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Observations of Odonata (Insecta) from heterogeneous habitat patches in Bankura district with the first report of *Microgomphus torquatus* (Selys, 1854) from West Bengal, India

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Abstract

The diversity and heterogeneity of Odonata was studied at 10 sites located across almost all parts of the Bankura district (except northwestern and northeastern boundary regions), in the state of West Bengal, India from July 2015 to June 2022. Analysis of variance and rarefaction was performed to study the β-diversity and compare the taxa abundance at the sites to understand the heterogeneity of Odonata observations. The seasonality of the species and their site-wise distribution were also studied. A total of 74 odonate species belonging to eight families, represented by 46 genera were recorded. The study adds 17 species to the known Odonata fauna of Bankura district, including the addition of *Microgomphus torquatus* (Selys) to the fauna of West Bengal. It also confirms the addition of *Ictinogomphus kishori* to the known Odonata fauna of West Bengal, which has been confused with and misidentified as *Ictinogomphus distinctus* for long, the latter being described from the state of West Bengal and is also found in the region adjacent to the study area. Most recorded odonates belonged to the family Libellulidae (29 species), followed by Coenagrionidae (19 species), Gomphidae (nine species), Platycnenididae (six species), Aeshnidae (five species), Macromiidae (three species), Lestidae (two species), and Chlorocyphidae (one species). Species diversity and abundance assessments are essential for conserving the habitats of the restricted and endemic (to peninsular India) species.

Key words: Diversity, damselfly, dragonfly, *Ictinogomphus*, *Microgomphus*, new record, Peninsular India

Introduction

Arthropoda, with over 1.5 million described species, represent 80% of the known animal species (Dijkstra, 2013; Stork, 2018). Odonata, constituting dragonflies and damselflies, is a rather small insect order of approximately 6,341 described extant species and possibly around 1,000 more awaiting description, (Kalkman et al., 2008; Paulson et al., 2021). However, odonates exhibit an extensive evolutionary history and exhibit a diverse range of adaptations (Hassall and Thompson, 2008).

They occur ubiquitously in most freshwater habitats, and a few species are known to be semi-terrestrial (living in tree holes, leaf axils and phytotelmata), while some occur in saline habitats such as marshes and mangroves (Kalkman et al., 2008). Many species are known to remain restricted to certain habitats, such as forest streams, acidic waters, or even tree holes (Suhling et al., 2015). Additionally, agricultural and urban land transformations, along with vegetation height are the significant factors affecting Odonata species richness and community composition (Kietzka et al., 2018).

Freshwater habitats account for only 1% of total earth area but account for 10% of global biodiversity (Strayer and Dudgeon, 2010). However, wetlands are under severe anthropogenic pressure and are considered to be one of the most jeopardized habitats in the world (Vörösmarty et al., 2010; Mondal et al., 2022a). Freshwater habitat diversity can be broadly classified into lentic (stagnant) and lotic (flowing), which differ considerably in organic matter, pH (Mishra and Yadav, 1978), dissolved oxygen (Mitsch and Day, 2004), nutrients (Essington and Carpenter, 2000), and turbidity among other parameters (Mondal et al., 2022b). Due to the dependence of both larval and adult Odonata on specific water conditions (Dolný et al., 2013) for survival, they are effectively used as an indicator of water quality (Harabiš and Dolný, 2012). Odonates, being both prey (to vertebrates, spiders, other insects including larger odonates) and top predators (in the vertebrate-free ecosystems) (Corbet, 1999), act as umbrella species for wetland biota conservation (Bried et al., 2007). The naiads and adults of Odonata act as biocontrol agents against pests of medical importance and control infectious tropical diseases such as dengue and malaria among others (Mitra, 2006). Odonates are also used as bioinsecticides against agricultural pests (Cudera et al., 2020). Given the anthropogenic and climate threats and the ecological and economic role of odonates, their ecosystems should be made a conservation priority (Barzoki et al., 2020).

India is home to 501 species of Odonata from 154 genera and 18 families (Bedjanič et al., 2020; Joshi et al., 2020; Joshi and Sawant, 2020; Payra et al., 2020; Subramanian and Babu, 2020; Bhakare et al., 2021). Of these known Indian taxa, 239 species belonging to 114 genera and 17 families are found in the state of West Bengal (Dawn, 2021). Bankura district, in the western part of West Bengal, is a transitional region where the Chhotanagpur Plateau, the northeastern extension of the Peninsular Shield, slopes eastward to join the Lower Gangetic Plain.

Bankura district is not well explored in terms of invertebrate diversity, particularly concerning odonates. Srivastava and Sinha (1993) and Mitra (1994) studied the odonate fauna of the district as a part of their broader Odonata surveys of the entire state, with the latter study resulting in description of a new species *Gomphidia leonorae* Mitra, 1994, from the Susunia Hills in Bankura district. Subsequently, both Mukherjee et al. (2016) and Ghosh (2020) studied Odonata fauna in the area, but only around the Gandheshwari River bank at Bankura town. However, consistent studies on Odonata diversity have been done in the adjacent Paschim Bardhaman district (Nayak and Roy, 2016; Nayak, 2020; Nayak and Roy, 2021), which shares the Durgapur Barrage as a prominent border with the Bankura district.

Since Bankura district comprises parts of the Chhotanagpur Plateau and the Lower Gangetic Basin, heterogeneous habitat patches have been extensively surveyed in the course of the present study to investigate the faunal diversity and the related species composition with regard to the heterogeneity of the study sites. This study highlights the Odonata richness and diversity in the ten selected sites across the district. Since Odonata is considered as a biological indicator taxon, odonate diversity, abundance, and richness have been studied to estimate the biodiversity in the district. This study provides a baseline to identify the keystone odonate species of this district and indicates the focal issues and probable hotspots of Odonata conservation interest within this study area. In addition, the outcomes of the present study suggests that other thorough studies of this type would further contribute to filling the lack of comprehensive odonate data and checklists across districts.

Material and Methods

Study site

Bankura district (Fig. 1). in the southwestern part of West Bengal, is transitioned from the Chhotanagpur Plateau and the lower Gangetic plains. The undulating laterites along with the alluvial plains lying between the Chhotanagpur Plateau and the Bhagirathi-Hooghly River is called Rarh (Rudra, 2018; Ghosh and Guchhait, 2019). The Damodar River (540 km long), the most important tributary of Bhagirathi-Hooghly (Das et al., 2021), forms the northern border of Bankura district with Paschim Bardhaman district. Silabati and Dwarakeshwar are the other major rivers which drain the Bankura district. These rivers and their tributaries carry the eroded sediments from the Indian Peninsular Shield (Das et al., 2021).

The Biharinath Hill (451 m) in northwestern part of Bankura distrct is the highest peak in the district. The Susunia Hill (448 m) is an eroded inselberg in the northern part of the district. These hills are mostly made up of quartzite. The Bankura district gently slopes towards the alluvial plains in the east and south. Though vastly deforested, the natural vegetation in the region is fragmented dry deciduous forest (Champion and Seth, 1968) interspersed between agricultural fields and scrublands.

According to Köppen-Geiger classification, tropical savannah climate prevails in the district (Beck et al., 2018). The annual mean daily maximum and minimum temperatures are 32.6 °C and 20.9 °C, respectively, though temperatures are known to reach 47 °C in May and fall to 5 °C in January (Anonymous, 2008). The annual average rainfall in the district is 115.52 cm, which varies between 140.8 cm in Bankura town to 85.7 cm in Barjora and Indas (Anonymous, 2008). June to September is the wet monsoon season, with July being the wettest month (Anonymous, 2021).

