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Habitat correlates of Odonata species diversity in the northern Western Ghats, India

Pankaj Koparde[1,2*], Prachi Mhaske[1] & Ankur Patwardhan[1]

[1] Department of Biodiversity, Abasaheb Garware College, Karve road, Pune-411004, Maharashtra, India

[2] Current address: Sálim Ali Centre for Ornithology & Natural History, Anaikatty (Post), Coimbatore-641108, Tamil Nadu, India;
* <pankajkoparde@gmail.com>

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Abstract. Sixty-two localities from Sahyadri Tiger Reserve, Maharashtra State, India, were surveyed for habitat correlates of Odonata diversity. Proximate habitat variables (canopy cover, area of water spread on transect, and altitude) and broad scale environmental variables derived from climate database were used. Seventy species were recorded during the survey. *Vestalis apicalis* was found to be the most abundant species. Multiple regression analysis failed to resolve relationship among variables. Proximate habitat variables, except altitude, showed slightly higher contribution in shaping species richness and diversity than broad-scale habitat variables. Canonical correspondence analysis based on species abundance data and multiple variables suggested that canopy cover and area of water on the transect are driving species assemblages. Almost all of the Western Ghats endemics recorded during the survey were found to be associated with high canopy forests and streams, suggesting the critical habitat requirement of these species. The study provides baseline and local habitat association data on Odonata, which can be used as evidence in the conservation of the Sahyadri Tiger Reserve corridor which is under threat of forest felling.

Key words. Dragonfly, Maharashtra, canopy cover, endemic, biodiversity, CCA, poisson multiple regression

Introduction

Odonata, being one of the most widely studied insect groups, has been well-documented in terms of its habitat requirements. Most Odonata are habitat sensitive (e.g., Subramanian 2005; Subramanian et al. 2008). Presence and/or absence of some species may indicate habitat health in terms of micro-habitat structure (e.g., Osborn & Samways 1996; Samways & Steytler 1996; Subramanian et al. 2008; Gómez-Anaya & Novelo-Gutiérrez 2010) and to some extent macro-habitat structure (Schindler et al. 2003;

Oppel 2005; Campbell et al. 2010; Dolný et al. 2011). Odonata species assemblages might vary depending upon habitat quality (Dijkstra & Lempert 2003; Schindler et al. 2003; Gómez-Anaya & Novelo-Gutiérrez 2010). Physical habitats are often dynamic and it is hard to depict them in quantitative terms, as not all the environmental variables can be measured. Although much descriptive literature on habitat/s of Odonata is available, few studies have conducted quantitative analyses of it. Such studies are important in detecting effect of habitat loss on Odonata. Few such studies have been used in conservation practices. Given this, it is highly important to determine local Odonata assemblage patterns and their habitat correlates.

The Western Ghats, a global biodiversity hotspot (Myers et al. 2000; Mittermeier et al. 2011), have a rich Odonata fauna that is relatively well-studied (Fraser 1933, 1934, 1936; Emiliyamma & Radhakrishnan 2000; Emiliyamma et al. 2005; Subramanian 2005, 2007; Subramanian & Sivaramkrishnan 2005; Ranganekar et al. 2010; Kulkarni et al. 2012; Kulkarni & Subramanian 2013; Subramanian et al. 2013; Koparde et al. 2014; Ranganekar & Naik 2014). A review by Subramanian (2007) has reported 176 species from Western Ghats, of which 68 are known to be endemic to the region. Despite this fact, the literature lacks articles on quantitative habitat association of Indian Odonata species, apart from a few research papers by Subramanian et al. (2005), Subramanian & Sivaramkrishnan (2005), Dinakaran & Anbalagan (2007), Subramanian et al. (2008), and Kulkarni & Subramanian (2013). The Western Ghats of Maharashtra State are characterized by highly fragmented forest cover. The fragmentation is increased by anthropogenic pressure (Gadgil et al. 2011). Studies pertaining to Odonata of Western Ghats of Maharashtra are scarce except for a few articles by Kulkarni et al. (2012), Kulkarni & Subramanian (2013) and Koparde et al. (2014). Species richness, diversity, and composition are likely to change in response to changes in environmental and habitat variables (e.g., Suh & Samways 2005; Flenner & Sahlén 2008). Most of the species endemic to Western Ghats are associated with closed forests and flowing water system (Subramanian et al. 2011). The habitat association of these species has been described by many (e.g., Fraser 1933, 1934, 1936; Subramanian 2005; Kiran & Raju 2013), in descriptive terms. Previous studies on stream insects in Western Ghats by Subramanian &

Sivaramkrishnan (2005) suggest that genus-level richness is affected by altitude, micro-habitat richness, canopy cover, number of dry months, and annual rainfall in various habitats such as cascades, riffles, and pools. In another study by Subramanian et al. (2005) on similar lines, only micro-habitat richness, canopy cover, and depth of water were found to have low correlation with genera richness. In a highly fragmented landscape, such as Western Ghats of Maharashtra, fine scale habitat variables (e.g., type of aquatic system, canopy cover, and elevation) may affect Odonata diversity more than broad-scale habitat variables (e.g., annual temperature and precipitation at the locality). Here, we hypothesize that these broad habitat variables may play a less important role in Odonata diversity than the aforementioned proximate habitat variables concerned with micro-habitat. In order to understand the effect of different environmental and habitat variables on Odonata diversity and assemblages, a study was carried out during 2011–2013. This paper investigates how the scale of habitat correlates influences Odonata diversity and species composition. We also explore if the descriptive literature on habitat association of endemic Odonata of Western Ghats can be tested in a systematic framework.

