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Dipti Thakuria & Jatin Kalita

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Diversity and distribution of odonates in Rani Reserve Forest, Assam, India

Dipti Thakuria¹  & Jatin Kalita² 

¹ Biodiversity and Conservation Laboratory, Department of Zoology, Gauhati University, Gopinath Bordoloi Nagar, Assam 781014, India.

² Department of Zoology, Gauhati University, Gopinath Bordoloi Nagar, Assam 781014, India.

¹ dipti.thakuria@gmail.com (corresponding author), ² kalitaj@live.com

Abstract: Odonata are the bioindicators of freshwater ecosystem health and is recognised as an excellent 'flagship' group among insects. Baseline knowledge on the diversity and distribution of odonates over spatiotemporal scale is the key to biodiversity conservation. Rani Reserve Forest of Assam is a mosaic of all the habitat types suitable for odonates. The present work aims at studying the diversity and distribution of Odonates in Rani Reserve Forest. The study was carried out from December 2014 to November 2017 by categorising the study area into three major habitat types: 1. lentic system, 2. lotic system and 3. terrestrial woodland. A total of 67 species belonging to 44 genera, representing 11 families were recorded. First published records of three species, *Onychothemis testacea* (Libellulidae), *Philoganga montana* (Philogangidae) and *Indocnemis orang* (Platycnemididae) from the state are also provided herewith. Species richness was the highest in lentic system whereas recorded the lowest in running waters of larger forested streams. Shannon diversity index also indicated that the lentic system is relatively diverse (2.95) and smaller streams of the lotic system showed the highest species evenness (0.87). Libellulidae (43%) was found to be the most dominant family belonging to suborder Anisoptera followed by Coenagrionidae (22%) of suborder Zygoptera. Philogangidae (1%) recorded the lowest number of species. Taxonomically related species showed distinct ecological segregation within these different habitat types occupying different microhabitats therein.

Keywords: Biodiversity, conservation, dragonfly, generalist, Odonata, specialist, species composition.

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Author details: DIPTI THAKURIA is a working as a PhD research scholar in Department of Zoology, Gauhati University, Assam. Her specific field of interest is on diversity, taxonomy and ecology of odonates. PROF. JATIN KALITA is a retired Professor from Department of Zoology, Gauhati University. His special field of interest is in entomology.

Author contribution: First author have worked on the field surveys and preparation of the manuscript under the complete guidance of second author.

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INTRODUCTION

Odonate abundance and diversity provides useful measures of habitat quality in both the aquatic and terrestrial environments (Clark & Samways 1996; Corbet 1999). This group of insects is very diverse, containing individuals with habitat specificities (Corbet 1999). The species assemblage of odonates is influenced by aquatic and terrestrial vegetation (Subramanian et al. 2008) along with channel width of streams (Dijkstra & Lempert 2003). They are found in a wide array of freshwater systems depending on biotic and abiotic constraints. Lentic and lotic systems ranging in physical habitat structure from seasonal to permanent is the habitat of many odonate species (Córdoba-Aguilar 2008). Some of the stenotypic species with low dispersal ability are specific to forest whereas more generalist species with high dispersal ability remain in disturbed open habitats (Clark & Samways 1996). Odonata shows strong response to change in the habitat because of their sensitivity to physical habitat quality (Clark & Samways 1996; Rith-Najarian 1998; Samways & Steytler 1996; Stewart & Samways 1998). The good physical condition of the forest is indicated by the presence of diverse forest species specially stenotypic species (Samways 1989; Corbet 1999).

Information on the species diversity and distribution of extant species of odonates is a prerequisite for an effective conservation strategy. Globally 6307 species of odonates have been reported (Schorr and Paulson, 2020), of which 493 species and 27 subspecies represented in 154 genera and 18 families exists in India (Subramanian and Babu, 2019). Studies on odonate fauna have been reported from various parts of northeastern India. Ninety species were reported from Nagaland (Joshi & Kunte 2014), 64 species from Mizoram (Prasad 2007), 68 species from Manipur (Srivastava & Sinha 2004), 65 species from Sikkim (Mitra 2003), 53 species from Tripura (Majumder et al. 2014), 92 species were recorded from Arunachal Pradesh (Mitra 2006) and 151 species from Meghalaya (Srivastava & Sinha 1995). Odonata fauna from many parts of northeastern India are still undocumented. The state Assam is a part of the eastern Himalayan biodiversity region, rich in rare endemic plant and animal species. Considering the remoteness, the odonate diversity of Assam has been understudied. Previous reports by Laidlaw (1914) described 20 species of dragonflies and damselflies from Assam and Burma. Borah et al. (2012) recorded seven species of damselflies from Gauhati University Campus, Assam; Baruah (2018) recorded 48 species of odonates

from Barpeta. Again, very recent studies by Boruah et al. (2016) reported 82 species under 51 genera belonging to 10 families from Kaziranga, Assam. The present study aims at providing a list of species and document habitat and seasonal distribution of Odonata fauna in the Rani Reserve Forest of Assam.

MATERIALS AND METHODS

Study area

The study was conducted in Rani Reserve Forest situated at 26.091–26.021 °N & 91.588–91.707 °E with an altitude ranging from 60–670 m in Kamrup District, Assam, northeastern India (Devi et al. 2012) (Figure 1). The study area is a mixed moist deciduous forest bordered by hills of Meghalaya on the southern side and Deepor Beel on the northern side which is a Ramsar site of northeastern India, covering an area of 45km². It is considered to be an ecotone between montane subtropical moist broadleaf forest of Meghalaya Plateau and sub Himalayan moist mixed deciduous forest of Assam Valley (Champion & Seth 1968). The unique geological and physiographical makeup of the area forms a special habitat mosaic of hilly terrain and supports habitat like streams, marshes, ponds, puddles suitable for Odonata fauna. The area has a sub-tropical climate with hot humid summer and cool dry winter. Annual rainfall ranges between 1,500–2,600 mm, relative humidity ranges from 47–98 %. The maximum temperature is between 37–39 °C and minimum temperature ranges from 6–7 °C. The climate of the region is divided into four seasons (Barthakur 1986): pre-monsoon (March–May), monsoon (June–September), post-monsoon (October–November) and winter (December–February).

Survey and Sampling

The study was conducted for three consecutive years from December 2014 to November 2017. Rani Reserve Forest (RRF) was categorised according to the habitat and ecological characteristics with which the organism's density is likely to be correlated (Sutherland 1996). Three distinct habitat types were selected for the study of odonates by random stratified sampling method: a) lentic water body b) lotic water body and c) terrestrial zone. Lentic system includes forested wetland like marshes; lotic system includes forested streams. Streams were further categorized into large streams and narrow streams whereas terrestrial zone includes the woodland along with the fringe areas of forest (Table 1).