Data collection

In order to attempt a thorough investigation of the Odonata diversity of the Bankura district, ten heterogeneous study sites (Fig. 2) have been chosen for regular surveys from diverse habitats and various geographical locations, altitudinal gradients, soil types, and varying anthropogenic interferences.

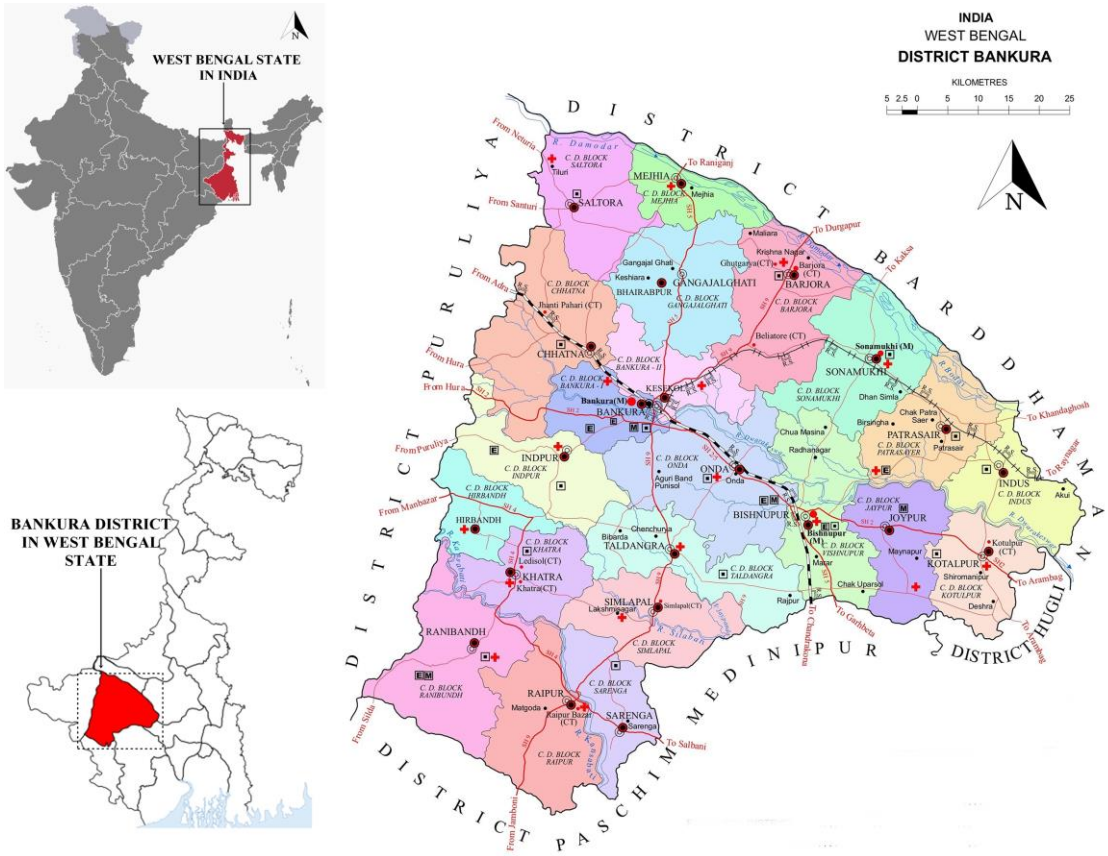

Figure 1: Map of the Bankura District with the map of the West Bengal state and the country India. (Compiled image using different sources to make a collage image of the map of Bankura district; Sources: Wikimedia Commons (https://commons.wikimedia.org)).

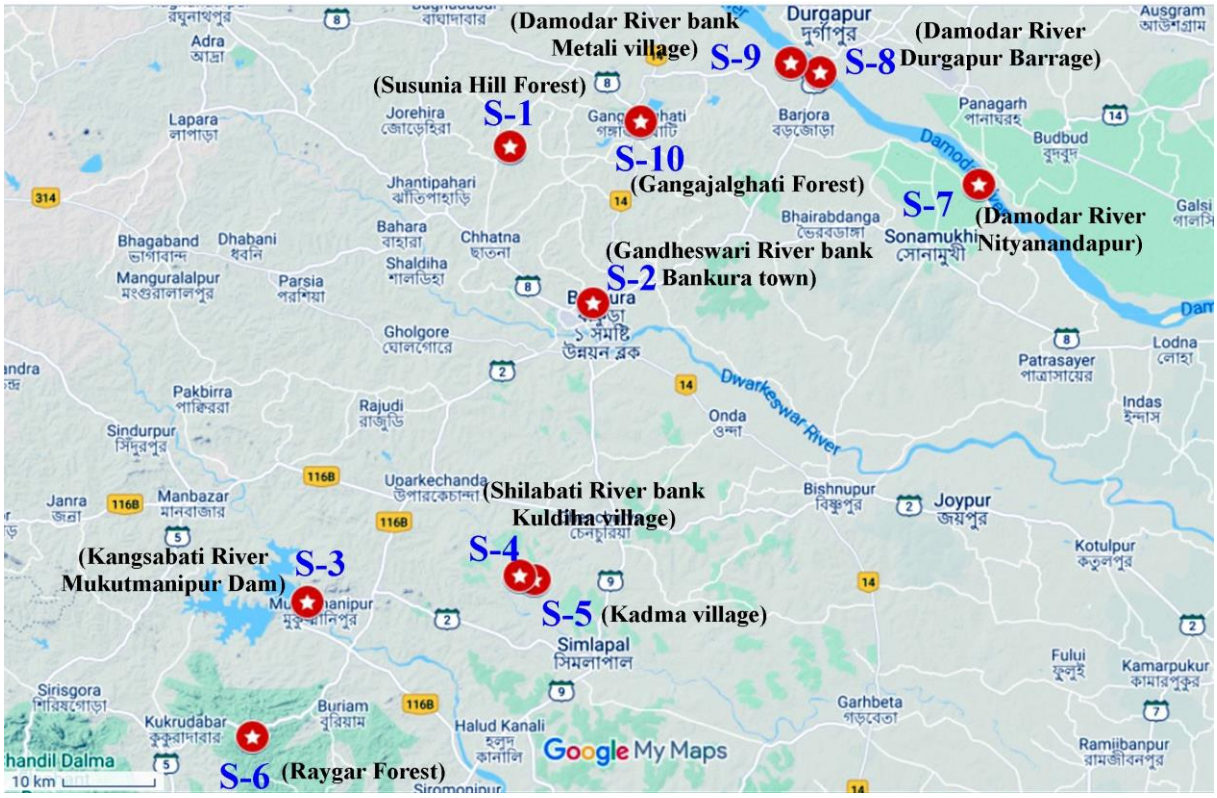

Figure 2: Study sites (S1–S10) under present investigation from Bankura District from West Bengal, India. (Source – Google maps).

The details of the study sites have been provided in Table 1. While six of the ten study sites (S2, S3, S4, S7, S8, S9) were riverine environments, these sites still exhibited habitat diversity between them, including variation of the riverbed character. Riverine study sites included a rocky riverbed of the Silabati River (S4) as well as a sandy riverbed on the Gandheshwari River (S2). Sandy riverbed sites downstream of Durgapur Barrage on the Damodar River were also studied (S8 and S7), while upstream of Durgapur Barrage on the Damodar River, the studied site was characterized by a wide and sluggish reservoir bed (S9). The same applied for another site (S3), however, its downstream was marked by boulders of igneous rocks. Further habitat diversity was represented by a study site of a typical nondescript rural setting with ponds, irrigation canals and agricultural fields (S5). The remaining study sites (S1, S6 and S10) represent forests, which also differ in habitat characteristics. These sites encompassed extensive hill forest in Susunia (S1), a humid, dense forest with seasonal streams (S6), and a site consisting of primary and planted forests (S10). Figs. 8–17 show the habitat types of the study sites.

