramanian and Babu (2017) for species listing.

Habitat correlates

For each visit to every site, we picked five random points along the 300 m transect line to collect data on habitat correlates. We measured water quality [dissolved oxygen (DO), biological oxygen demand (BOD), pH and turbidity] and habitat structure (canopy cover, ambient temperature, humidity, ground cover, aquatic vegetation and pollution attributes). For water quality assessment, we collected surface water in four separate bottles and processed the samples in the lab. We measured DO and BOD following Grant and Tingle (2002). We used a pH meter to measure pH. We followed Koparde (2016) for measuring water turbidity. We took observations of canopy cover using a densitometer. We used a thermo-hygrometer to measure ambient air temperature, water temperature and humidity. We estimated ground and aquatic cover (aquatic herbaceous cover, terrestrial vegetation cover, terrestrial grass cover and terrestrial bare ground cover) using a quadrat. We graded aquatic variables such as the area of water spread within the sampling zone and river water flow from 0 (absent) to 3 (high). We collected data on urbanization parameters using the presence–absence scoring method. These parameters included the number of garbage piles, perching site substrates, industrial effluents, check dams, canalization, riparian deforestation, flow modification, agricultural runoff and grazing (0 = absent and 1 = present).

Data analysis

Diversity and distribution analysis

We drew species saturation curves to judge the representation of species assemblage. We calculated diversity indices (Simpson and Shannon) for each site. We used two estimators of species (CHAO2 and Jack1) to make the analysis robust (Walther and Moore 2005). To understand the effects of urbanization on Odonates, we performed variable reduction on environmental variables using a principle component analysis (PCA). From PCA, we shortlisted variables contributing to 95% of the total variation in the data. We then used two ordination techniques to explore species–habitat relations, canonical correspondence analysis (CCA) and redundancy analysis (RDA). We performed these analyses on the combined Odonata data, i.e. damselflies and dragonflies combined. For both CCA and RDA, we used variables shortlisted through PCA, namely, BOD, terrestrial bare ground cover, aquatic herbaceous cover, terrestrial herbaceous cover, canopy cover, humidity, temperature, water turbidity and water spread. We used Rstudio v3.0.1 (R Core Team 2013) for the data analysis.

Results

Multivariate analysis of species–habitat association

We short-listed nine variables that captured 95% of the variation in our predictor dataset, through PCA. The CCA on Odonata ($P = 0.1$; Supplementary Fig. S1) did not produce significant results (summary in Table 1). The RDA (Summary in Table 1) on Odonata across sites ($P = 0.3$; Supplementary Fig. S2) data did not show linearity. According to the RDA, the species data and environmental variables were not linearly related to each other. The summary of site characteristics is presented in Table 2.

Diversity and distribution of Pune odonates

During the systematic sampling, we recorded 15 species (dragonflies = 8 and damselflies = 7; Supplementary Tables S2 and S3 and Table 2). Among the sampled odonates, Libellulidae ($n = 7$) and Coenagrionidae ($n = 5$) families were well represented. Among dragonflies, *Trithemis aurora* (relative abundance = 0.31) was the most abundant species followed by *Brachythemis contaminata* (relative abundance = 0.08) and *Orthetrum sabina* (relative abundance = 0.08; Supplementary Table S3). Among damselflies, *Pseudoniagron rubriceps* (relative abundance = 0.13) was the most abundant species followed by *Disparoneura quadrimaculata* (relative abundance = 0.05; Supplementary Table S3). Complete turnover from high to low urbanization gradient was observed in *D.quadrimaculata*, *Libellago indica* and *T.aurora* (Fig. 2 and Supplementary Table S4). Towards higher urbanization gradient, *O.sabina, Ictinogomphus rapax* and *Ischnura senegalensis* were frequently observed (Fig. 2 and Supplementary Table S4). *Brachythemis contaminata*, *Crocothemis servilia*, *P.rubriceps* and *Ceriagrion coromandelianum* were widespread across the urbanization gradient (Fig. 2 and Supplementary Tables S2–4). Among the sampled localities, Balewadi was the most diverse locality, followed by Mulshi (Table 2).