The sampling was done twice a day, in the morning

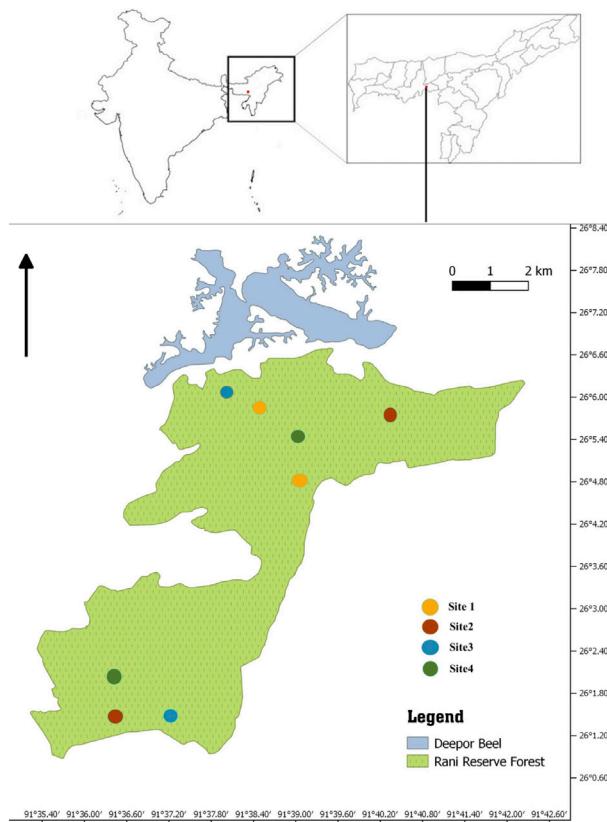


Figure 1. Study area at Rani Reserve Forest, Assam.

between 0700–1300 hrs and in the afternoon between 1400–1700 hrs. Sampling of odonates was done by the permanent belt transects method with fixed width (250x10m) and random forest trail. A total of four transects were laid on each site (with similar habitat type). In the case of lentic and lotic habitat, transects were laid along the edges of each waterbody. Thus, altogether a total of 16 transects were laid in the study

area. Data were collected by direct search technique at the potential microhabitat of odonates. All the surveys and samplings were limited to sunny days when dragonflies are most active at the water bodies (Loiola & De Marco 2011). The photographs of the species were taken using a Canon 700D with a 90mm lens and those that could not be identified in the field were collected and carried to the laboratory for further identification.

Collection and preservation

The specimens were collected using a sweeping net and were stored in 70% ethyl alcohol following the method employed by Subramanian et al. (2008). A few were dried on pins for further identification. All the odonates were identified following the standard literature of Fraser (1933, 1934, 1936), Mitra (2002a), Subramanian (2009), and Nair (2011). Web forums (Odonata of India, DragonflySouthAsia) were also used for finding the data records of species. All the examination, dissection and measurements were carried out under a Leica EZ4 E stereo zoom microscope.

Data analysis

Biodiversity indices were used for the determination of species diversity at different sites. Shannon Wiener diversity index (H'), Peilou's evenness index (J') were calculated using PAST ver. 3. Relative frequency and relative abundance of species were calculated. Species accumulation curves were created and Bray-Curtis cluster analysis (single link) was performed using Biodiversity Pro software version 2. The Odonata community structure of the study sites was compared.

Table 1. Selected sites in Rani Reserve Forest, Assam.

Habitat type	Study sites	Co-ordinates	Number of transects	Habitat characteristics
Lentic water body (H1)	Site 1 (marshes)	26.102°N 91.646°E 26.089°N 91.651°E	4	Bottom substrate is composed of clay and mud, rich in organic matter, surrounded by vegetation, high intensity of light penetration.
Lotic water body (Stream) (H2)	Site 2 (large streams)	26.023°N 91.611°E 26.099°N 91.668°E	4	Sandy substrate at the bottom, open and wide, include streams in hilly terrains with rocks and boulders, deeper with many sunny patches.
	Site3 (small streams)	26.109°N 91.642°E 26.023°N 91.627°E	4	Sandy substrate at the bottom, relatively closed and narrow, runs through dense vegetation, rarely wider than 2 meters, shallow with very less sunny patches, loaded with detritus
Terrestrial zone (H3)	Site 4 (woodland)	26.097°N 91.650°E 26.097°N 91.650°E	4	Forest fringes covered with woody vegetation, less canopy cover

RESULTS

A total of 67 species belonging to 44 genera and 11 families represented by 5,197 individuals (Tables 2,3) were recorded from the study area including three species, *Onychothemis testacea* Laidlaw, 1902, *Philoganga montana* (Hagen in Selys, 1859), and *Indocnemis orang* (Förster in Laidlaw, 1907), which is the first published record from the state of Assam. Out of the total recorded species, the suborder Anisoptera was represented by four families 27 genera and 38 species whereas seven families 17 genera and 29 species were represented in the suborder Zygoptera.

The family-wise composition of odonates showed that out of the 11 families recorded, the highest number of species was from Libellulidae (43%) followed by Coenagrionidae (22%), whereas Philogangidae (1%) recorded the lowest number of species (Figure 2; Table 2). Based on the relative abundance (Table 2), it was found that *Brachythemis contaminata* (Fabricius, 1793) (14%) was the most dominant species followed by *Crocothemis servilia* (Drury, 1770) (8%). The greatest number of individuals of *B. contaminata* and *C. servilia* occurred in Site 4 (terrestrial woodland) of the study area with 415 individuals and 308 individuals, respectively. Species diversity and composition changes with respect to change in the microhabitat. Species richness, however, was the highest in Site 1 of RRF (32 species) and declined gradually in Site 4 (30 species), Site 2 (27 species), and lowest in Site 3 (22 species) (Table 3, Figure 3). Out of the 11 families recorded, all of them were sighted in Site 2 of the forested streams (Figure 3), which is characterised by open canopy and high light intensity. The Shannon diversity index also indicated that odonate diversity in lentic water body (Site 1) is relatively diverse (2.95) followed by terrestrial woodland zone (Site 4) (2.86) and narrow stream of lotic system (Site 3) (2.64). The lowest diversity was observed at Site 2 (2.35) of the lotic water body which is characterised by a large stream with open area. The Simpson indices, however, also showed that Site 1 (0.92) and Site 4 (0.92) are relatively more diverse than all other sites (Table 3) whereas species evenness was highest in Site 3.

Species abundance varied across seasons in different habitat of the Rani Reserve Forest. In Site 1 of the study area, the highest number of individuals of odonates was recorded during pre-monsoon in March 2015 (116 individuals) while the lowest was recorded during the post-monsoon in November 2016 (8 individuals) (Figure 4). In Site 2 on the other hand, species abundance peaked during the monsoon season which recorded the

highest individual in September 2017 (49 individuals) whereas declined sharply during winter (Figure 5). In Site 3, the highest number of individuals of odonates were recorded during the pre-monsoon season in May 2016, (27 individuals) and showed a sharp decline during winter (Figure 6). In Site 4, the species abundance showed a sharp peak during pre-monsoon with the highest individuals in May 2016 (142 individuals) and gradually decline towards post monsoon (Figure 7).

The species accumulation curve when plotted for each sampling site reached its stability (asymptote) at 67 species after 140 sampling replicates (Figure 8). Cluster analysis dendrogram (Figure 9) based on Bray-Curtis' similarity of Odonata assemblage in different habitats showed two major branches within 0–50 % similarity distance. Species harboured in the stream had species assemblage most dissimilar to other habitat types and appeared as a separate group. Meanwhile species of lentic and terrestrial woodland zone had similar species assemblages and are clustered accordingly. Stream dwelling odonates showed analogous segregation to different types of streams. Species like *Euphaea ochracea* Selys, 1859 and *Aristocypha quadrimaculata* Selys, 1853 were predominantly found in the larger streams (Figure 11). These species were observed to occur in forest cover with plenty of sunny patches. Other species like *Coelicia bimaculata* Laidlaw, 1914, *Coelicia didyma* (Selys, 1863) were also found to share similar closed habitat and prefer shady places nearby smaller streams (Figure 12). Species like *Brachythemis contaminata*, *Crocothemis servilia*, and *Palpopleura sexmaculata* (Fabricius, 1787), however, were observed to prefer open habitat and were usually found to occur in standing water and perching in forest fringes, terrestrial woodland (Figures 10, 13). Other than this, habitat requirements were found to be seen overlapping in many species like *Euphaea ochracea* which occur predominantly in both shady and open forested streams.