Methods

Study site

Although highly fragmented, the landscape of the northern Western Ghats retains some of the unique topographic features such as lateritic plateaux. The part of the northern Western Ghats that lies in Maharashtra State, India, is located roughly between 15°30'N to 20°30'N and 73°E to 74°E. Most of this landscape is under legal protection. The largest protected area is Sahyadri Tiger Reserve (Fig. 1), a 1,165 km² forested landscape that lies between 16°57'N to 17°49'N and 73°35'E to 73°54'E. The core area of the Sahyadri Tiger Reserve (STR) is 600.12 km² and the buffer zone is 565.45 km². It is spread across four districts, namely Satara, Sangli, Kolhapur, and Ratnagiri. The forest type of the core area is primarily evergreen, semi-evergreen, and moist deciduous forest; whereas that of the buffer area is primarily dry deciduous, and scrubland. Koyna wildlife sanctuary and Chandoli national park are protected areas within the Reserve, situated on the banks of Shivsagar and Vasantsagar water reservoirs respectively. The Reserve also supports many inland freshwater habitats suitable for Odonata including streams, ponds, puddles, and marshes. The bioclimate of the region is not uniform given the topography of the landscape. The vegetation structure changes from evergreen, moist-deciduous forest patches in the core area to dry-deciduous, scrub-forest in the buffer area. The annual temperature ranges from 13°C to 35°C. Annual mean precipitation is 178 mm. The study area experiences three distinct seasons: Summer (February–May; mean temperature 26°C, mean precipitation 24 mm); Monsoon (June–October; mean temperature 22°C, mean precipitation 497 mm), and Winter (November–January; mean temperature 22°C, mean precipitation 16 mm) (Hijmans et al. 2005). The post-monsoon season (November–March) is the best season to observe Odonata in the field, in India (Subramanian 2005; Nair 2011).

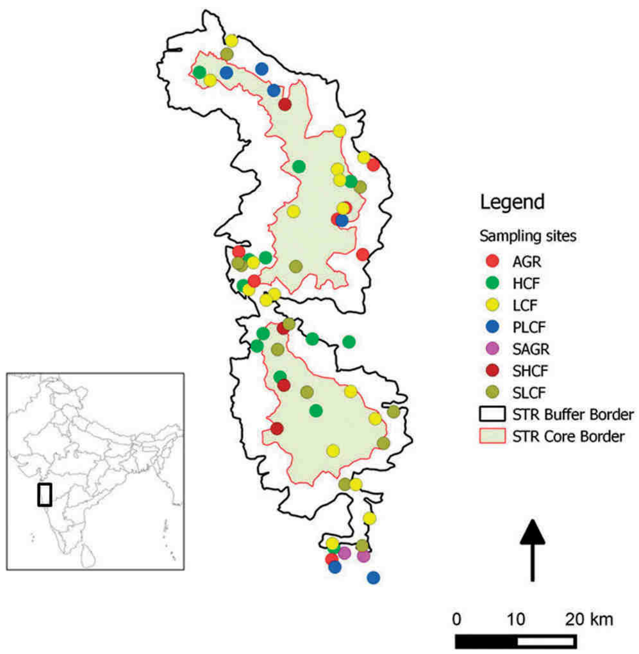

Figure 1. Map of the study area 'Sahyadri Tiger Reserve' (STR) and localities surveyed in northern Western Ghats, Maharashtra State, India (www.diva-gis.org/docs). Abbreviations used for the sampled forest-wetland systems are given in Table 1.

Sampling and data collection

Sampling was carried out during the post-monsoon season (September–March), when Odonata activity is at its peak. Belt transects of 500 × 10 m were used to survey Odonata. An 8×40 (magnification × lens diameter) binocular was used to observe Odonata. Records other than on transects were noted separately. Odonata were identified using field-guides (Subramanian 2005; Nair 2011) and taxonomic monographs (Fraser 1933, 1934, 1936). The recorded species were listed according to the classification by Dijkstra et al. (2013) and Subramanian (2014). Area of water spread and canopy cover on transect were measured on a 0–10 scale, 0 being absence. Area of water spread on transect was estimated by observing the proportion of area of water spread with respect to total area of transect. The position of transect differed for different wetland systems. For instance, for streams and marshes, the transect passed through the stream; whereas for ponds and reservoirs, the transect was placed on the shore. Canopy cover was measured at intervals of 50 m, on a 500 m transect, giving 11 survey points. The mode value of canopy cover was used for further analysis. Transects with more than 30 % (more than 3 on 0–10 scale) of area of water spread were considered to be wetland systems, which were further classified as pond/reservoir/stream. Transects with average canopy cover of 40 % or more (equal or greater than 4 on 0–10 scale) were considered as closed forest systems. We created new variables by combining canopy cover and wetland systems. Each locality was defined based on these variables. These new variables are representative of forest-wetland systems. Table 1 summarizes the forest-wetland systems. In the present study, there were no areas in which we could find pond/reservoir in high canopy forest. Sixty-two localities from STR were studied for Odonata diversity and habitat correlates (Tab. 2). Sampling sites were selected randomly covering the entire STR landscape and major wetland systems. The data on mean annual precipitation, mean summer precipitation, mean monsoon precipitation, mean winter precipitation, mean annual temperature, mean summer temperature, mean monsoon temperature, mean winter temperature, mean temperature of driest quarter, and mean precipitation of driest quarter were obtained from WorldClim database at 30’ resolution (1 km² grid) (Hijmans et al. 2005). The data on altitude was collected in the field using a Garmin Map 60CSx GPS. For convenience, all

Table 1. Forest-wetland systems. FWS – Forest-wetland system; AWST – Area of water spread on transect; CC – Canopy cover

FWS	Abbre-viation	AWST	CC	Forest type	Wetland type
Low Canopy Forest	LCF	< 30 %	< 40 %	scrub-land/moist-deciduous forest	NULL
Agriculture	AGR	< 30 %	< 40 %	agriculture (paddy field)	NULL
High Canopy Forest	HCF	< 30 %	> 40 %	moist-deciduous/ semi-evergreen forest	NULL
Streams in low canopy forest	SLCF	> 30 %	< 40 %	agriculture/scrub-land/ moist-deciduous forest	stream
Streams in agriculture	SAGR	> 30 %	< 40 %	agriculture	stream
Streams in high canopy forest	SHCF	> 30 %	< 40 %	Moist-deciduous/ semi-evergreen forest	stream
Pond/reservoir in low canopy forest	PLCF	> 30 %	< 40 %	Agriculture/scrub-land/ moist-deciduous forest	pond/ reservoir

the variables have been divided into three sets: a) proximate habitat variables include canopy cover, area of water spread on transect and altitude; b) broad-scale habitat variables were extracted from WorldClim database; c) forest-wetland systems.