Discussion

Species responses along the urbanization gradient

Our study returned species and site-specific data, identifying urban tolerant and sensitive species, highlighting the role of regional studies in uncovering effects of urbanization on species. Our study sites fit in an urbanization gradient (Fig. 1). The land-use map and our ground-truthing indicated that RTO and Aundh sites are situated on the higher end of the urbanization gradient whereas Balewadi has intermediate urbanization. Mulshi, Nande and Paud are at the low urbanization end of the gradient (Fig. 1). We did not find a significant change in Odonata richness and compositions from low to high urbanization, contradicting Willigalla and Fartmann (2012), but supporting studies reporting no change in richness (summarized in Villalobos-Jiménez et al. 2016). our ordination analyses (CCA and RDA) of Odonata data (Supplementary Figs S1 and S2) did not produce significant statistical results contrasting with Koparde (2016),

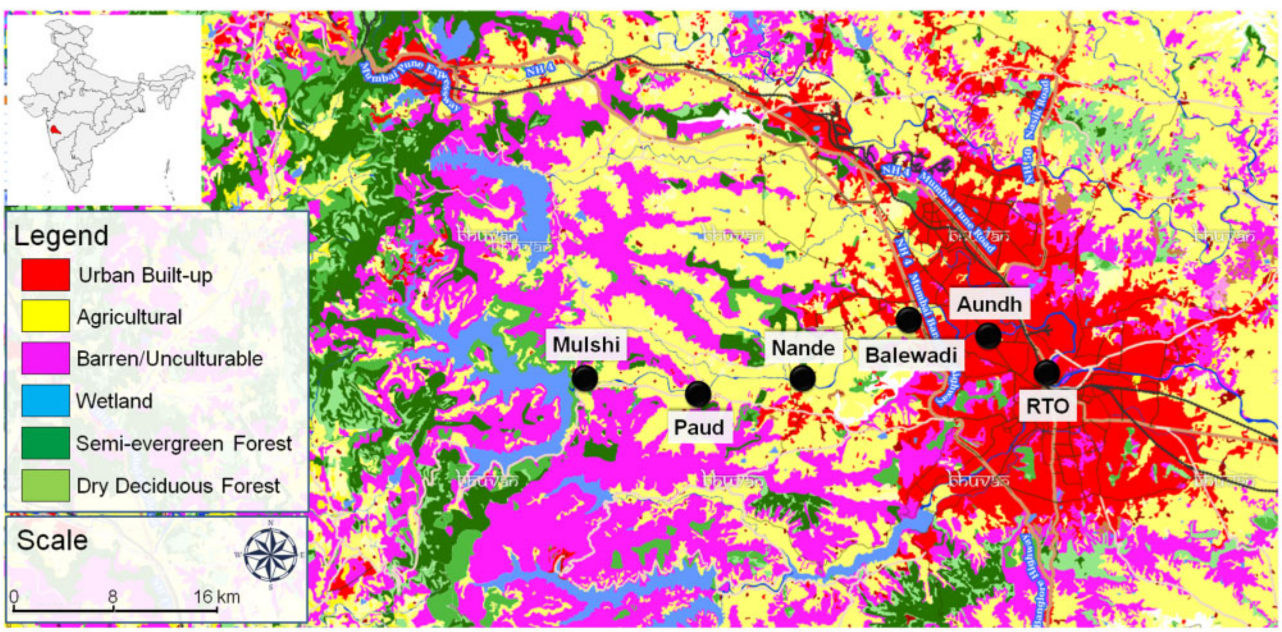

Figure 1: Study sites plotted on land-use map. Mulshi is farthest, whereas Aundh and RTO are the closest from the built-up land-use.

Table 1: Summary of CCA and RDA[a]

Analysis	Dataset	Percent of variation captured in axis 1	Significant predictor/s of axis 1	Percent of variation captured in axis 2	Significant predictor/s of axis 2
CCA	Odonata ($P = 0.1$)	29.21	Terrestrial herbaceous cover, water turbidity and aquatic herbaceous cover	23.51	Canopy cover, humidity, temperature and water spread on transect
RDA	Odonata ($P = 0.3$)	70.42	Temperature, terrestrial herbaceous cover, water turbidity and water spread on transect	18.47	Canopy cover, temperature, water turbidity and water spread on transect

[a]Assessing the response of odonates to a tropical urbanization gradient.