Five species belonging to the genus *Macromia* Rambur, 1842 (Image C), *Zygonyx* Hagen, 1867 (Image A), *Calicnemia* Strand, 1928 (Image M) and *Protosticta* Selys, 1885 (Image P) could not be identified. Field notes of first published records of the species from Assam are also provided herewith. All the three species are rare and scarcely reported, known only from handful of records.

***Onychothemis testacea* Ris, 1912 (Libellulidae) (Image B).**

This species was found predominantly in the larger streams of the study area (Figure 11) during the pre-

Table 2. Checklist of Odonata fauna recorded in the study area with their relative abundance. (species marked in asterisk * are recorded less than 3 individual each)

	Family	Species	IUCN Category	Relative abundance
1	Aeshnidae	<i>Gynacantha khasiaca</i> MacLachlan, 1896	DD	0.002
2		<i>Gynacantha dravida</i> Lieftinck, 1960	DD	0.002
3		<i>Gynacantha bayadera</i> Selys, 1891	Unknown	0.002
4	Gomphidae	<i>Burmagomphus sp.</i> Williamson, 1907	Unknown	0.002
5		<i>Heliogomphus spirillus</i> (Fraser, 1922)	DD	0.008
6		<i>Ictinogomphus rapax</i> (Rambur, 1842)	LC	0.060
7		<i>Paragomphus lineatus</i> (Selys, 1850)	LC	0.029
8		<i>Macrogomphus annulatus</i> (Selys, 1854)	DD	0.004
9	Macromiidae	<i>Macromia sp.</i> Rambur, 1842	Unknown	0.014
10	Libellulidae	<i>Brachythemis contaminata</i> (Fabricius, 1793)	LC	0.145
11		<i>Rhodothemis rufa</i> (Rambur, 1842) *	LC	0.000
12		<i>Rhyothemis variegata</i> (Linnaeus, 1763)	LC	0.026
13		<i>Neurothemis intermedia</i> (Rambur, 1842)	LC	0.022
14		<i>Neurothemis tullia</i> (Drury, 1773)	LC	0.007
15		<i>Neurothemis fulvia</i> (Drury, 1773)	LC	0.038
16		<i>Brachydiplax sobrina</i> (Rambur, 1842)	LC	0.010
17		<i>Palpopleura sexmaculata</i> (Fabricius, 1787)	LC	0.029
18		<i>Potamarcha congener</i> (Rambur, 1842)	LC	0.022
19		<i>Orthetrum pruinosum</i> (Burmeister, 1839)	LC	0.032
20		<i>Orthetrum luzonicum</i> (Brauer, 1868)	LC	0.031
21		<i>Orthetrum sabina</i> (Drury, 1770)	LC	0.061
22		<i>Orthetrum triangulare</i> (Selys, 1878)	LC	0.005
23		<i>Orthetrum glaucum</i> (Brauer, 1865)	LC	0.016
24		<i>Orthetrum chrysostigma</i> (Selys, 1891)	LC	0.009
25		<i>Crocothemis servilia</i> (Drury, 1770)	LC	0.085
26		<i>Tholymis tillarga</i> (Fabricius 1798)	LC	0.021
27		<i>Urothemis signata</i> (Rambur, 1842)	LC	0.008
28		<i>Trithemis festiva</i> (Rambur, 1842)	LC	0.003
29		<i>Trithemis pallidinervis</i> (Kirby, 1889)	LC	0.016
30		<i>Trithemis aurora</i> , (Burmeister, 1839)	LC	0.001
31		<i>Diplacodes trivialis</i> (Rambur, 1842)	LC	0.025
32		<i>Brachydiplax chalybea</i> Brauer, 1868	LC	0.026
33		<i>Pantala flavescens</i> (Fabricius, 1798)	LC	0.026
34		<i>Acisoma panorpoides</i> Rambur, 1842	LC	0.005
35		<i>Onychothemis testacea</i> Laidlaw, 1902	LC	0.011
36		<i>Zygonyx sp.</i> Hagen, 1867	Unknown	0.008
37		<i>Aethriamanta brevipennis</i> (Rambur, 1842)	LC	0.002
38		<i>Camacinia gigantea</i> (Brauer, 1867) *	LC	0.000
39	Coenagrionidae	<i>Ceriagrion cerinorubellum</i> (Brauer, 1865)	LC	0.029
40		<i>Ceriagrion rubrae</i> Laidlaw, 1916	Unknown	0.001
41		<i>Ceriagrion olivaceum</i> Laidlaw, 1914	LC	0.006
42		<i>Ceriagrion coromandelianum</i> (Fabricius, 1798)	LC	0.044
43		<i>Agriocnemis pygmaea</i> (Rambur, 1842)	LC	0.016

	Family	Species	IUCN Category	Relative abundance
44		<i>Agriocnemis clauseni</i> Fraser, 1922	LC	0.006
45		<i>Agriocnemis pieris</i> Laidlaw, 1919	LC	0.009
46		<i>Agrocnemis lacteola</i> Selys, 1877	LC	0.007
47		<i>Agriocnemis femina</i> (Brauer, 1868)	LC	0.021
48		<i>Ischnura aurora</i> (Brauer, 1865)	LC	0.005
49		<i>Onychargia atrocyana</i> (Selys, 1865)	LC	0.005
50		<i>Pseudagrion microcephalum</i> (Rambur, 1842)	LC	0.004
51		<i>Pseudagrion decorum</i> (Rambur, 1842)	LC	0.001
52		<i>Aciagrion pallidum</i> Selys, 1891 *	LC	0.000
53		<i>Mortonagrion aborense</i> (Laidlaw, 1914)	LC	0.011
54	Chlorocyphidae	<i>Libellago lineata</i> (Burmeister, 1839)	LC	0.013
55		<i>Aristocypha quadrimaculata</i> Selys, 1853	LC	0.012
56	Platycnemididae	<i>Calicemia miles</i> (Laidlaw, 1917)	LC	0.005
57		<i>Calicnemia</i> sp. Strand, 1928	Unknown	0.004
58		<i>Copera marginipes</i> (Rambur, 1842)	LC	0.001
59		<i>Copera vittata</i> Selys, 1863	LC	0.002
60		<i>Indocnemis orang</i> (Förster in Laidlaw, 1907) *	LC	0.000
61		<i>Coelicia bimaculata</i> Laidlaw, 1914	LC	0.001
62		<i>Coelicia didyma</i> (Selys, 1863)	LC	0.001
63		<i>Coelicia schmidti</i> Asahina, 1984	DD	0.003
64	Euphaeidae	<i>Euphaea ochracea</i> Selys, 1859	LC	0.064
65	Platistictidae	<i>Protosticta</i> sp. Selys, 1855 *	Unknown	0.000
66	Calopterygidae	<i>Neurobasis chinensis</i> (Linnaeus, 1758)	LC	0.010
67	Philogangidae	<i>Philoganga montana</i> (Hagen in Selys, 1859) *	LC	0.000