The ten selected sites were surveyed between July 2015 to June 2022 to assess odonate diversity. A direct searching method (Ausden and Drake, 2006) was applied to record odonates diversity and abundance. Each study site was surveyed at least twice every month (Nayak and Roy, 2016) during the total study period of almost seven years in order to understand the seasonal variation of occurrence and abundance odonates.

Odonates were photographed (Figs. 18–132, Supplementary File 1) using a Nikon Coolpix P600 point and shoot camera and/or a Nikon D5300 DSLR camera equipped with a Nikkor Af-p 70-300 mm lens. Specimens were not collected during the entire study period as this study used only noninvasive techniques. Individuals were photographed and mostly identified in situ. In particular cases when photographed individuals could not be readily identified, such as for *Agriocnemis splendidissima* Laidlaw, 1919, *Anax ephippiger* (Burmeister, 1839), *Cyclogomphus heterostylus* (Selys, 1854), *Libellago indica* (Fraser, 1928), *Macromia cingulata* Rambur, 1842, *Macromia flavicincta* Selys, 1874, *Macrogomphus montanus* Selys, 1869, *Microgomphus torquatus* Selys, 1854, *Pseudagrion australasiae* Selys, 1876 the works of Fraser (1933; 1934; 1936), Subramanian (2005), Mitra (2006), Ramachandran and Raju (2020), and Singh (2022) were used to facilitate identifications.

Data analysis

The Dominance_D (Simpson, 1949), Simpson's 1-D (Hurlbert, 1971), Shannon's 1-D (Shannon, 1948), and Evenness indices (Pielou, 1966), as well as the Berger-Parker index (Berger and Parker, 1970) were calculated for observed taxa. Individual rarefaction analysis (Sanders, 1968; Hurlbert, 1971; Heck et al., 1975) of Odonata was done among the sites to estimate species richness for a given number of individual samples. The α-diversity (Whittaker, 1960) of the study sites was calculated as an indicator of the species richness of the study sites. The global β-diversity of the entire study area was calculated using Whittaker's index (Whittaker, 1960) to measure the heterogeneity and change in species composition among them. Hierarchical classical clustering was done using a single linkage algorithm with the Bray-Curtis similarity index (Bray and Curtis, 1957) and 10,000 bootstraps among sites to create the UPGMA Dendrogram (Sokal and Michener, 1958), which provides the ecological proximity relationship of the study sites (Fig. 3, Supplementary File2). The entire analysis was performed with PAST software (Version 4.08, Hammer et al., 2001; Anonymous, 2021a).

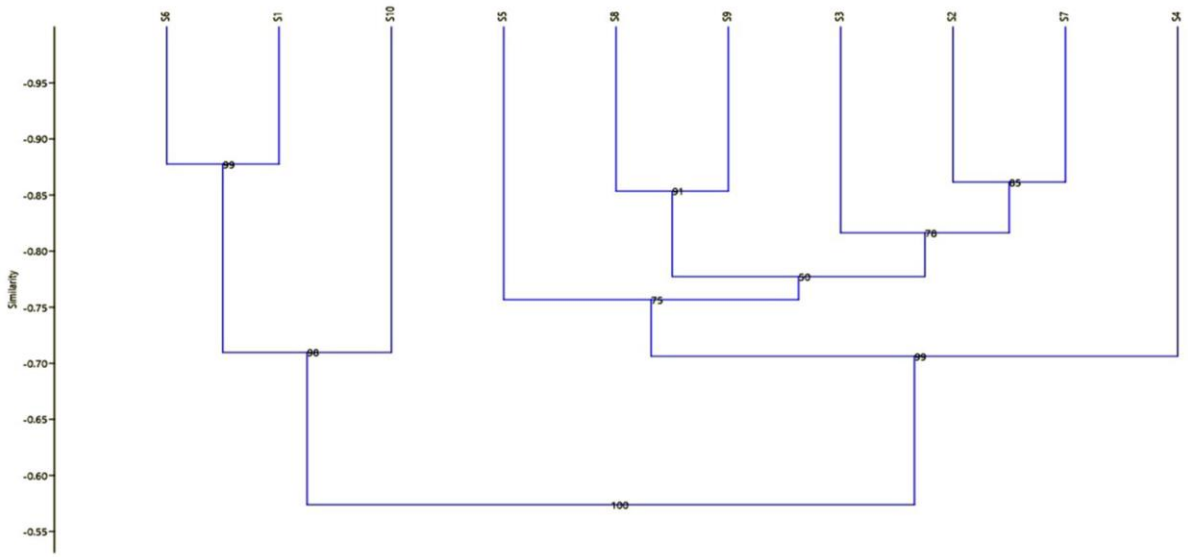

Figure 3: UPGMA Dendrogram for distance analysis of the study sites.

Results

Status and abundance of Odonata

The present study resulted in records for 74 species of odonates (Figs. 18–132). The site and seasonality findings of these 74 species along with their IUCN Red List status have been provided in Table 2. Of the recorded taxa, 28 (38%) are damselflies belonging to the suborder Zygoptera and the remaining 46 species (62%) are dragonflies of the suborder Anisoptera (Table 3). Out of the 28 damselflies, the highest number of species were recorded from the family Coenagrionidae (19 species; 7 genera), followed by Platycnemididae (6 species; 6 genera), Lestidae (2 species; 1 genus), and Chlorocyphidae (1 species; 1 genus) (Fig. 4, Table 3). Among the 46 species of dragonflies, the family Libellulidae was found to be the most specious and abundant family (29 species; 20 genera), followed by Gomphidae (9 species; 6 genera), Aeshnidae (5 species; 3 genera), and Macromiidae (3 species; 2 genera) (Fig. 5, Table 3).

Findings of newly reported Odonata from the study area

Out of 74 odonate species recorded in the present study, 17 species, of which six are gomphids, have not been previously reported from the Bankura district (Mukherjee et al., 2016; Ghosh, 2020; Dawn, 2021). Of these six gomphid species, *Microgomphus torquatus* (Selys, 1854) is reported as a new record for the entire state. Six damselflies of Coenagrionidae are also new records for Bankura district, though among them, *Pseudagrion spencei* Fraser, 1922 is locally common. *Mortonagrion aborense* (Laidlaw, 1914), though commonly reported from the Gangetic and Coastal plains of West Bengal, is reported here for the first time from the Bankura district in the state. This also represents its first report from the Chhotanagpur plateau region in the western part of West Bengal.

Diversity of Odonata across the study sites

The number of Odonata species was highest in study site S8 (55 species), followed by S5 (52 species) and S4 (51 speicies). The Dominance index of all ten study sites range from 0.0278 (S8) to 0.0533 (S6). The Simpson's 1-D index of all sites was greater than 0.94, indicating high diversity. The Berger-Parker index indicating single taxa dominance is noticeably high in S10 (0.098), followed by S6 (0.089). The Shannon's index also demonstrates similar trends in biodiversity of the study sites.