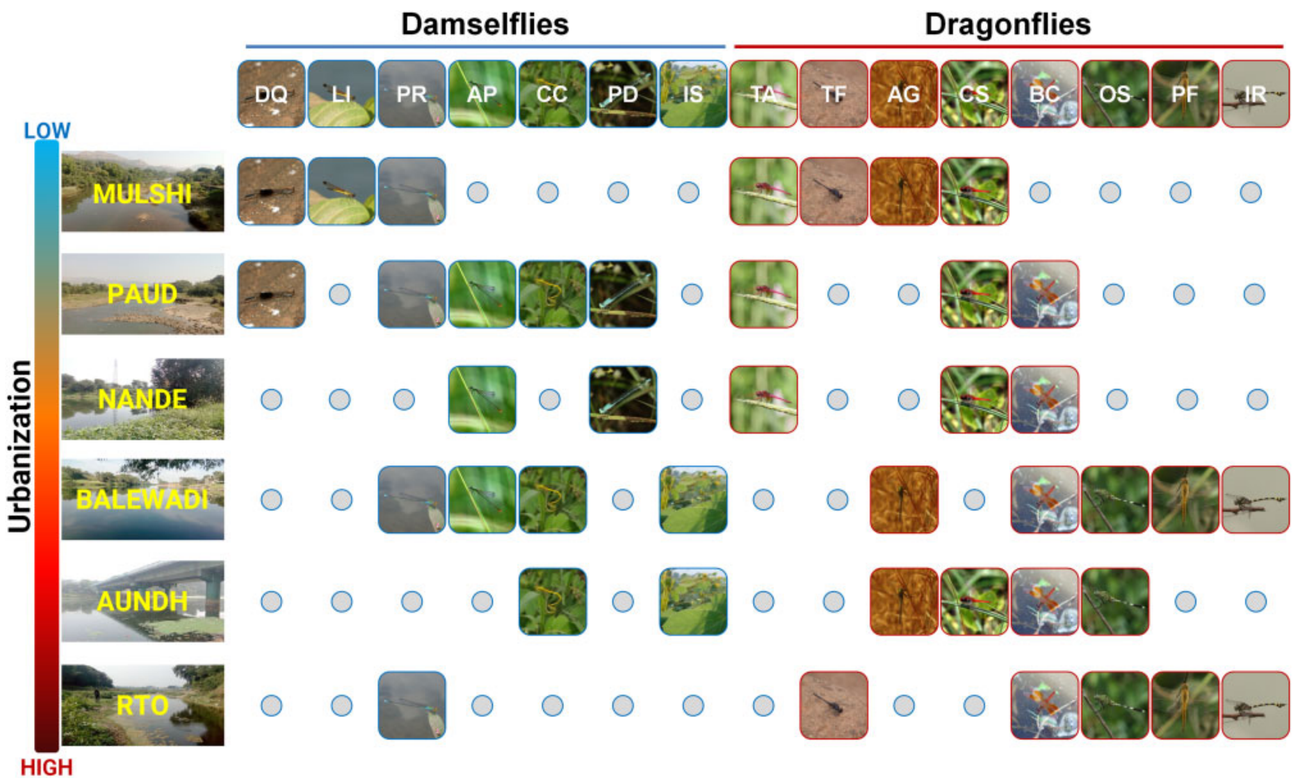

Figure 2: The plot of dragonflies and damselflies across sites surveyed based on the presence-absence matrix. DQ, *Disparoneura quadrimaculata;* LI, *Libellago indica;* PR, *Peudagrion rubriceps;* AP, *Agriocnemis pygmaea;* CC, *Criagrion coromandelianum;* PD, *Pseudagrion decorum;* IS, *Ischnura senegalensis;* TA, *Trithemis aurora;* TF, *Tithemis festiva;* AG, *Anax guttatus;* CS, *Crocothemis servilia;* BC, *Brachythemis contaminata;* OS, *Orthetrum sabina;* PF, *Pantala flavescens;* IR, *Ictinogomphus rapax*. Gray circles represent absence.