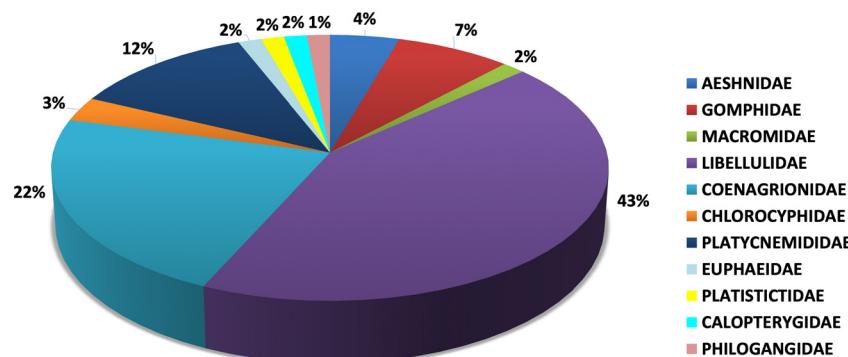


Figure 2. Percentage composition of odonates (family wise) in Rani Reserve Forest.

monsoon season in May and June. Altogether, four individuals of these species were observed to occur in forest cover with plenty of sunny patches. The males were usually found perching on the dry twigs over forested streams and were aggressively chasing other dragonflies in its territory. The male is black coloured with metallic lustre and easily identified by its prominent yellow bands along the abdomen and synthorax. Eyes

are green in colour. Wings hyaline with brown in the apices.

***Philoganga montana* Selys, 1859 (Philogangidae) (Image F).**

The species was observed in the month of July and is found to be associated with freshwater habitat. Only a single individual was sighted in a belt transect of 250x10

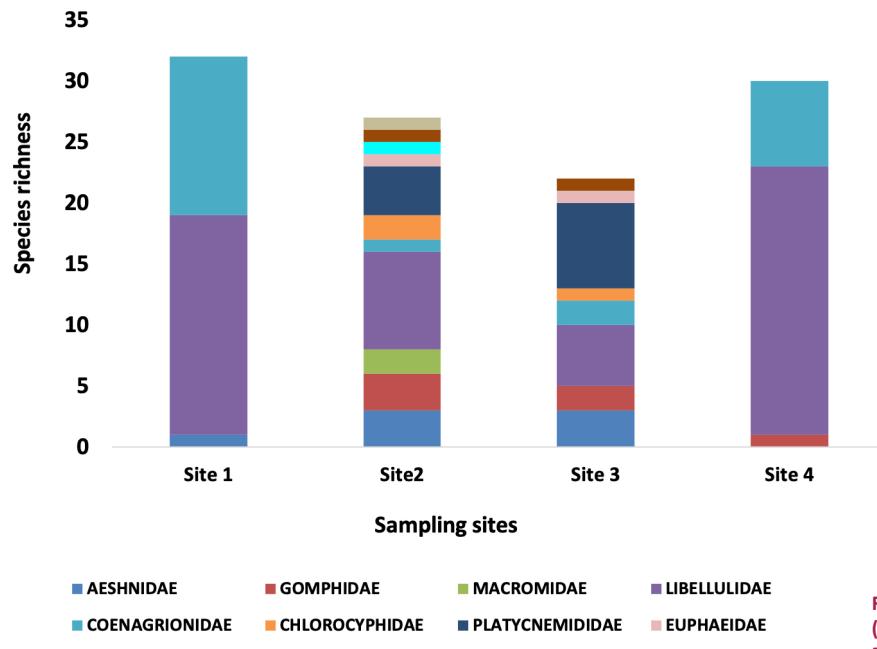


Figure 3. Species composition of odonates (family wise) at different sites of Rani Reserve Forest.

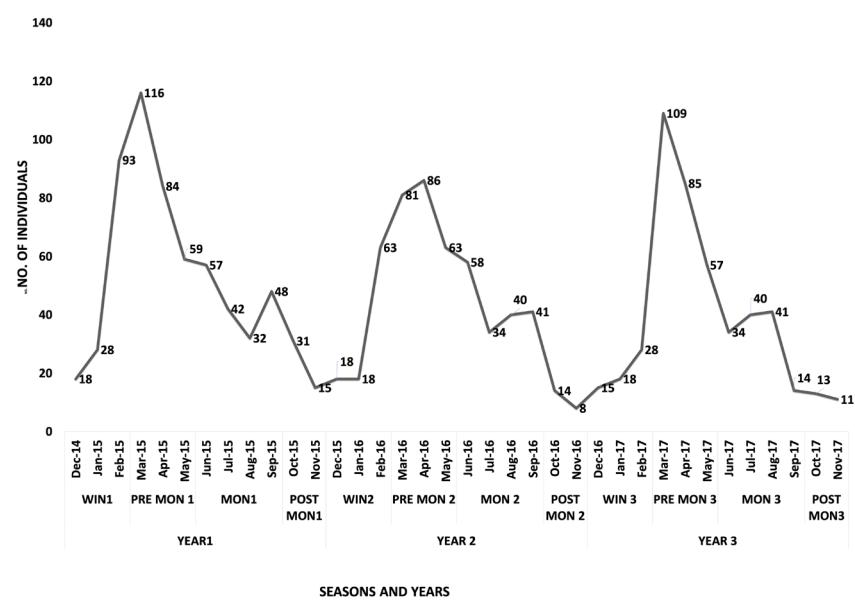


Figure 4. Seasonal variation of odonates in Site 1 (Marshes).

in sunny patches of larger stream (144m) with sandy substrate. It was observed that *P. montana* does not appear to be active and prefers to perch on overhanging branching twigs of trees 1–2 m above the water surface. While perching in the hanging position, the wings were spread horizontally. The female is known to oviposit in the bark of the tree. Flight of the species is relatively low. This species is facing serious threat of habitat loss due to deforestation. The species of this genera are quite robust in size with large head and rounded eyes.

The male is predominantly matte black coloured on dorsum with blue markings in thorax extending towards segment 1 and segment 2. Abdomen distinctly longer than wings or extending at least to wing tips. Wings hyaline. Anal appendages black. Superiors longer than segment 10. Legs black.

Indocnemis orang (Förster in Laidlaw, 1907) forma *orang* (Platycnemididae) (Image G,H).

Two individuals were sighted during the survey. /.

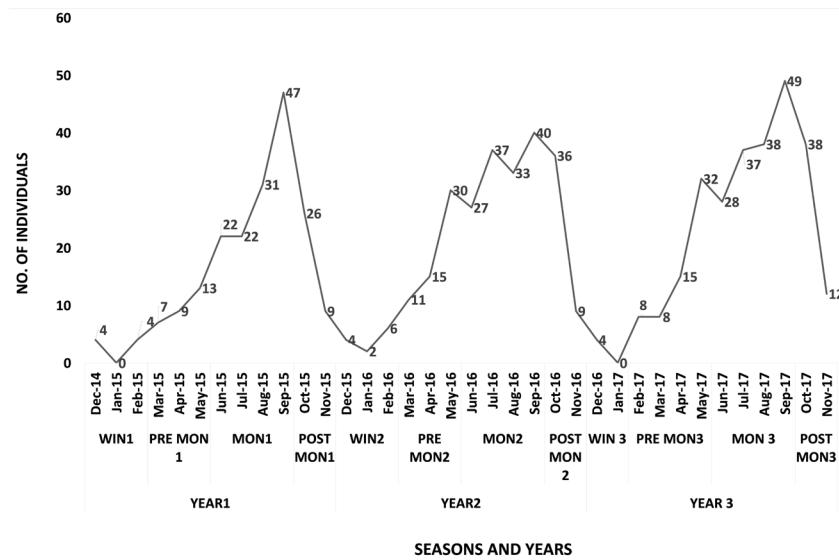


Figure 5. Seasonal variation of odonates in Site 2 (larger stream).