The Evenness index shows S3 (0.835) to be the most even and S5 (0.647) as the least even. The diversity indices of ten study sites are provided in Table 4. The comparative count of specimens observed in the study sites is illustrated using the individual-based rarefaction curves (95% confidence interval) (Fig. 6). The α-diversity profile (Fig. 7) shows S8 and S4 to be the most diverse sites, while S6 and S10 are the least diverse. The global β-diversity of the entire study area across the study sites was found to be 0.836 according to Whittaker's index (Supplementary File 2).

Table 1: Brief description of the selected study sites including altitude, geo–coordinates (Using Google Earth Version 9.135.0.3), and habitat types.

Location (study site)	Altitude (elevation above sea level in meters); Coordinates (latitude and longitude)	Habitat type
S1- Susunia Hill Forest	127 m; 23°24′07″N, 86°59′34″E	Remnant dry deciduous forest around an eroded inselberg (solitary hill). Grassland, ponds, and paddy field border the forest.
S2- Gandheswari River bank, Bankura town	79 m; 23°14′51″N, 87°04′21″E	Riverine habitat (near a crematorium) with sandy riverbed.
S3- Kangsabati River, Mukutmanipur Dam	129 m; 22°57′51″N, 86°47′03″E	Riverine habitat with rocky riverbed. The 38 m high, 10098 m long earthen dam on the river creates a large deep reservoir (average depth of water is 126 m) in the upstream surrounded by dry deciduous forests and grasslands.
S4- Silabati River bank, Kuldiha village	76 m; 22°59′16″N, 86°59′50″E	Riverine habitat with a rocky riverbed.
S5- Kadma village	95 m; 22°59′24″N, 86°00′50″E	Rural habitat with paddy, pulse and vegetable fields with mixed vegetation, ponds and an irrigation canal.
S6- Raygar Forest	215 m; 22°50′02″N, 86°43′25″E	Dry deciduous forest in the connecting zone between the Chhotanagpur Plateau and the Kangsabati Basin. A seasonal rain-fed stream with rocky bed flows through the site.
S7- Damodar River, Nityanandapur	54 m; 23°21′58″N, 87°27′54″E	Riverine habitat with a sandy riverbed. Weir on the river channeling water into irrigation canals. Mixed vegetation and agricultural field are present on the riverbanks in this rural landscape.
S8- Damodar River, Durgapur Barrage	62 m; 23°28′24″N, 87°18′06″E	Riverine habitat with a sandy riverbed. A 12 m high, 692 m long barrage on the river channeling water into irrigation canals on both sides of the river. Barrage also creates a deep reservoir on the upstream, having a maximum depth of 64 m. Mixed vegetation, grasslands and ornamental gardens are present on the riverside.
S9- Damodar River bank, Metali village	68 m; 23°28′55″N, 87°16′23″E	Riverine habitat on the reservoir created by the barrage at site S8. Ponds and agricultural fields are present in this rural landscape. The stagnant water hosts floating plants.
S10- Gangajalghati Forest	127 m; 23°25′29″N, 87°07′32″E	Fragmented dry deciduous forest in this peneplain region. The forest is surrounded by rural landscape of paddy fields, ponds, and an irrigation canal.

Table 2: List of observed Odonata (Insecta) fauna from selected heterogeneous sites of Bankura district, West Bengal, India along with their IUCN Red List status (LC: Least Concern; DD: Data Deficient; NA: This taxon has not yet been assessed for the IUCN Red List; NC: This taxon is not in the Catalogue of Life). Species marked with an asterisk (*) are a new record for the Bankura District. Species marked with double asterisks (**) is a new record for West Bengal. Species marked with (e) indicating species endemic to India, WG= Western Ghats.

Sl. No.	Odonate species	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	IUCN Status	Season of occurrence (Month)
Suborder Zygoptera Selys, 1854													
Superfamily Lestoidea Calvert, 1901													
Family Lestidae Calvert, 1901													
1	*Lestes praemorsus* Hagen in Selys, 1862	+				+						LC	March-November
2	*Lestes concinnus* Hagen in Selys, 1862								+			LC	October
Superfamily Calopterygoidae Selys, 1850													
Family: Chlorocyphidae Cowley, 1937													
3	*Libellago indica* (Fraser, 1928) e				+							NE	October
Superfamily Coenagrionoidea Kirby, 1890													
Family Coenagrionidae Kirby, 1890													
4	*Agriocnemis kalinga* Nair and Subramanian, 2014					+						NE	June-November
5	*Agriocnemis lacteola* Selys, 1877	+			+	+						LC	March-December
6	*Agriocnemis splendidissima* Laidlaw, 1919*						+					LC	November
7	*Agriocnemis pygmaea* (Rambur, 1842)	+	+	+	+	+	+	+	+	+	+	LC	January-December
8	*Amphiallagma parvum* (Selys, 1867)		+	+	+	+		+	+			LC	March-November
9	*Ceriagrion cerinorubellum (Brauer, 1865)*		+					+	+	+		LC	March-October
10	*Ceriagrion coromandelianum (Fabricius, 1798)*	+	+	+	+	+	+	+	+	+	+	LC	January-December
11	*Ischnura nursei (Morton, 1907)*			+		+			+			LC	August-October
12	*Ischnura rubilio Selys, 1876*	+	+	+	+	+	+	+	+	+	+	NE	March-November
13	*Ischnura rufostigma Selys, 1876**					+			+			LC	March, October
14	*Ischnura senegalensis (Rambur, 1842)*	+	+	+	+	+	+	+	+	+	+	LC	January-December
15	*Mortonagrion aborense (Laidlaw 1914)**					+						LC	September
16	*Paracercion calamorum (Ris, 1916)**				+	+						LC	June-October
17	*Paracercion malayanum (Selys, 1876)*				+	+			+	+		LC	June-October
18	*Pseudagrion australasiae Selys, 1876**				+							LC	June-September
19	*Pseudagrion decorum (Rambur, 1842)*	+	+	+	+			+	+	+	+	LC	January-December
20	*Pseudagrion microcephalum (Rambur, 1842)*	+	+	+		+		+	+	+		LC	March-December
21	*Pseudagrion rubriceps Selys, 1876*	+	+	+	+	+		+	+	+		LC	January-December
22	*Pseudagrion spencei Fraser, 1922**				+			+	+	+		LC	May-December
Family Platycnemididae Yakobson and Bainchi, 1905													
23	*Pseudocopera ciliata* (Selys, 1863)	+	+	+	+	+	+	+	+	+	+	LC	January-December
24	*Copera marginipes* (Rambur, 1842)				+	+						LC	May-December
25	*Caconeura ramburi* (Fraser, 1922) e						+					DD	April-October
26	*Disparoneura quadrimaculata* (Rambur, 1842) e				+	+						LC	March-November
27	*Onychargia atrocyana* (Selys, 1865)	+	+	+	+	+	+	+	+	+	+	LC	January-December
28	*Prodasineura verticalis* (Selys, 1860)				+							LC	March-October
Suborder Anisoptera Selys, 1854													
Superfamily Aeshnoidea Leach, 1815													
Family Aeshnidae Leach, 1815													
29	*Anaciaeschna jaspidea* (Burmeister, 1839)*									+		LC	March
30	*Anax ephippiger* (Burmeister, 1839)*					+						LC	June, July
31	*Anax guttatus* (Burmeister, 1839)				+	+		+	+			LC	March-December
32	*Anax indicus* Lieftinck, 1942*	+		+	+				+	+		LC	March-December
33	*Gynacantha dravida* Lieftinck, 1960		+			+						DD	January-December