wherein damselfly compositions changed along wetlands and related pollution variables. We did not detect complete turnover, but partial exclusivity in species composition when the sites situated on the extreme ends of the urbanization gradient (Mulshi and RTO) were compared. Our results differ from Koparde (2016), which looked at seasonal odonate variation, possibly due to the short time scale of our study. However, through the predictor data collection, we found that urbanization gradient correlates to pollution gradient, with sites located in the highly urbanized and densely built-up areas such as RTO, Aundh, Balewadi, experiencing higher levels of water pollution provided by BOD and water turbidity values (Table 2). Based on the information of the exclusive presence of two endemic species, *D.quadrimaculata* (Mulshi and Paud) and *L.indica* (Mulshi) in the low urbanization sites and their absence in moderate and high urbanized sites, we posit that these species are less tolerant of high urbanization (Fig. 2 and Supplementary Table S4). Towards highly urbanized sites (Aundh and RTO) damselfly richness decreased and dragonfly richness increased (Fig. 2 and Supplementary Tables S3 and S4). The low damselfly species richness at a high urbanization site could indicate the ill effects of urbanization on damselflies (Koparde 2016). Based on their relative abundances across sites (Supplementary Tables S3 and S4), we identified *D. qudrimaculata* and *L.indica* as non-urban/urban sensitive species, *P.rubriceps*, and *C.coromandelianum* as generalists and *I.senegalensis* as an urban specialist. Most dragonflies had a wider range across the urbanization gradient; however, *O.sabina* and *I.rapax* were exclusively observed in highly urbanized sites. Both the species can be considered as specialized urban dwellers (Fig. 2 and Supplementary Tables S3 and S4). *Trithemis aurora* was found to be a non-urban species, and *B.contaminata* and *C.servilia* were generalists (Fig. 2 and

Table 2: Site-specific summary of diversity, species richness and habitat characteristics across the urbanization gradient (Mulshi = low and RTO = high)[a]

Data	Category	Parameter	Mulshi ($n=7$)	Paud ($n=8$)	Nande ($n=7$)	Balewadi ($n=9$)	Aundh ($n=9$)	RTO ($n=6$)
Species data	Diversity	Simpson's Diversity Index	0.8047	0.5873	0.7778	0.843	0.7347	0.782
		Shannon Diversity Index	1.801	1.348	1.561	1.972	1.537	1.564
	Species richness	Observed no. of species	7	8	5	9	6	6
		Chao2	6.8	9.3	6.9	14.9	8.3	8
		Jack1	6.8	8.1	7	8.2	8.9	5.7
Predictor data	Physical environment	Air temperature	27.7 ± 3.2	27.4 ± 4.3	24.57 ± 2.92	23.93 ± 5.44	26.22 ± 5.44	24.78 ± 0.29
		Humidity	51.8 ± 7.4	42.2 ± 12.2	50.47 ± 4.48	42.73 ± 13.47	44.15 ± 11.65	60.57 ± 6.45
	Water quality	BOD	311.25 ± 27.08	235 ± 137	377.5 ± 342.94	173.8 ± 107.25	90 ± 128.72	100 ± 92.6
		Water turbidity	Low	Medium	High	Medium	High	High
	Habitat structure	Terrestrial bare ground cover	83.33 ± 10.2	7.5 ± 12	0	45.34 ± 22.15	68.33 ± 20.65	93.33 ± 11.54
		Aquatic herbaceous cover	0	8.4 ± 3.4	9.37 ± 13.25	36 ± 43.35	28.43 ± 32.53	80 ± 34.64
		Terrestrial herbaceous cover	6.34 ± 9.45	2.5 ± 5	0	7.62 ± 8.92	7.2 ± 8.02	0
		Water spread on transect	Low	Medium	Low	Low	Low	Low
		Canopy cover	41.45 ± 20.44	8.28 ± 5.86	54.7 ± 19.55	35.82 ± 14.3	11.07 ± 5.76	1.61 ± 0.51

[a]*n*, number of temporal replicates.