Data analysis

For all statistical analyses R software v3.1.1 and PAST v3.2 (Hammer et al. 2001) were used. For Chao1 and Chao2 estimates of species richness, EstimateS 9.1.0 (Colwell 2013) was used. This measure provides the best estimate of species richness (e.g., Colwell & Coddington 1994; Walther & Morand 1998; Walther & Martin 2001; Chao 2004). Simpson's diversity index, Fisher's alpha index, relative abundance, and relative frequency were calculated. Each species was assigned an occurrence value based on percentage frequency. A Poisson multiple regression analysis was used to determine drivers of diversity. For this, proximate and broad-scale habitat variables were used. As variables derived from climate database are often correlated, a Kendall's tau correlation analysis was carried out. Variables that were highly correlated ($\tau > 0.8$ or $\tau < -0.8$ at $p < 0.01$) were discarded. We

Table 2. Localities in Sahyadri Tiger Reserve, northern Western Ghats, Maharashtra State, India. surveyed during 2011-2013. FWS – Forest wetland systems; SF – Surrounding forest; KC – Koyna WLS core area; KB – Koyna WLS buffer area; CNC – Chandoli NP core area; CNB – Chandoli NP buffer area; SCRB – Scrubland; AGR – Agriculture (paddy field); SEVG – Semi-evergreen forest; MDCD – Moist-deciduous forest.

Locality	Latitude	Longitude	FWS	SF	PA	AWST	CC
Adoshi	17.699	73.706	PLCF	SCRB	KC	6	0
Akalpe	17.733	73.687	PLCF	SCRB	KC	6	0
Amba 1	16.966	73.818	SAGR	AGR	CNB	5	0
Amba 2	16.97457	73.801221	HCF	SEVG	CNB	0	7
Amba 3	16.981	73.799	LCF	SCRB	CNB	0	0
Arav	17.727	73.631	PLCF	SCRB	KC	6	0
Atoli	17.30535	73.767214	HCF	MDCD	CNB	0	8
Bahe	17.30061	73.825293	HCF	MDCD	CNB	3	9
Chalakewadi 1	17.581	73.864	AGR	SCRB	KB	3	0
Chalakewadi 2	17.546	73.843	SLCF	SCRB	KB	5	1
Chandel	17.16331	73.711052	SHCF	SEVG	CNC	5	8
Dhopeshwar	16.927	73.864	PLCF	SCRB	CNB	5	0
Golivane	17.021	73.858	LCF	SCRB	CNB	2	0
Jholambi	17.179	73.867	LCF	SCRB	CNC	0	0
Kalambe	17.075	73.819	SLCF	MDCD	CNB	7	3
Kasani	17.19	73.896	SLCF	SCRB	CNB	7	0
Kathi 1	17.495	73.807	AGR	SCRB	KB	2	0
Kathi 2	17.493	73.814	PLCF	SCRB	KB	5	0
Katrewadi 1	17.6348	73.8104	LCF	SCRB	KB	2	0
Kemse 1	17.38966	73.657781	HCF	MDCD	KB	0	4
Kemse 2	17.38339	73.666205	LCF	SCRB	KB	0	1
Kharoshi	17.77756	73.639083	LCF	SCRB	KC	0	0
Kolne 1	17.32225	73.721077	SHCF	SEVG	CNC	3	7
Kolne 2	17.329	73.73	SLCF	SCRB	CNC	3	0
Kumbharli 1	17.397	73.675	AGR	AGR	KB	0	0
Kumbharli 2	17.37593	73.706932	LCF	SCRB	KB	0	0
Male 1	17.31381	73.689008	HCF	MDCD	CNC	0	6
Male 2	17.2886	73.7121	SLCF	SCRB	CNC	4	0

Locality	Latitude	Longitude	FWS	SF	PA	AWST	CC
Mandur 1	17.14	73.88	SLCF	AGR	CNB	7	3
Manoli 2	16.956	73.798	AGR	SCRB	CNB	1	3
Manoli	16.944	73.803	PLCF	SCRB	CNB	5	2
Metindoli	17.67682	73.723697	SHCF	MDCD	KC	3	4
Navja	17.42	73.741	SLCF	SEVG	KB	5	2
Nechal	17.367	73.694	LCF	SCRB	KB	0	0
Paneri	17.222	73.828	LCF	MDCD	CNC	0	1
Patharpunj	15.95104	74.0001	HCF	SEVG	CNC	0	7
Pophali 1	17.44329	73.650413	AGR	SCRB	KB	2	0
Pophali 2	17.43074	73.667042	HCF	MDCD	KB	0	5
Pophali 3	17.42192	73.654726	SLCF	SCRB	KB	5	0
Rundiv	17.24483	73.71603	HCF	SEVG	CNC	2	7
Saatar	17.221	73.758623	SLCF	SCRB	CNB	5	0
Siddheshwar	17.19156	73.773	HCF	SEVG	CNC	0	7
Sonpatra 1	17.43396	73.693199	HCF	MDCD	KB	0	6
Sonpatra 2	17.42641	73.67334	LCF	SCRB	KB	1	0
Tanali	17.128	73.8	LCF	SCRB	CNC	2	0
Thoseghar	17.593	73.849	LCF	SCRB	KB	0	0
Thoseghar S1	17.574	73.807	LCF	SCRB	KB	1	0
Thoseghar S21	17.513	73.82	AGR	SCRB	KB	2	0
Thoseghar S22	17.512	73.816	LCF	SCRB	KB	2	0
Uchat	17.75652	73.631744	SLCF	SCRB	KB	5	2
Udgiri	17.07479	73.836064	LCF	SCRB	CNB	0	0
Vakoli 1	16.96138	73.848435	SAGR	AGR	CNB	4	0
Vakoli 2	16.97756	73.846364	SLCF	MDCD	CNB	4	2
Valvan 1	17.72765	73.588185	HCF	MDCD	KC	0	7
Valvan 2	17.715	73.605325	LCF	SCRB	KC	1	3
Vashishti Dam	17.4256	73.649428	SLCF	SCRB	KB	4	1
Vatole	17.439	73.847	AGR	SCRB	KB	2	0
Velhe 1	17.55484	73.828	HCF	MDCD	KC	0	5
Velhe 2	17.557	73.811	LCF	MDCD	KC	0	0
Vetti	17.232	73.722	SHCF	MDCD	CNC	4	4
West Kusawade	17.5071	73.737405	LCF	SCRB	KC	3	2
West Velhe	17.57833	73.7459	HCF	MDCD	KC	0	7