Table 2. (Continued)

Sl. No.	Odonate species	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	IUCN Status	Season of occurrence (Month)
Superfamily Gomphoidea Rambur, 1842													
Family Gomphidae Rambur, 1842													
34	*Cyclogomphus heterostylus* Selys, 1854*[e(WG)]								+			DD	July
35	*Cyclogomphus ypsilon* Selys, 1854*[e(WG)]				+				+			NE	June -November
36	*Ictinogomphus kishori* Ram, 1985*				+	+		+	+	+		DD	May-July
37	*Ictinogomphus rapax* (Rambur, 1842)	+	+	+	+	+	+	+	+	+	+	LC	March-November
38	*Macrogomphus annulatus* (Selys,1854) [e]								+	+		DD	April-September
39	*Macrogomphus montanus* Selys, 1869*				+				+	+		DD	June, July
40	*Microgomphus torquatus* (Selys, 1854)** [e (WG)]				+							DD	September
41	*Paragomphus lineatus* (Selys, 1850)		+		+	+		+	+	+		LC	February-November
42	*Platygomphus dolabratus* Selys, 1854*								+			LC	June-September
Superfamily Libelluloidea Leach, 1815													
Family Libellulidae Leach, 1815													
43	*Acisoma panorpoides* Rambur, 1842		+	+	+	+		+	+	+		LC	March-December
44	*Aethriamanta brevipennis* (Rambur, 1842)	+	+	+	+		+	+	+	+	+	LC	March-October
45	*Brachydiplax chalybea* Brauer, 1868		+	+	+	+		+	+	+		LC	May –October
46	*Brachydiplax sobrina* (Rambur, 1842)	+	+	+	+	+	+	+	+	+	+	LC	March-November
47	*Brachythemis contaminata* (Fabricius, 1793)	+	+	+	+	+	+	+	+	+	+	LC	January-December
48	*Bradinopyga geminata* (Rambur, 1842)		+	+	+	+	+	+	+	+	+	LC	January-December
49	*Crocothemis servilia* (Drury, 1770)	+	+	+	+	+	+	+	+	+	+	LC	January-December
50	*Diplacodes nebulosa* (Fabricius, 1793)					+			+	+		LC	July-October
51	*Diplacodes trivialis* (Rambur, 1842)	+	+	+	+	+	+	+	+	+	+	LC	January-December
52	*Lathrecista asiatica* (Fabricius, 1798)	+				+	+					LC	May-October
53	*Macrodiplax cora* (Brauer, 1867)			+	+	+		+	+			LC	May-August
54	*Neurothemis fulvia* (Drury, 1773)	+	+	+	+	+	+	+	+	+	+	LC	January-December
55	*Neurothemis intermedia* (Rambur, 1842)					+	+	+		+		LC	January-December
56	*Neurothemis tullia* (Drury, 1773)	+	+	+	+	+	+	+	+	+	+	LC	January-December
57	*Orthetrum glaucum* (Brauer, 1865)					+						LC	December
58	*Orthetrum pruinosum* (Burmeister, 1839)	+	+	+	+	+	+	+	+	+	+	LC	January-December
59	*Orthetrum sabina* (Drury, 1770)	+	+	+	+	+	+	+	+	+	+	LC	January-December
60	*Pantala flavescens* (Fabricius, 1798)	+	+	+	+	+	+	+	+	+	+	LC	June-September
61	*Potamarcha congener* (Rambur, 1842)	+	+	+	+	+	+	+	+	+	+	LC	January-December
62	*Rhodothemis rufa* (Rambur, 1842)		+	+	+	+		+	+	+		LC	March-November
63	*Rhyothemis variegata* (Linnaeus, 1763)	+	+	+	+	+	+	+	+	+	+	LC	March-December
64	*Tholymis tillarga* (Fabricius, 1798)	+	+	+	+	+	+	+	+	+	+	LC	January-December
65	*Tramea basilaris* (Palisotde Beauvois, 1805)			+	+	+			+			LC	October-November
66	*Tramea limbata* (Desjardins, 1832)	+			+	+	+		+		+	LC	March-December
67	*Trithemis aurora* (Burmeister, 1839)		+	+	+		+	+	+			LC	April-October
68	*Trithemis festiva* (Rambur, 1842)		+	+	+			+	+			LC	March-October
69	*Trithemis pallidinervis* (Kirby, 1889)	+	+	+	+	+	+	+	+	+	+	LC	March-December
70	*Urothemis signata* (Rambur, 1842)	+	+	+	+	+	+	+	+	+	+	LC	March-October
71	*Zyxomma petiolatum* Rambur, 1842	+	+	+	+	+	+	+	+	+	+	LC	February-September
Family Macromiidae Needham, 1903													
72	*Epophthalmia vittata* Burmeister, 1839	+				+	+		+	+	+	LC	May-October
73	*Macromia cingulata* Rambur,1842*								+	+		LC	June, July
74	*Macromia flavicincta* Selys, 1874*[e]								+	+		DD	June, October

Table 3: Number of species in odonate families and orders at each study site.

Order or Family	Study sites									
	S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**
Lestidae	01	-	-	-	01	-	-	01	-	-
Chlorocyphidae	-	-	-	01	-	-	-	-	-	-
Coenagrionidae	08	09	09	12	14	05	10	13	10	05
Platycnemididae	02	02	02	05	04	03	02	02	02	02
Aeshnidae	01	01	01	02	03	-	01	02	01	-
Gomphidae	01	02	01	06	03	01	03	07	05	01
Libellulidae	18	22	24	25	26	20	23	26	22	18
Macromiidae	01	-	-	-	01	01	-	03	03	01
Zygoptera	11	11	11	18	19	08	12	16	12	07
Anisoptera	21	25	26	33	33	22	27	38	31	20
Total	32	36	37	51	52	30	39	54	43	27

Table 4: Diversity indices (Taxa_S, Individuals, Dominance_D, Simpson_1-D, Shannon_H, Evenness_e^H/S and Berger-Parker indices) of the ten study sites (S1-S10).

Diversity indices	Study sites									
	S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**
Taxa_S	32	36	37	51	52	31	39	55	44	27
Individuals	1001	1362	1451	1450	1677	970	1658	2333	1931	765
Dominance_D	0.04821	0.04017	0.03702	0.0305	0.03677	0.05325	0.03509	0.0278	0.03309	0.05271
Simpson_1-D	0.9518	0.9598	0.9630	0.9695	0.9632	0.9467	0.9649	0.9722	0.9669	0.9473
Shannon_H	3.185	3.358	3.43	3.637	3.515	3.106	3.455	3.715	3.534	3.084
Evenness_e^H/S	0.7551	0.798	0.8346	0.7443	0.6467	0.7206	0.8118	0.7464	0.7787	0.809
Berger-Parker	0.07788	0.0719	0.06338	0.0585	0.05958	0.0886	0.05911	0.04242	0.05126	0.09798