Supplementary Tables S3 and S4). Our preliminary results regarding urban specialization in odonates are supported by natural history observations (Solimini et al. 1997; Subramanian and Sivaramakrishnan 2005; Ferreras-Romero et al. 2009; Kulkarni and Subramanian 2013). This study was limited to adult sampling, but sampling larvae can provide an accurate estimation of diversity (Koparde et al. 2019) and insights into the species–habitat relations. We sampled a relatively short stretch (~30 km) of the Mula River; therefore, we suspect that we might have missed the species turnover due to natural river zoning; hence, our results could be indicative of zoning solely due to urbanization. We recommend future sampling to include a long stretch of the river with a greater number of sampling sites, taking multiple temporal replicates over 2–3 years to capture seasonal variation. We also urge sampling adult as well as larval life stages to document diversity more comprehensively and accurately (Golfieri et al. 2016; Koparde et al. 2019). We recommend sampling predictors using a continuous scale instead of a categorical scale that we used in our sampling, as it is more accurate and objective.

Diversity and distribution of Pune odonates

Our short term, intensive sampling revealed a subset of odonate diversity recorded from Pune City. We captured 21.4% (15 of 70 species) of the known diversity during our sampling. Balewadi, a locality in the mid-urbanization zone, turned out to be the most diverse amongst the sampled localities (Table 2). Balewadi meets the criteria of intermediate disturbance locality amongst the sampled sites (Table 2). The moderate level of urbanization at the site is linked with the highest diversity amongst all the sites (Table 2). We suggest that this pattern can be explained using the IDH (Connell 1978). Similar results are reported from the African landscape (Stewart and Samways 1998) and New Zealand (Townsend et al. 1997). In both the studies, the authors found that Odonata diversity and richness were higher at moderately disturbed rivers and low at highly disturbed ones. The different habitat characteristics and river stability also interacted to give rise to this result. Possibly, a similar effect could be acting on a smaller scale, at the sites across the Mula River. Further studies on niche use, microhabitat preferences in riverside odonates along disturbance gradients are warranted to understand more about causal factors which lead to the trend of high diversity at the moderate disturbance. Following our observations, such studies may provide strong empirical support for IDH in urban riparian ecosystems.

Conservation implications

Our study elucidates the present status of urban riverine habitats in and around Pune and responses of odonates to urbanization, leading to partial site-wise exclusivity in some species. We noted several anthropogenic threats at the river, such as dumping of sewage, intensive logging and canalization. Although we recorded these factors as secondary data, specific future studies will be needed to investigate the effects of anthropogenic activities on urban tropical odonate ecology and behavior. Although it is hard to judge the cumulative impact of such activities on odonates, other research shows it might alter species composition (Stewart & Samways 1998, Monteiro-Júnior et al. 2014, Koparde 2016, Villalobos-Jiménez et al. 2016). Up to 30% loss of fish fauna (Wagh and Ghate 2002) and 31% loss of odonate fauna (Kulkarni and Subramanian 2013) within and around Pune emphasizes the fact that uncontrolled urbanization leads to rapid species losses. In Kulkarni and Subramanian (2013), the authors recorded 31% odonate fauna loss in 50 years (1960–2010) in and around Pune. This large decline was attributed to the rapid urbanization, river disturbances and other anthropogenic pressures that were measured using garbage buildup and land use. Contrarily, our study did not report significant differences in odonate compositions across sites along an urbanization gradient, possibly because of the short time scale of the study and lack of larval sampling. We found that high species diversity was associated with the site where local disturbances were at moderate levels, such as observed at Balewadi (Table 2).

Therefore, lessening the burden of anthropogenic pressure on water-bodies in highly populated built-up areas may help. Patches of conserved wetlands within the urban matrix can provide refuge to habitat specialists and rare species. Conservation of such areas can potentially harbor high diversity (Goertzen and Suhling 2013). Reducing the built-up around the freshwater bodies might sustain local odonate diversity if the built-up is kept at moderate or low levels. We think long-term monitoring of diversity and identification of areas with city conserved wetlands may boost our understanding of urban odonate biodiversity and ecosystem function.

Supplementary data

Supplementary data are available at *JUECOL* online.

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