ran twelve Poisson multiple regression models to check the effect of various variables on Simpson's diversity index and Fisher's alpha index. These models include proximate and broad-scale habitat variables in combination, as well as in separate analyses. The significance of each model was tested using a goodness of fit test. If the test is statistically significant, it suggests that the data does not fit the model. A canonical correspondence analysis (CCA) was performed on species abundance data and all variable datasets. A Monte-Carlo permutation test ($n = 10{,}000$) was performed on CCA for significance testing. A cluster analysis using the Bray-Curtis algorithm was carried out with 10,000 bootstraps to understand overlap and uniqueness of species between different forest-wetland systems in terms of species composition.

Results

Diversity and distribution of Odonata of Sahyadri Tiger Reserve

A total of 70 species of Odonata belonging to 45 genera and ten families represented by 1,215 individuals was recorded during the survey. 64 species were recorded on transects. 43 species belonged to the suborder Anisoptera, and 27 species belonged to the suborder Zygoptera. Table 3 summarizes the records. The Chao1 estimate of species richness ranged from 64–114 and Chao2 ranged from 67–140. *Vestalis apicalis* Selys, 1873 was found to be the most abundant species followed by *Trithemis aurora* (Burmeister, 1839) and *Pantala flavescens* (Fabricius, 1798) (Tab. 3). *Diplacodes trivialis* (Rambur, 1842) was the most widespread species in the study area followed by *P. flavescens* and *Trithemis festiva* (Rambur, 1842). The most diverse locality for Odonata fauna was Vakoli 1, followed by Uchat and Male 2.

Effect of habitat variables on Odonata diversity and species richness

In a preliminary correlation analysis on multiple variables, mean temperature and precipitation of summer, monsoon, winter, and driest quarter were discarded. Altitude and mean annual temperature were highly negatively correlated ($\tau = -0.96814$, $p = 0.00000001$), therefore effect of altitude was checked separately and all the analyses were re-run substituting altitude in place of mean annual temperature. Table 4 summarizes output of models 1–12.

Table 3. Check-list of Odonata recorded during this survey in Sahyadri Tiger Reserve, northern Western Ghats, Maharashtra State, India. Abbreviations used for the sampled forest-wetland systems are given in Table 1. RA – Relative abundance; Oc – Local occurrence calculated from relative frequency; * – Recorded off transect; # – Endemic to Western Ghats (Subramanian 2007); R – Rare; FC – Fairly common; C – Common; UC – Uncommon; X – presence.

No	Taxon	RA	Oc	Hcf	Shcf	Lcf	Slcf	Plcf	Agr	Sagr
Lestidae Calvert, 1901										
1	*Lestes elatus* Hagen in Selys, 1862	0.0016	R			X				
2	*Lestes umbrinus* Selys, 1891	0.0016	R				X	X		
Platystictidae Kennedy, 1920										
3	*Protosticta hearseyi* Fraser, 1922#	0.0091	R	X	X					
Calopterygidae Selys, 1850										
4	*Vestalis apicalis* Selys, 1873	0.0857	FC	X	X	X	X			
5	*Vestalis gracilis* (Rambur, 1842)	0.0016	FC	X		X	X	X		
Chlorocyphidae Cowley, 1937										
6	*Libellago lineata* (Burmeister, 1839)	0.0016	R			X	X			
7	*Heliocypha bisignata* Hagen in Selys, 1853	0.0272	FC		X	X	X	X		
Euphaeidae Yakobson & Bianchi, 1905										
8	*Euphaea fraseri* (Laidlaw, 1920)#	0.0124	R		X					
Platycnemididae Yakobson & Bianchi, 1905										
9	*Copera marginipes* (Rambur, 1842)	0.0247	FC				X	X		X
10	*Copera vittata* Selys, 1863	0.0033	R				X			
11	*Caconeura ramburi* (Fraser, 1922)#	0.0058	UC	X	X					
12	*Disparoneura quadrimaculata* (Rambur, 1842)	0.0198	FC		X	X	X		X	X
13	*Elattoneura nigerrima* (Laidlaw, 1917)	0.0041	R				X			X
14	*Prodasineura verticalis* (Selys, 1860)	0.0058	UC				X			X
Coenagrionidae Kirby, 1890										
15	*Aciagrion hisopa* (Selys, 1876)	0.014	UC			X	X	X		X
16	*Aciagrion occidentale* Laidlaw, 1919	0.0049	R				X			
17	*Aciagrion pallidum* Selys, 1891	0.0025	UC	X	X		X			
18	*Agriocnemis pygmaea* (Rambur, 1842)	0.0066	UC				X	X	X	
19	*Agriocnemis splendidissima* Laidlaw, 1919	0.066	FC			X	X	X		X
20	*Ceriagrion coromandelianum* (Fabricius, 1798)	0.0008	R				X			