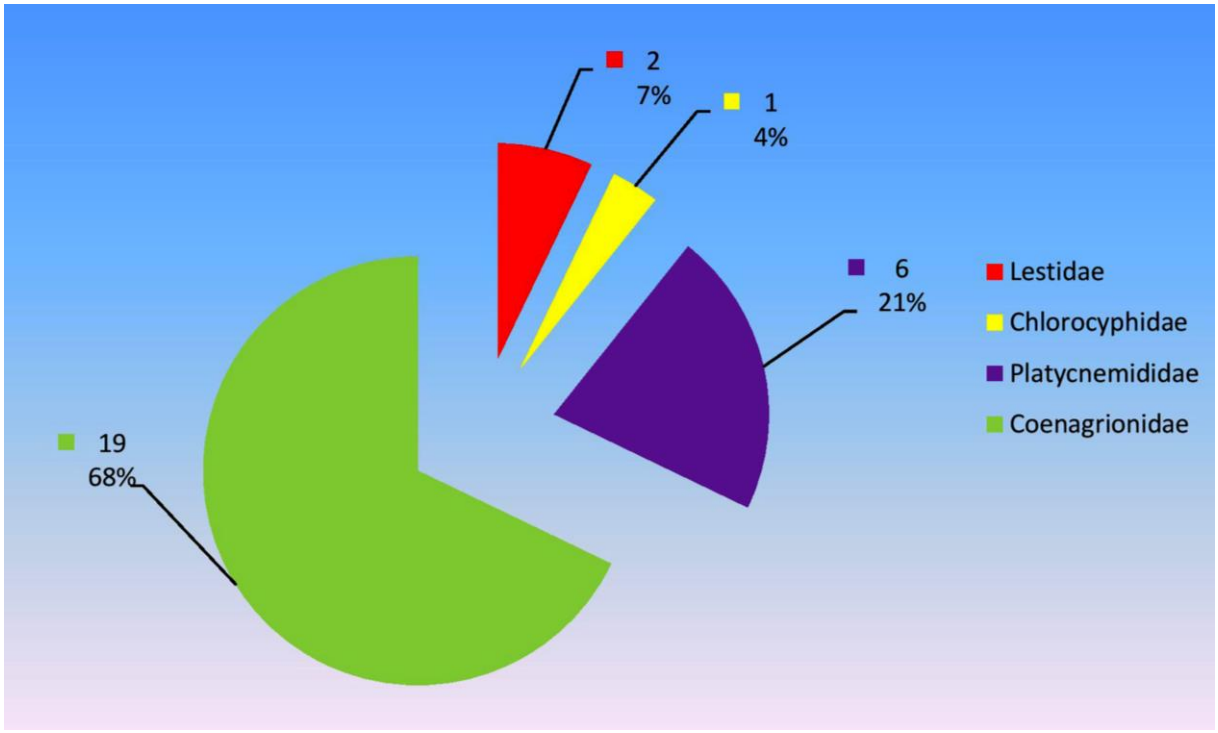

Figure 4: Pie chart of the 28 Zygopteran species reported in this present works. Percentage of contribution in total 28 Zygopteran species is showing family wise in this figure.

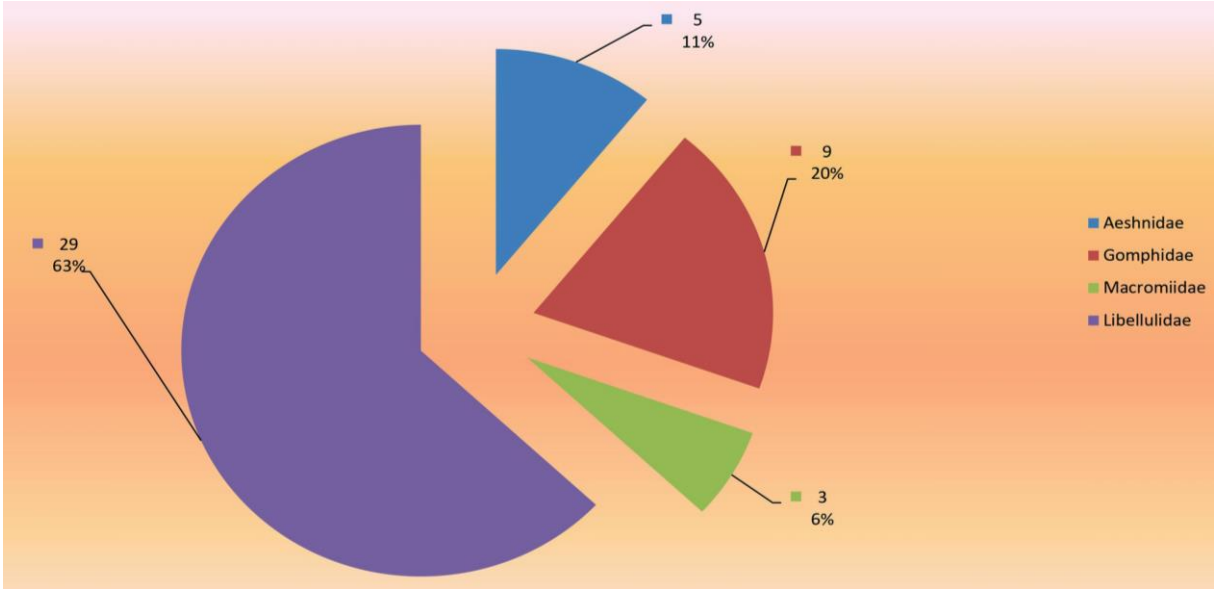

Figure 5: Pie chart of the 46 Anisopteran species reported in this paper. Percentage of contribution in total 46 Anisopteran species is showing family wise in this figure.

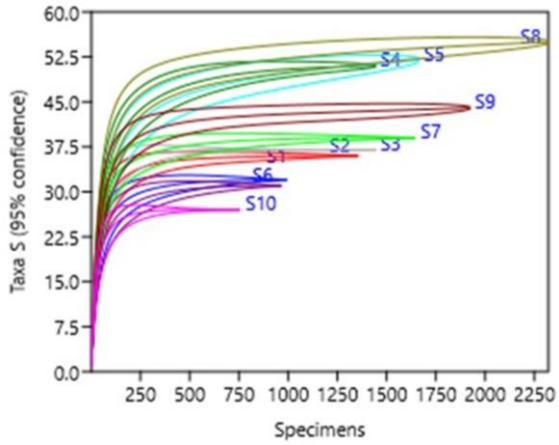

Figure 6: Individual-based Rarefaction Analysis Plot.

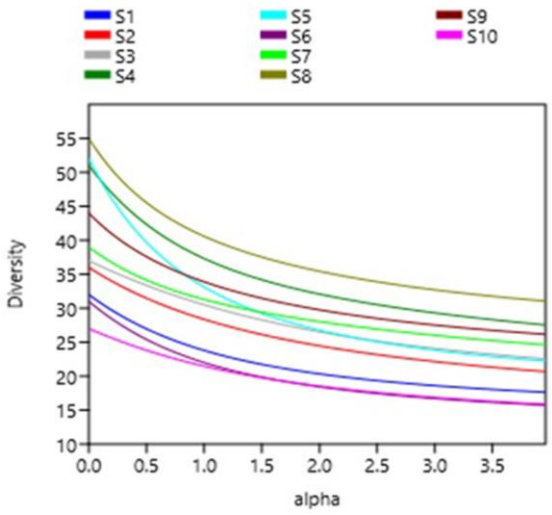

Figure 7: α-diversity of the study sites.