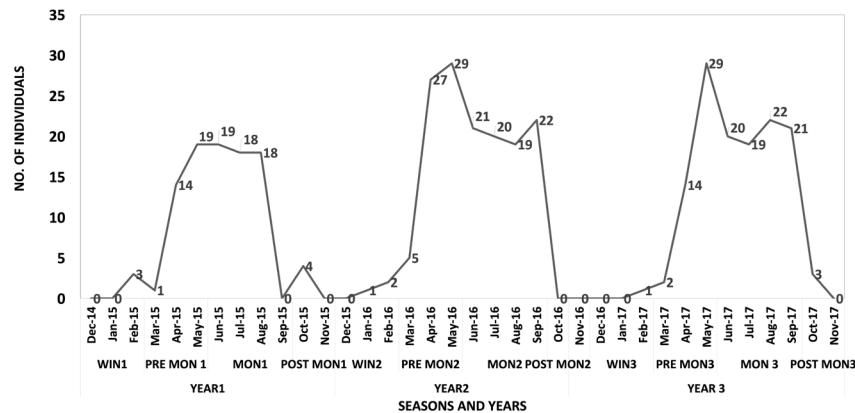


Figure 6. Seasonal variation of odonates in Site 3 (narrower stream).

orang was found perching on overhanging vegetation in the sun flecked patches near the stream with the sandy bottom. The matured male species is steely black coloured with light blue and citron coloured thoracic markings. Segments 9 and 10 of abdomen is light blue coloured dorsally. Wings hyaline, pterostigma black. Legs black. The species can be identified by a large shield-shaped stripe on synthorax which is light blue coloured in matured male. Cerci black with blue marking dorsally. Immature male species is similar except the thoracic shield is citron coloured.

DISCUSSION

The Odonata occupies almost all kinds of habitats along the permanent gradient ranging from running waters and lakes to small temporary rain pools (Corbet 1999). Habitat structures are known to affect the

suitability of an area for odonates (Hawking & New 1999). Our study demonstrates that Odonata diversity and distribution vary across different sites of the Rani Reserve Forest. This variation is probably determined by the interaction between intrinsic habitat and extrinsic environmental parameters. Odonata fauna of RRF is primarily dominated by Libellulidae that comprises 43% of the total species richness. Novelo-Gutiérrez & Gómez-Anaya (2009) also reported that Libellulidae gathers most of the Odonata species with wider distribution and richness. This follows a general trend which is also widely represented in surveys locally and globally (Rashid et al. 2001; Salmah 1996; Salmah & Afzan 2004). The larger body size of the species in this family may be the cause of greater dispersion and distribution (Dalzochio et al. 2011).

Of the total families which were recorded in the study area, all were found to occur in the larger stream of the lotic system. This is probably because of the open

Table 3. Diversity of odonates at different sites of study area.

Landuse type	No. of species	No. of individuals	Diversity Index (H')	Evenness (J')	Simpsons (1- D)
Site1	32	1665	2.95	0.59	0.92
Site2	27	645	2.35	0.39	0.81
Site3	22	414	2.64	0.63	0.90
Site4	30	2473	2.86	0.58	0.92

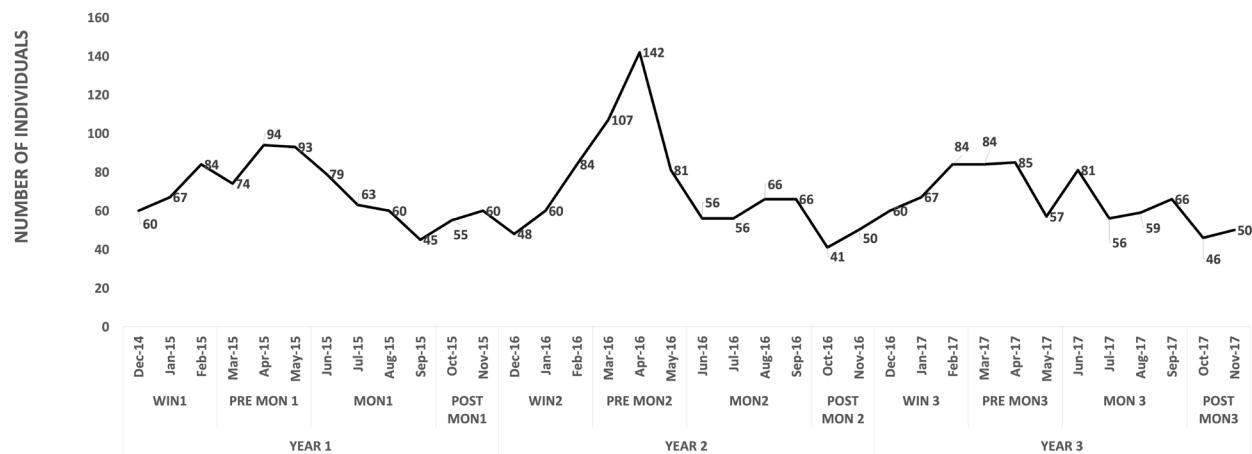


Figure 7. Seasonal variation of odonates in Site 4 (terrestrial zone).

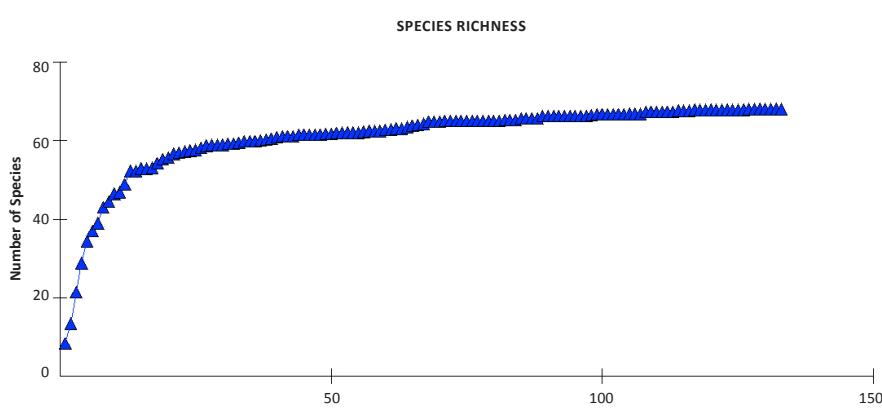


Figure 8. Species accumulation curve.

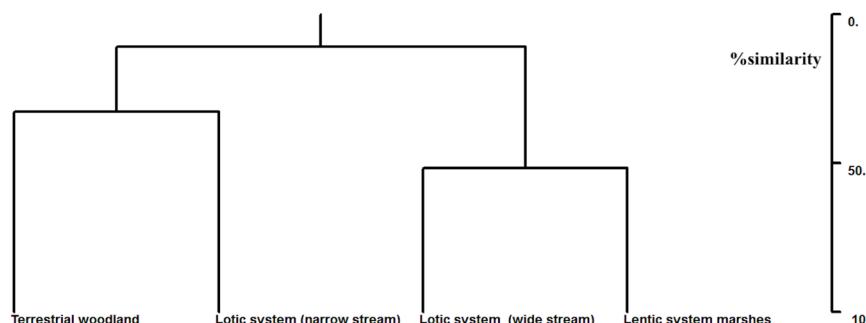


Figure 9. Cluster analysis of Bray-Curtis similarity indices in different sites of Rani Reserve Forest.