No	Taxon	RA	Oc	Hcf	Shcf	Lcf	Slcf	Plcf	Agr	Sagr
21	*Ceriagrion olivaceum* Laidlaw, 1914	0.0041	UC	X			X			
22	*Ischnura aurora* (Brauer, 1865)	0.0016	R						X	X
23	*Ischnura senegalensis* (Rambur, 1842)*							X	X	X
24	*Pseudagrion decorum* (Rambur, 1842)*							X		
25	*Pseudagrion indicum* Fraser, 1924#	0.0016	R							X
26	*Pseudagrion microcephalum* (Rambur, 1842)	0.0041	UC				X	X		X
27	*Pseudagrion rubriceps* Selys, 1876	0.0412	FC				X	X		X
	Aeshnidae Leach, 1815									
28	*Anax guttatus* (Burmeister, 1839)	0.0008	R						X	
29	*Anax immaculifrons* Rambur, 1842	0.0115	FC	X	X	X	X	X	X	
30	*Gynacaha bayadera* Selys, 1891	0.0066	FC	X	X		X		X	
31	*Gynacaha dravida* Lieftinck, 1960*	0.0016	R		X			X		
	Gomphidae Rambur, 1842									
32	*Gomphidia kodaguensis* Fraser, 1923#	0.0008	R			X				
33	*Heliogomphus promelas* (Selys, 1873)#	0.0008	R	X						
34	*Ictinogomphus rapax* (Rambur, 1842)*						X	X		
35	*Paragomphus lineatus* (Selys, 1850)	0.0016	R			X	X		X	
	Macromiidae Needham, 1903									
36	*Epophthalmia vittata* Burmeister, 1839	0.0016	R			X	X			
37	*Macromia* spp. Rambur, 1842	0.0025	R		X					
	Libellulidae Leach, 1815									
38	*Acisoma panorpoides* Rambur, 1842	0.0016	R							X
39	*Brachythemis contaminata* (Fabricius, 1793)	0.0033	R			X	X			
40	*Bradinopyga geminata* (Rambur, 1842)	0.0107	FC	X	X	X	X			
41	*Cratilia lineata* Förster, 1903	0.0091	FC	X	X	X	X			
42	*Crocothemis servilia* (Drury, 1770)	0.0346	C	X		X	X	X	X	X
43	*Diplacodes trivialis* (Rambur, 1842)	0.0816	C	X		X	X	X	X	X
44	*Hylaeothemis indica* Fraser, 1946	0.0008	R	X						
45	*Idionyx* spp. Hagen, 1867	0.0008	R	X						
46	*Indothemis carnatica* (Fabricius, 1798)	0.0016	R			X		X		
47	*Lathrecista asiatica* (Fabricius, 1798)	0.1402	FC	X	X	X	X		X	
48	*Neurothemis fulvia* (Drury, 1773)	0.0157	FC	X	X	X	X	X		
49	*Neurothemis intermedia* (Rambur, 1842)	0.0239	FC	X	X	X	X	X		
50	*Neurothemis tullia* (Drury, 1773)	0.0016	R				X			

No	Taxon	RA	Oc	Hcf	Shcf	Lcf	Slcf	Plcf	Agr	Sagr
51	*Onychothemis testacea* Laidlaw, 1902*				X					
52	*Orthetrum chrysis* (Selys, 1891)*						X			
53	*Orthetrum glaucum* (Brauer, 1865)	0.0132	FC				X			X
54	*Orthetrum luzonicum* (Brauer, 1868)	0.0107	FC				X	X	X	X
55	*Orthetrum pruinosum* (Burmeister, 1839)	0.042	FC		X	X	X	X	X	X
56	*Orthetrum sabina* (Drury, 1770)	0.0313	C			X	X	X	X	X
57	*Orthetrum taeniolatum* (Schneider, 1845)	0.0322	FC			X	X	X		
58	*Orthetrum triangulare* (Selys, 1878)*			X						
59	*Palpopleura sexmaculata* (Fabricius, 1787)	0.0033	UC				X			
60	*Pantala flavescens* (Fabricius, 1798)	0.0816	C			X	X	X	X	X
61	*Potamarcha congener* (Rambur, 1842)	0.0025	UC			X			X	X
62	*Rhodothemis rufa* (Rambur, 1842)	0.0008	R			X				
63	*Tholymis tillarga* (Fabricius, 1798)	0.0041	UC	X			X			
64	*Tramea basilaris* (Palisot de Beauvois, 1807)	0.0049	UC	X		X	X		X	
65	*Tramea limbata* (Desjardins, 1832)	0.0049	UC			X	X	X	X	X
66	*Trithemis aurora* (Burmeister, 1839)	0.0824	C		X	X	X	X	X	X
67	*Trithemis festiva* (Rambur, 1842)	0.0684	C		X	X	X	X	X	X
68	*Trithemis kirbyi* Selys, 1891	0.0074	UC				X	X		X
69	*Trithemis pallidinervis* (Kirby, 1889)	0.0008	R			X				
70	*Zygonyx iris* Kirby, 1869	0.0016	R		X					

Effect of habitat variables on Odonata species assemblage

The CCA was statistically significant based on Monte Carlo permutation test ($n = 10000$) at $p = 0.001$ for the first two axes. Axis 1 and axis 2 captured 31.48 % and 14.96 % of variation in data respectively. Area of water spread on transect and canopy cover exerted strongest influence on first two axes (Tab. 5). Axis 1 was influenced by canopy cover and axis 2 by area of water spread on transects (Fig. 2). The Bray-Curtis cluster analysis was supported by a cophenetic correlation coefficient of 0.9103. It showed that closed forest localities form a separate group in terms of species composition with respect to other localities. Within low canopy forest areas, streams in low canopy forest areas form a separate group (Fig. 3).

Table 4. Poisson multiple regression models. SPRICH – Species richness; AWST – Area of water spread on transect; CC – Canopy cover; PPT – Annual mean precipitation; TEMP – Annual mean temperature; ALT – Altitude; SDI – Simpson's diversity index; FAI – Fisher's alpha index.