Discussion

Overview

Out of the 74 species recorded during the consistent fieldwork from the selected ten heterogeneous study sites in Bankura district, seven species are known to be endemic to India. Of these, *Cyclogomphus heterostylus* Selys, 1854, *Cyclogomphus ypsilon* Selys, 1854, *Microgomphus torquatus* Selys, 1854 are known to be restricted only to the Western Ghats, while *Macrogomphus annulatus* Selys, 1854, *Macromia flavicincta* Selys, 1874, *Caconeura ramburi* Fraser, 1922 and *Disparoneura quadrimaculata* Rambur, 1842 are known to be endemic to India (Kalkman et al., 2020). The high endemism of gomphids is in consonance with the findings of Subramanian and Babu (2017). While *Microgomphus torquatus* is a new record for the entire state of West Bengal, *Cyclogomphus heterostylus* and *Cyclogomphus ypsilon* were previously recorded from the Damodar riverbed bordering the district (Nayak and Roy, 2016; Nayak and Roy, 2021). Repeated sightings of these two *Cyclogomphus* spp. and the sighting of *Microgomphus torquatus* support their status as endemic throughout the Indian plateau region and its surroundings, instead of the previous known restricted range in the Western Ghats.

Among the ten sites studied, the highest diversity of odonates (but only anisopterans) were recorded from S8. Anisopterans, particularly libellulids and the zygopteran coenagrionids and lestids (known lentic species) primarily contributed to the richness of the Odonata fauna. The finding of Libellulidae as the most diverse odonate family, followed successively by Coenagrionidae, Gomphidae, Platycnemididae, Aeshnidae, and Macromiidae, with Chlorocyphidae represented by only a single species, conforms with the findings of Nayak and Roy (2021) from the neighboring Paschim Bardhaman district.

Figure 8: Study Site 1 - Susunia Hill Forest

Figure 9: Study Site 2 - Gandheswari River bank, Bankura town; Photo by Sourav Chakraborty

Figure 10: Study Site 3 - Kangsabati River, Mukutmanipur Dam

Figure 11: Study Site 4 - Silabati River bank, Kuldiha village

Figure 12: Study Site 5 - Kadma village

Figure 13: Study Site 6 - Raygar Forest

Figure 14: Study Site 7 - Damodar River, Nityanandapur

Figure 15: Study Site 8 - Damodar River, Durgapur Barrage

Figure 16: Study Site 9 - Damodar River bank, Metali village

Figure 17: Study Site 10 - Gangajalghati Forest

Figure 18: *Lestes praemorsus* Hagen in Selys, 1862 male; Site: S5; Date: 28 March 2020

Figure 19: *Lestes concinnus* Hagen in Selys, 1862 male; Site: S8; Date: 16 October 2016

Figure 20: *Libellago indica* (Fraser, 1928) male; Site: S4; Date: 14 October 2020

Figure 21: *Libellago indica* (Fraser, 1928) female; Site: S4; Date: 15 October 2020

Figure 22: *Agriocnemis kalinga* Nair and Subramanian, 2014 male; Site: S5; Date: 30 October 2019

Figure 23: *Agriocnemis kalinga* Nair and Subramanian, 2014 female; Site: S5; Date: 01 June 2021

Figure 24: *Agriocnemis lacteola* Selys, 1877
male; Site: S4; Date: 05 August 2018

Figure 25: *Agriocnemis lacteola* Selys, 1877
female; Site: S5; Date: 21 June 2019

Figure 26: *Agriocnemis splendidissima* Laidlaw, 1919
male; Site: S6; Date: 15 November 2020

Figure 27: *Agriocnemis pygmaea* (Rambur, 1842)
copula; Site: S4; Date: 08 December 2020

Figure 28: *Amphiallagma parvum* (Selys, 1867)
copula; Site: S5; Date: 22 October 2020

Figure 29: *Ceriagrion cerinorubellum* (Brauer, 1865)
male; Site: S8; Date: 13 September 2017

Figure 30: *Ceriagrion coromandelianum* (Fabricius, 1798)
copula; Site: S5; Date: 13 June 2018

Figure 31: *Ischnura nursei* Morton, 1907
male; Site: S5; Date: 22 October 2019

Figure 32: *Ischnura rubilio* Selys, 1876
male; Site: S5; Date: 22 September 2019

Figure 33: *Ischnura rubilio* Selys, 1876
female; Site: S8: Date: 30 May 2017

Figure 34: *Ischnura rufostigma* Selys, 1876
male; Site: S8; Date: 05 March 2017

Figure 35: *Ischnura rufostigma* Selys, 1876
female; Site: S5; Date: 19 October 2017

Figure 36: *Ischnura senegalensis* (Rambur, 1842)
copula; Site: S5; Date: 15 March 2020

Figure 37: *Mortonagrion aborense* (Laidlaw 1914)
male; Site: S5; Date: 02 September 2021

Figure 38: *Paracercion calamorum* (Ris, 1916)
male; Site: S5; Date: 01 June 2021

Figure 39: *Paracercion malayanum* (Selys, 1876)
male; Site: S8; Date: 03 November 2018

Figure 40: *Pseudagrion australasiae* Selys, 1876 copula; Site: S5; Date: 04 July 2020

Figure 41: *Pseudagrion decorum* (Rambur, 1842) male; Site: S4; Date: 16 June 2016

Figure 42: *Pseudagrion decorum* (Rambur, 1842) female; Site: S8; Date: 04 November 2018

Figure 43: *Pseudagrion microcephalum* (Rambur, 1842) male; Site: S9; Date: 31 January 2020

Figure 44: *Pseudagrion microcephalum* (Rambur, 1842) female; Site: S9; Date: 28 October 2018

Figure 45: *Pseudagrion rubriceps* Selys, 1876 copula; Site: S5; Date: 14 October 2020

Figure 46: *Pseudagrion spencei* Fraser, 1922 copula; Site: S8; Date: 07 September 2017

Figure 47: *Copera marginipes* (Rambur, 1842) male; Site: S4; Date: 22 September 2020

Figure 48: *Copera marginipes* (Rambur, 1842)
female; Site: S5; Date: 30 June 2019

Figure 49: *Caconeura ramburi* Fraser, 1922
male; Site: S6; Date: 30 June 2019

Figure 50: *Disparoneura quadrimaculata* (Rambur, 1842)
male; Site: S5; Date: 05 July 2019

Figure 51: *Onychargia atrocyana* (Selys, 1865)
male; Site: S9; Date: 29 October 2018

Figure 52: *Onychargia atrocyana* (Selys, 1865)
female; Site: S9; Date: 19 May 2019

Figure 53: *Prodasineura verticalis* (Selys, 1860)
copula; Site: S5; Date: 22 October 2020

Figure 54: *Pseudocopera ciliata* (Selys, 1863)
copula; Site: S4; Date: 07 November 2020

Figure 55: *Anaciaeschna jaspidea* (Burmeister, 1839)
male; Site: S9; Date: 30 March 2022

Figure 56: *Anax ephippiger* (Burmeister, 1839)
female; Site: S5; Date: 29 June 2019

Figure 57: *Anax indicus* Lieftinck, 1942
male; Site: S8; Date: 09 May 2020

Figure 58: *Anax guttatus* (Burmeister, 1839)
male; Site: S4; Date: 14 October 2020

Figure 59: *Gynacantha dravida* Lieftinck, 1960
male; Site: S5; Date: 13 July 2020

Figure 60: *Gynacantha dravida* Lieftinck, 1960
female; Site: S5; Date: 13 July 2020

Figure 61: *Cyclogomphus heterostylus* Selys, 1854
female; Site: S8; Date: 07 July 2014

Figure 62:*Cyclogomphus ypsilon* Selys, 1854
copula; Site: S4; Date: 12 November 2017

Figure 63: *Ictinogomphus kishori* Ram, 1985
male; Site: S4; Date: 26 July 2019

Figure 64: *Ictinogomphus kishori* Ram, 1985
female; Site: S8; Date: 30 May 2017

Figure 65: *Ictinogomphus rapax* (Rambur, 1842)
male; Site: S9; Date: 19 May 2019