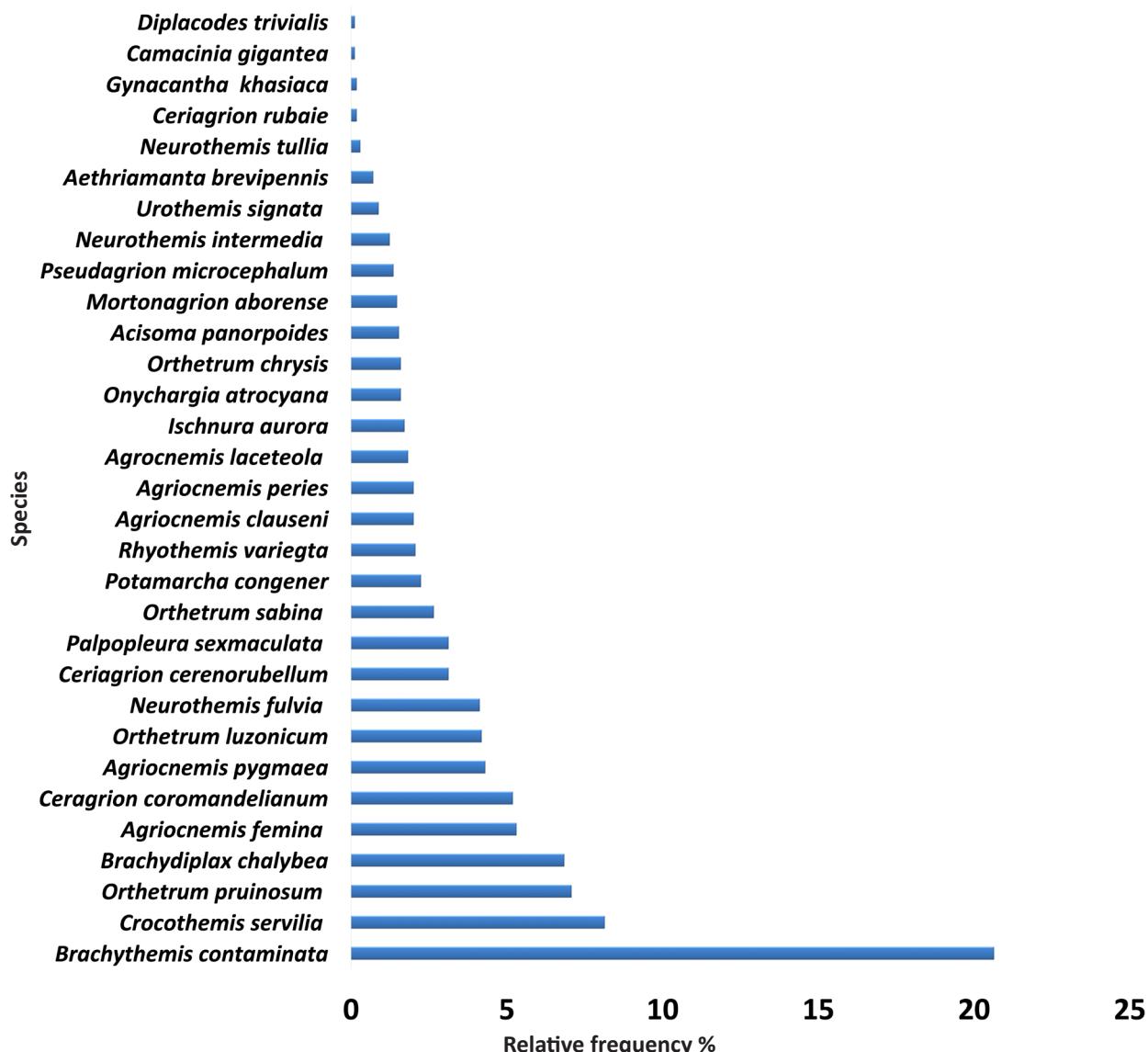


Figure 10. Frequency distribution of odonates in Site 1 (lentic system).

canopy cover and the presence of riparian vegetation nearby. The surrounding riparian vegetation plays a great role in supporting numerous life activities of odonates like foraging, perching structures for thermoregulation, nocturnal roosting, mate attraction, copulation, protection from unfavourable weather conditions and emergence (Buchwald 1992, Wildermuth 1993, McKinnon and May 1994, Rouquette and Thompson 2007). Moreover, the balance of sun and shade caused from the nearby vegetation is also an important factor resulting in the habitat selection (Dijkstra & Lempert 2003).

Highest species richness and species diversity was recorded in the lentic system (Site 1) relative to lotic (Site2, Site3) and terrestrial woodland habitat (Site 4).

Higher number of species in lentic system can be linked to higher colonisation rate of widespread generalist species such as libellulids (Subramanian et al. 2008). However, heterogeneity in vegetation, availability of resources and openness of water bodies might provide good breeding sites for many odonate species (Bond et al. 2006). Moreover, the declination of odonate species diversity and abundance during the post monsoon and winter season are probably associated with habitat dryness and differences in microhabitat conditions compared to the monsoon and pre-monsoon seasons. Field observations suggested that the physical attributes of a particular habitat changes with the change in season, resulting in the seasonal variation of species. But different species may respond differently to habitat