No	Model	Goodness of fit test	Model fits data	Results
1	SPRICH ~ AWST + CC + PPT + TEMP	p = 0.004	NO	effect of AWST and CC at p < 0.05
2	SPRICH ~ AWST + CC + PPT + ALT	p = 0.003	NO	effect of AWST and CC at p < 0.05
3	SPRICH ~ AWST + CC + ALT	p = 0.003	NO	effect of AWST and CC at p < 0.05
4	SPRICH ~ PPT + TEMP	p < 0.001	NO	effect of PPT at p < 0.05
5	SDI ~ AWST + CC + PPT + TEMP	p = 1	YES	No significant effect of any variables
6	SDI ~ AWST + CC + PPT + ALT	p = 1	YES	No significant effect of any variables
7	SDI ~ AWST + CC + ALT	p = 1	YES	No significant effect of any variables
8	SDI ~ PPT + TEMP	p = 1	YES	No significant effect of any variables
9	FAI ~ AWST + CC + PPT + TEMP	p < 0.001	NO	effect of AWST and CC at p < 0.001
10	FAI ~ AWST + CC + PPT + ALT	p < 0.001	NO	effect of AWST and CC at p < 0.001
11	FAI ~ AWST + CC + ALT	p < 0.000001	NO	effect of AWST and CC at p < 0.001
12	FAI ~ PPT + TEMP	p < 0.001	NO	No significant effect of any variables

Table 5. Values for axis 1 and 2 of different variables obtained in canonical correspondence analysis.

Variables	Description	Axis 1	Axis 2
AWST	Area of water spread on transect	-0.31505	-0.46876
Canopy cover	Canopy cover	0.908706	-0.2412
ALT	Altitude in meters	0.063418	0.324567
PPT	Mean annual precipitation in mm	0.199895	-0.08853

Variables	Description	Axis 1	Axis 2
TEMP	Mean annual temperature in degree celsius	-0.08561	-0.31314
PLCF	Pond/reservoir in low canopy forest	-0.22914	0.031612
SAGR	Stream in agriculture (paddyfield)	-0.13576	-0.19749
HCF	High canopy forest	0.771148	-0.12779
SHCF	Stream in high canopy forest	0.291415	-0.16173
SLCF	Stream in low canopy forest	-0.26073	-0.48257
AGR	Agriculture (paddyfield)	-0.23825	0.170657
LCF	Low canopy forest	-0.25416	0.559464
AH	*Aciagrion hisopa*	-0.17007	-1.17183
AO	*Aciagrion occidentale*	-0.88573	-1.08728
AP	*Aciagrion pallidium*	0.840023	-0.53094
APan	*Acisoma panorpoides*	-0.7317	-1.64806
Apyg	*Agriocnemis pygmya*	-0.81358	0.161933
AS	*Agriocnemis splendidissima*	-0.3866	-1.28271
AG	*Anax guttatus*	-0.8209	2.06463
AI	*Anax immaculifrons*	-0.11968	-0.13052
BC	*Brachythemis contaminata*	-0.41514	1.87693
BG	*Bradinopyga geminata*	-0.12105	0.04665
CR	*Caconeura ramburi*	2.90255	-0.19429
CC	*Ceriagrion coromandelianum*	-0.11607	-2.02898
CO	*Ceriagrion olivaceum*	1.35895	-0.64487
CM	*Copera marginipes*	-0.51656	-1.55066
CV	*Copera vittata*	1.62109	-0.50493
CL	*Cratilla lineata*	1.71031	0.28603
CS	*Crocothemis servilia*	-0.36506	0.113149
DT	*Diplacodes trivialis*	-0.596	1.79608
DQ	*Disparoneura quadrimaculata*	-0.54781	-0.91932
EN	*Elattoneura nigerrima*	-0.77748	-1.64685
EV	*Epophthalmia vittata*	-0.47128	1.04956
EF	*Euphaea fraseri*	2.20991	-0.47546
GK	*Gomphidia kodaguensis*	0.319412	2.31644
GB	*Gynacantha bayadera*	1.45126	0.034593
GD	*Gynacantha dravida*	0.136866	-0.01031
HP	*Heliogomphus promelas*	3.11169	-0.21512
HI	*Hylaeothemis indica*	3.11169	-0.21512
Isp	*Idionyx* sp.	3.11169	-0.21512

Variables	Description	Axis 1	Axis 2
IC	*Indothemis carnatica*	-0.77581	1.4425
IA	*Ischnura aurora*	-0.76071	1.36924
LA	*Lathrecista asiatica*	1.35767	0.243602
LE	*Lestes elatus*	-0.25383	3.21404
LU	*Lestes umbrinus*	-0.58309	-0.53566
LL	*Libellago lineata*	-0.42904	-0.03508
Msp	*Macromia* sp.	2.13695	-0.408
NF	*Neurothemis fulvia*	0.422692	-0.26085
NI	*Neurothemis intermedia*	0.09702	-0.20195
NT	*Neurothemis tullia*	0.154605	-1.6177
OG	*Orthetrum glaucum*	-0.05074	0.552532
OL	*Orthetrum luzonicum*	-0.68201	-0.47811
OP	*Orthetrum pruinosum*	-0.53654	0.245645
OS	*Orthetrum sabina*	-0.62998	0.286743
OT	*Orthetrum taeniolatum*	-0.59983	1.01873
PS	*Palpopleura sexmaculata*	-0.32919	-1.73163
PF	*Pantala flavescens*	-0.5233	1.5364
PL	*Paragomphus lineatus*	-0.69852	-1.84859
PC	*Potamarcha congener*	-0.41571	0.913003
PV	*Prodasineura verticalis*	-0.62318	-1.45403
PH	*Protosticta hearseyi*	2.84585	-0.26773
PI	*Pseudagrion indicum*	-0.7317	-1.64806
PM	*Pseudagrion microcephalum*	-0.20332	-1.21093
PR	*Pseudagrion rubriceps*	-0.67421	-1.20751
RB	*Rhinocypha bisignata*	0.007045	-0.86936
RR	*Rhodothemis rufa*	-0.50573	2.84
TT	*Tholymis tillarga*	0.500541	-0.4299
TB	*Tramea basilaris*	0.356902	1.18236
TL	*Tramea limbata*	-0.49017	0.972019
TA	*Trithemis aurora*	-0.63741	-0.47091
TF	*Trithemis festiva*	-0.56165	-0.60919
TK	*Trithemis kirbyi*	-0.76246	-1.42525
TP	*Trithemis pallidinervis*	-0.54835	2.68694
VA	*Vestalis apicalis*	2.20657	0.249879
VG	*Vestalis gracilis*	1.31079	-0.06045
ZI	*Zygonyx iris*	1.26974	-0.30099

Discussion

The taxonomy and natural history of the Odonata of India is well known, but few studies from India have focused on quantitative habitat correlates of diversity and habitat associations. Species diversity and composition are likely to change with respect to changes in micro-habitat and other environmental variables. Detecting the relation between variables that might affect species presence is crucial to understand gain or loss of species diversity and to answer which species might get affected the most if environment or habitat changes. This becomes important if species in question are endemic or threatened. During this study, we were interested to know, given a set of environmental variables, which variables might affect diversity and species composition the most. All the localities in the study area were apparently non-polluted, and are difficult to reach by roads. Therefore, the influence of anthropogenic disturbance on all the sampling sites was either absent or minimal. Most of the sampling was done in the post-monsoon season, when Odonata activity is at its peak. The observed number of species, i.e., 70, falls between the expected range of Chao1 (n = 64–114) and Chao2 (n = 67–

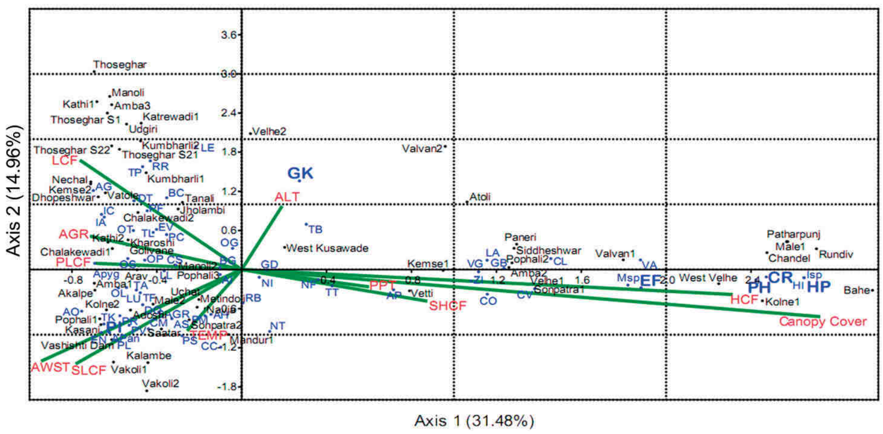

Figure 2. Canonical correspondence analysis (CCA) on species assemblage and multiple habitat variables in Sahyadri Tiger Reserve, northern Western Ghats, Maharashtra State, India. Table 5 lists abbreviations used in CCA diagram. Text in blue colour shows species. Text in bold blue colour shows species endemic to Western Ghats. Text in red colour shows habitat variables.

140), suggesting that the study successfully recorded a near complete list of Odonata in the study area. We recorded one species which was not previously known from Maharashtra State namely, *Gomphidia kodaguensis* Fraser, 1923, which is known from central and southern Western Ghats (Goa, Karnataka, and Kerala; Ranganekar & Naik 2014). A single specimen was observed at Valvan. During the study we also obtained multiple records of *Elattoneura nigerrima* (Laidlaw, 1917), *Onychothemis testacea* Laidlaw, 1902, and *Zygonyx iris* Kirby, 1869, which are under-recorded from the northern Western Ghats (Fraser 1933; Babu et al. 2013; Koparde et al. 2014).

The Poisson multiple regression analysis on species richness (models 1–4, table 4) indicate effect of canopy cover, area of water spread on transect, and annual mean precipitation, but not all the predicted models had a good fit to the data. Models based on Simpson's diversity index (models 5–8, table 4) were statistically significant (models fitted data), but did not show any effect of variables on the diversity index. The regression analysis on Fisher's alpha index (models 9–12) showed that canopy cover and area of water spread on transect are affecting diversity index values; however the models did not

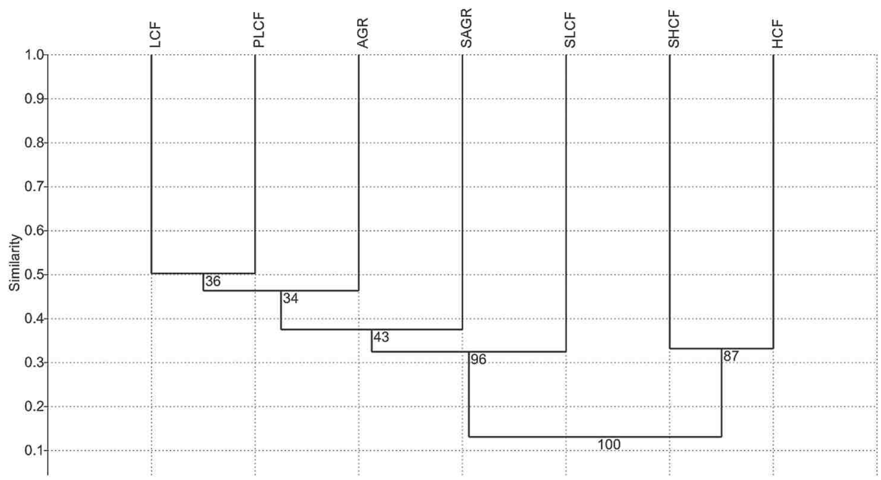

Figure 3. Cluster analysis based on Odonata species assemblages in Sahyadri Tiger Reserve, northern Western Ghats, Maharashtra State, India. Nodal values show bootstrap support out of 100. Abbreviations used are derived from Table 1.