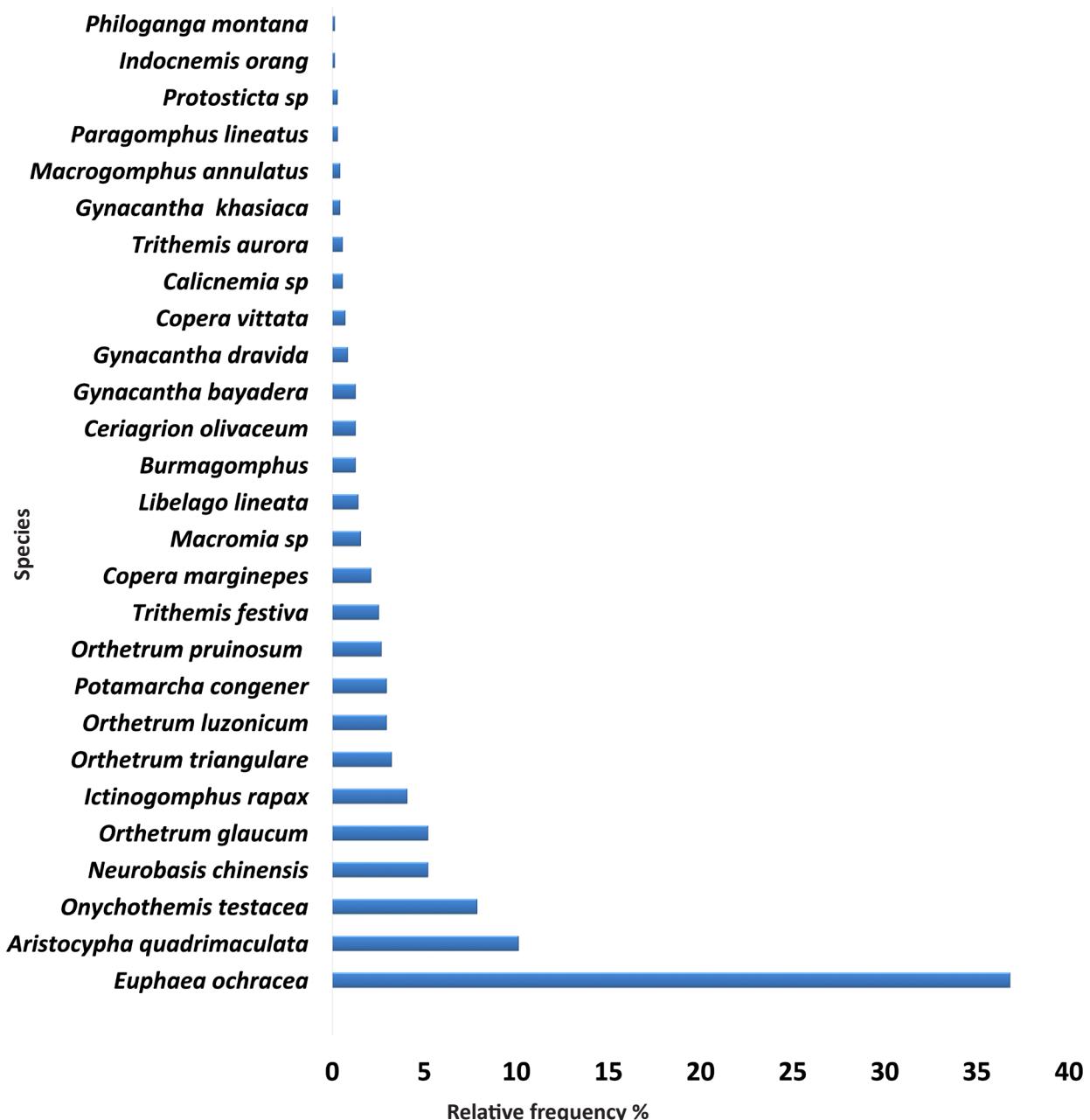


Figure 11. Frequency distribution of odonates in Site 2 (lotic system).

factors and environmental parameters affecting diversity. Hence summarising them without due consideration of habitat variability and other factors will not give the conclusion. Our current data do not reveal this pattern of seasonality affecting the diversity with abiotic factors.

The present study also revealed that communities of forest streams, however, segregate from other habitat types and supports many unique species. Similar were the findings of Dijkstra & Lampert (2003) which reported that odonates of running water are strongly selected by

their habitat. Subramanian et al. (2011) also reported in their findings that stenotypic Odonata are mostly found in the streams. Species belonging to the family Platystictidae, Platycnemididae, and Euphaeidae usually remain restricted to closed canopy forested streams, dense riparian vegetation forested landscape which was similar to the findings of Koparde et al. (2014). In the present study *Euphaea ochracea* was found to occur predominantly in both larger streams and smaller streams. Overlapping of habitat requirements may

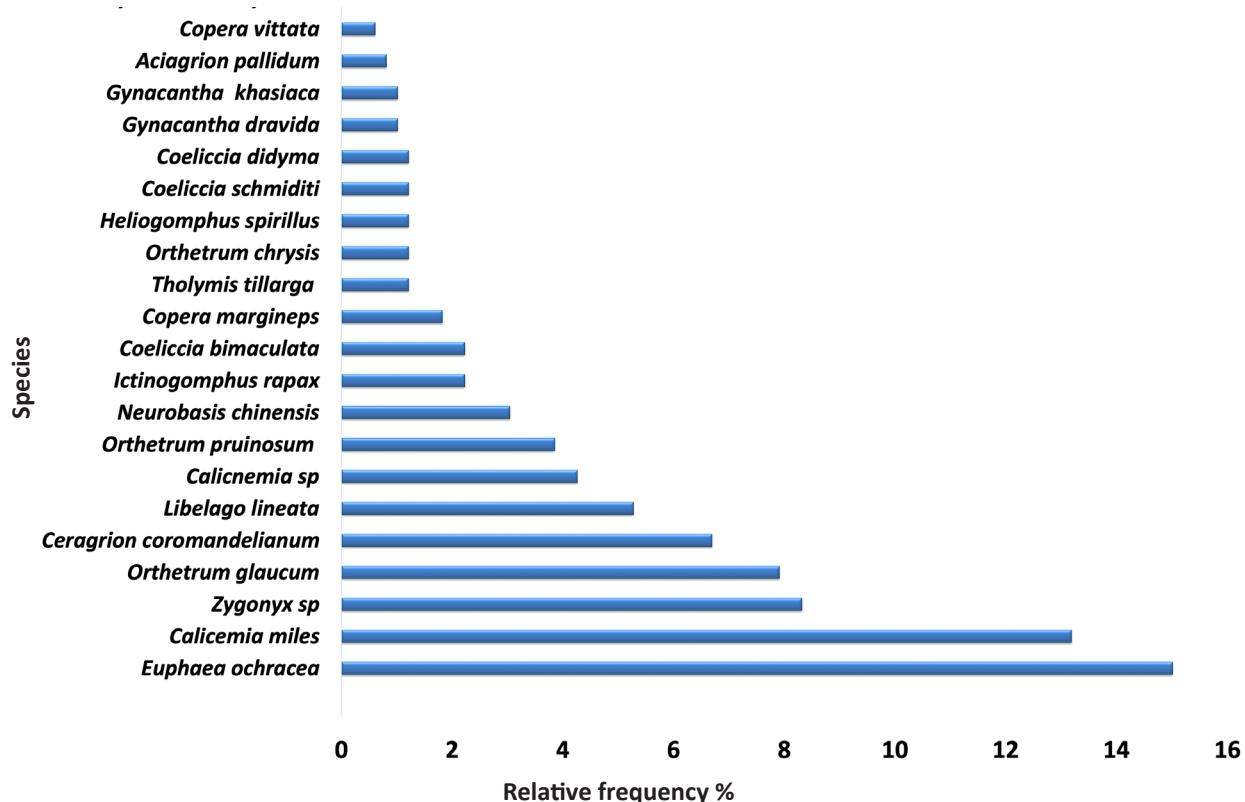


Figure 12. Frequency distribution of odonates in Site 3 (lotic system).

be the reason for the occurrence of species such as *Euphaea ochracea* in both larger and narrower streams. Spatial distribution of lotic species can be attributed due to differences in current velocity of water and respiratory physiology of the respective species (Zahner 1959, 1960).

The odonate fauna assemblage also showed clear distinction in the transition from smaller streams towards larger forested wetland systems. The dominance of Zygoptera like *Calicnemis miles* and species belonging to genus *Coeliccia* in the lotic systems (narrow streams) may be attributed due the heterogeneity of dense riparian vegetation which reduces the light input but also generates a more stable thermal environment (Dijkstra & Lempert 2003).

Many stenotypic species are narrowly distributed and occur only in small patches of suitable habitats (Koparde et al. 2014). Streams in high canopy forests have very low similarity in species composition compared to other forest wetlands (Koparde et al. 2015) which corresponds to our study as well. In the present study, *Onychothemis testacea* were found to prefer open sunny patches in rapidly flowing stream. Nair (2011) also reported that *O. testacea* inhabits fast flowing streams, waterfalls and areas surrounded by dense forest. Rangnekar & Naik

(2014) on the other hand, reported this species from Goa and were found to occur in shady places. The preference of openness and shade may probably be because of the habitat requirements of the species. Previous records of *O. testacea* from Maharashtra is by Prasad (1996) and Koparde et al. (2014, 2015). Other spatial records of this species are also retrieved across the south to various localities of northeastern India including Assam in public domain www.indianodonata.org (Anonymous 2020a) which signifies the range extension of species.

Philoganga montana was previously reported from Bangladesh, Myanmar (Mitra 2002b) and is commonly found around Phewa Tal lake in Pokhara Valley in central Nepal (Kemp & Butler 2001). Very little information is available about this species. The species is also known to occur from West Bengal (Lahiri 1987; DragonflySouthAsia 2020) and was recorded from Bhutan very recently by Gyeltshen (2017). Previously *P. montana* has been reported in northeastern India from Shillong, Khasi Hills of Meghalaya at two localities bordered by montane stream (Fraser 1934). Lahiri (1987) again reported it from Shillong, Umran, Urmoi, Garampani of Meghalaya. Distributions of this species is also known from Arunachal Pradesh (Anonymous 2020b) (media code: br805), however, it has not been formally recorded from Assam.

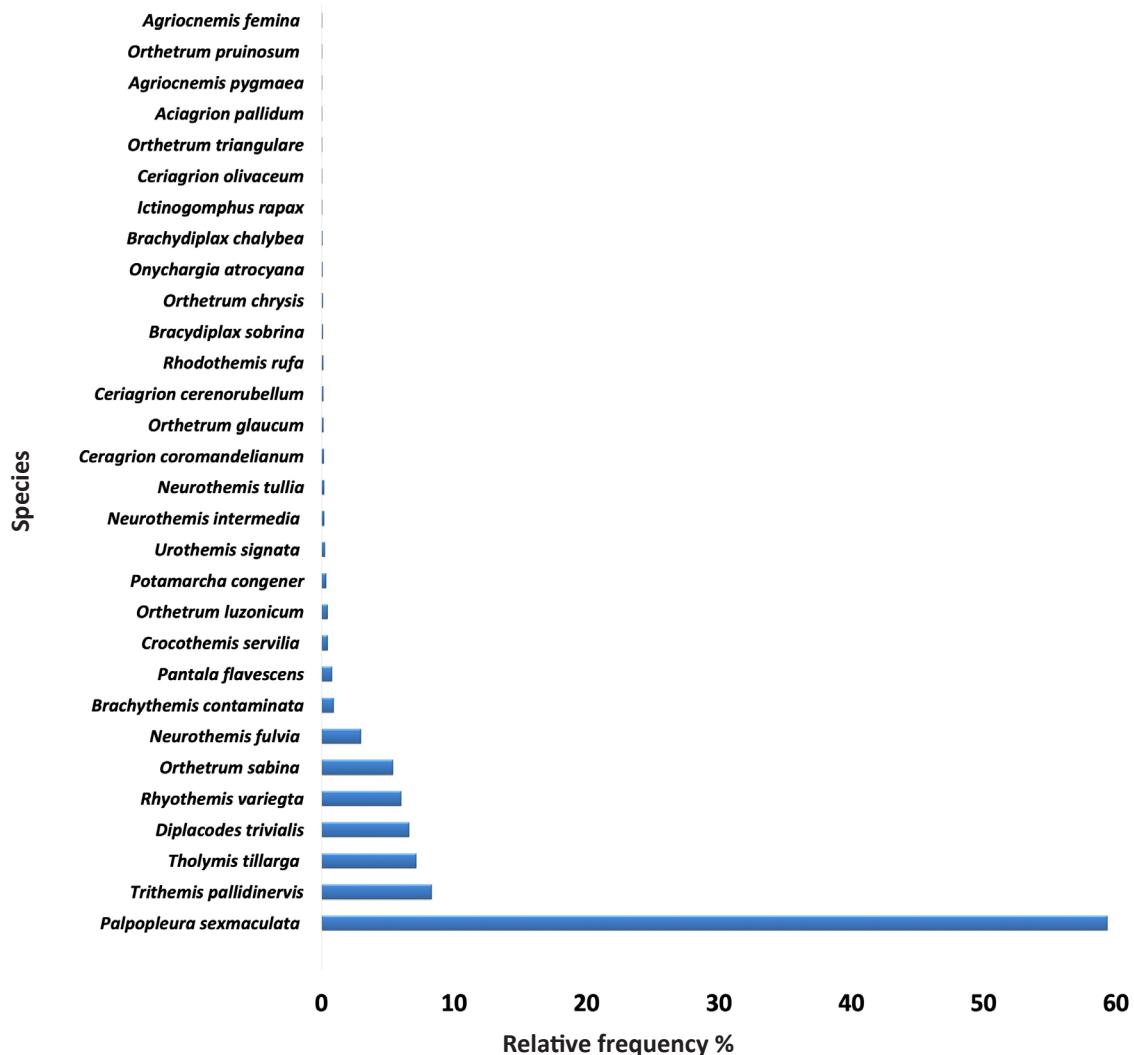


Figure 13. Frequency distribution of odonates in Site 4 (terrestrial zone).

P. montana inhabit montane stream at relatively high altitude. But the present study revealed the occurrence of this species from Assam at low altitudes (144m), which indicates the range extension of this species southwards Assam towards plains.

The genus *Indocnemis* on the other hand consists of only one species Asahina (1997). However, *I. orang* has two forms differing in size: *I. orang* originally described from Malaysia is slightly smaller than the second form *I. kempfi* from Assam (Asahina 1997). Norma Rashid (2003) stated that this species is common in cleared forested streams which also corresponded to our study as well. *I. orang* in this paper are similar to the description of Toan (2018) in respect of the large dorsal shield on the synthorax and dark cerci which are entirely black or with blue mark dorsally. Records from public domain (Anonymous 2020c) also shows the occurrence of this

species in Arunachal Pradesh (media code: am354). The present record from Assam, however, reveals the range extension of this species southwards and also from higher altitude to lower altitude.

Thus, the presence of lentic and lotic freshwater systems of the area along with the heterogeneity in forest vegetation supports a diverse community of odonates in RRF. These numbers of Odonata species demonstrate the need for more intensive surveys to document the complete fauna of Odonata in this area and hence its conservation is directly linked to the conservation of ecosystem health. The stenotypic species are strongly specific to a narrow range of habitat and the grave and accelerating destruction of habitats may cause serious threats to such habitat specific group of odonate species. Therefore, to ensure the conservation of such species, the protection of their microhabitat is highly



Image 1. Photographic records of species sighted: A—*Zygonyx* sp. | B—*Onychothemis testacea* | C—*Macromia* sp. | D—*Heliogomphus spirillus* | E—*Burmagomphus* sp. | F—*Philoganga montana* | © Dipti Thakuria



G



H



I



J



K



L



M



N

Image 2. Photographic records of species sighted: G—*Indocnemis orang* (mature male) | H—*Indocnemis orang* (immature male) | I—*Aristocypha quadrimaculata* | J—*Calicnemia miles* (male) | K—*Calicnemia miles* (female) | L—*Ceriagrion rubiae* | M—*Calicnemia* sp. | N—*Agriocnemis pieris*. © Dipti Thakuria



Image 2. Photographic records of species sighted: O—*Coelliccia didyma* | P—*Protosticta* sp. © Dipti Thakuria

important. This study provides baseline data on local habitat association of Odonata. The information can be used as evidence in formulating conservation measures in RRF where cutting and felling of trees is continued illegally.

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