have a good fit to the data. To check the effect of broad-scale habitat variables, i.e., mean annual temperature and precipitation, and proximate habitat variables, i.e., canopy cover, area of water spread on transect, and altitude, we carried out the analyses in combination as well as separately. In all the analyses, there was no statistical significance relating the variables to diversity index or species richness. Diversity and species richness indices summarize abundance and species number data in a single value. As different species may respond differently to changes in environment, summarizing them in a single variable may result in loss of data. This might be the reason behind failure of the multiple regression analysis to identify any significant variables. The multiple regression analysis shows that all the proximate habitat variables, except altitude, influence species richness and diversity as compared to broad-scale environmental variables in the study area. However, in all these models we did not find a case where the model fitted the data and the variables in the model showed statistically significant effect on dependent variables. Subramanian & Sivaramkrishnan (2005) and Subramanian et al. (2005) found that altitude, micro-habitat complexity, canopy cover, number of dry months, and annual rainfall were driving diversity and distribution of stream insect communities in Kudremukh national park, Western Ghats. In their studies, mean annual temperature did not show a significant correlation with diversity and distribution of aquatic insects. In the present study, we did not find correlation between mean annual temperature and diversity and species richness of Odonata, but could recover weak effect of canopy cover. Further, we found a weak effect of area of water spread on transect on diversity and species richness of Odonata. Subramanian & Sivaramkrishnan (2005) and Subramanian et al. (2005) looked at aquatic insect communities and present study restricts to Odonata. This might limit the power of comparison of results obtained.

To explore the effect of different habitat variables on species composition, we performed canonical correspondence analysis. CCA revealed that canopy cover and area of water spread on transect are driving species composition, as compared to other variables (Fig. 2; Tab. 5). Proximate habitat variables, except altitude, were found to be major driver for changes in species assemblages. Oppel (2005) reports that shading, water speed and water permanence affected Odonata species assemblages in a study done at Papua New Guinea. Oppel (2005) measured shading in terms of percent of shade on water body, which is analogous but not same as that of canopy cover. Most of the Western Ghats endemic species recorded during the survey were found to be associated with high canopy cover, high canopy forests, and streams in high canopy forests (Fig. 2). Bray-Curtis cluster analysis (Fig. 3) also showed a similar trend with high canopy forests having very low similarity in species composition as compared to other forest-wetland systems. The pattern of Western Ghats endemic species associated with dense forests has been discussed by Fraser (1933, 1934, 1936), Subramanian et al. (2011), and Kiran & Raju (2013). Similar studies from Mt. Hamiguitan wildlife sanctuary in the Philippines by Villanueva & Mohagan (2010) has reported that dense montane forests showed high number of species endemic to Mindanao as compared to other forest types.

Although lot of descriptive literature on habitat association of Indian Odonata is available, quantitative testing of the same has not been attempted before. In the present study, we found a similar habitat association of species from Western Ghats of Maharashtra, as described in literature. Most of endemic species recorded in the study were found to be associated with high canopy cover and streams. According to Subramanian et al. (2011), endemic Odonata of Western Ghats are mostly found in riverine habitats such as montane streams and rivers. Western Ghats endemics like *Protosticta hearseyi* Fraser, 1922 and *Euphaea fraseri* (Laidlaw, 1920) are known to inhabit montane streams in dense forests (Fraser 1933, 1934, 1936; Subramanian 2005; Nair 2011). *Heliogomphus promelas* (Selys, 1873) and *Caconeura* sp. occur in good water and forest quality (Nair 2011). Most of the localities in which these species were recorded were either semi-evergreen or moist-deciduous forests. Species, other than those endemic to Western Ghats, showed consensus in their habitat association as described in literature and observed during the present study. For instance *Lestes elatus* Hagen in Selys, 1862, is known to inhabit ponds or lakes (Subramanian 2005; Nair 2011) in scrub jungles during the post-monsoon and drier season (Fraser 1933). Similarly, *Indothemis carnatica* (Fabricius, 1798) is known to inhabit heavily weeded ponds and lakes. During our study, we found both these species near ponds with low or no canopy cover (Fig. 2).

In the present study we considered only three proximate habitat variables viz. canopy cover, area of water spread on transect and altitude, which may not represent overall effect of all the proximate habitat variables such as water quality, water flow-rate, substrate structure, and vegetation structure in combination, on species assemblage. Adding more continuous habitat variables to the analysis may be more informative on the effect of habitat change on Odonata diversity.

The tiger corridor between Koyna wildlife sanctuary and Chandoli national park is highly fragmented in terms of forest cover. Most of the new records were observed in Bahe, Atoli, and Kolne 1 localities, all of which fall in the corridor area. Other than these areas, Chandel and Rundiv locality of Chandoli national park (Fig. 1) were found to be rich in endemic species. The corridor area has smaller patches of forest, which are under high pressure of wood-cutting by local villagers. Developmental activities such as wind-mills and road widening were observed to be the causal agents of habitat disturbance. Studies have shown that anthropogenic disturbances can have detrimental effects on Odonata species (Martins 2009; Villanueva & Mohagan 2010) or may affect species assemblage (Dinakaran & Anbalagan 2007; Reece & McIntyre 2009; Kulkarni & Subramanian 2013). Subramanian et al. (2011) points towards agricultural pollution and urban and industrial development as the major threats to the Odonata fauna of Western Ghats. Many endemic species are narrowly distributed across Western Ghats, occurring in only small patches of suitable habitats (Subramanian et al. 2011; Koparde et al. 2014). To ensure conservation of such species, it is highly important to protect their micro-habitats, especially closed forested streams. The core areas of Sahyadri Tiger Reserve are under legal protection and with current status of the population of endemic species, it is easy to conserve them. However, the conservation of the species in buffer areas, especially in the corridor area, is highly dependent on conservation of forests within.

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