Figure 66: *Ictinogomphus rapax* (Rambur, 1842)
female; Site: S9; Date: 09 May 2019

Figure 67: *Macrogomphus annulatus* (Selys,1854)
male; Site: S9; Date: 22 June 2020

Figure 68: *Macrogomphus annulatus* (Selys, 1854)
female; Site: S9; Date: 24 June 2020

Figure 69: *Macrogomphus montanus* Selys, 1869
male; Site: S9; Date: 02 June 2021

Figure 70: *Microgomphus torquatus* (Selys, 1854)
teneral female; Site: S4; Date: 22 September 2020

Figure 71: *Paragomphus lineatus* (Selys, 1850)
male; Site: S8; Date: 03 November 2018

Figure 72: *Paragomphus lineatus* (Selys, 1850)
female; Site: S9; Date: 09 May 2019

Figure 73: *Platygomphus dolabratus* Selys, 1854
male; Site: S8; Date: 09 May 2020

Figure 74: *Platygomphus dolabratus* Selys, 1854
female; Site: S8; Date: 25 June 2020

Figure 75: *Acisoma panorpoides* Rambur, 1842
male; Site: S9; Date: 09 May 2019

Figure 76: *Acisoma panorpoides* Rambur, 1842
female; Site: S9; Date: 09 May 2019

Figure 77: *Aethriamanta brevipennis* (Rambur, 1842)
male; Site: S9; Date: 24 June 2020

Figure 78: *Aethriamanta brevipennis* (Rambur, 1842)
female; Site: S9; Date: 24 June 2020

Figure 79: *Brachydiplax chalybea* Brauer, 1868
male; Site: S9; Date: 09 May 2019

Figure 80: *Brachydiplax chalybea* Brauer, 1868
female; Site: S8; Date: 25 June 2020

Figure 81: *Brachydiplax sobrina* (Rambur, 1842)
male; Site: S9; Date: 09 May 2019

Figure 82: *Brachydiplax sobrina* (Rambur, 1842)
female; Site: S8; Date: 13 September 2016

Figure 83: *Brachythemis contaminata* (Fabricius, 1793)
male; Site: S8; Date: 04 November 2015

Figure 84: *Brachythemis contaminata* (Fabricius, 1793)
female; Site: S9; Date: 06 May 2018

Figure 85: *Bradinopyga geminata* (Rambur, 1842)
male; Site: S5; Date: 09 June 2019

Figure 86: *Bradinopyga geminata* (Rambur, 1842)
female; Site: S4; Date: 02 November 2020

Figure 87: *Crocothemis servilia* (Drury, 1770)
male; Site: S9; Date: 23 May 2018

Figure 88: *Crocothemis servilia* (Drury, 1770)
female; Site: S9; Date: 03 November 2018

Figure 89: *Diplacodes nebulosa* (Fabricius, 1793)
copula; Site: S5; Date: 22 October 2019

Figure 90: *Diplacodes trivialis* (Rambur, 1842)
male; Site: S8; Date: 03 November 2018

Figure 91: *Diplacodes trivialis* (Rambur, 1842)
female; Site: S9; Date: 20 June 2020

Figure 92: *Lathrecista asiatica* (Fabricius, 1798)
male; Site: S5; Date: 29 July 2020

Figure 93: *Lathrecista asiatica* (Fabricius, 1798)
female; Site: S5; Date: 06 September 2017

Figure 94: *Macrodiplax cora* (Brauer, 1867)
male; Site: S5; Date: 24 July 2020

Figure 95: *Macrodiplax cora* (Brauer, 1867)
female; Site: S5; Date: 21 July 2020

Figure 96: *Neurothemis fulvia* (Drury, 1773)
male; Site: S9; Date: 25 December 2020

Figure 97: *Neurothemis fulvia* (Drury, 1773)
female; Site: S9; Date: 23 June 2020

Figure 98: *Neurothemis intermedia* (Rambur, 1842)
male; Site: S9; Date: 14 December 2021

Figure 99: *Neurothemis intermedia* (Rambur, 1842)
female; Site: S5; Date: 26 December 2021

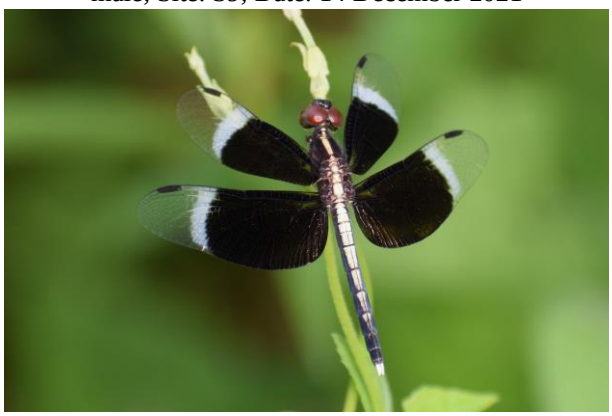

Figure 100: *Neurothemis tullia* (Drury, 1773)
male; Site: S9; Date: 09 May 2019

Figure 101: *Neurothemis tullia* (Drury, 1773)
female; Site: S5; Date: 10 December 2020

Figure 102: *Orthetrum glaucum* (Brauer, 1865)
female; Site: S5; Date: 01 December 2019

Figure 103: *Orthetrum pruinosum* (Burmeister, 1839)
male; Site: S9; Date: 20 June 2020

Figure 104: *Orthetrum pruinosum* (Burmeister, 1839) female; Site: S9; Date: 26 June 2020

Figure 105: *Orthetrum sabina* (Drury, 1770) copula; Site: S10; Date: 25 November 2020

Figure 106: *Pantala flavescens* (Fabricius, 1798) male; Site: S8; Date: 16 October 2016

Figure 107: *Pantala flavescens* (Fabricius, 1798) female; Site: S8; Date: 16 October 2016

Figure 108: *Potamarcha congener* (Rambur, 1842) male; Site: S9; Date: 26 June 2020

Figure 109: *Potamarcha congener* (Rambur, 1842) female; Site: S8; Date: 16 October 2016

Figure 110: *Rhodothemis rufa* (Rambur, 1842) male; Site: S9; Date: 09 May 2019

Figure 111: *Rhodothemis rufa* (Rambur, 1842) female; Site: S9; Date: 28 October 2018

Figure 112: *Rhyothemis variegata* (Linnaeus, 1763) male; Site: S5; Date: 11 July 2019

Figure 113: *Rhyothemis variegata* (Linnaeus, 1763) female; Site: S8; Date: 01 September 2019

Figure 114: *Tholymis tillarga* (Fabricius, 1798) male; Site: S8; Date: 16 October 2016

Figure 115: *Tholymis tillarga* (Fabricius, 1798) female; Site: S10; Date: 26 November 2020

Figure 116: *Tramea basilaris* (Palisot de Beauvois, 1805) male; Site: S9; Date: 14 October 2019

Figure 117: *Tramea basilaris* (Palisot de Beauvois, 1805) female; Site: S5; Date: 04 November 2019

Figure 118: *Tramea limbata* (Desjardins, 1832) male; Site: S4; Date: 18 October 2020

Figure 119: *Trithemis aurora* (Burmeister, 1839) male; Site: S5; Date: 12 July 2019

Figure 120: *Trithemis aurora* (Burmeister, 1839) female; Site: S5; Date: 21 July 2019

Figure 121: *Trithemis festiva* (Rambur, 1842) male; Site: S4; Date: 16 December 2020

Figure 122: *Trithemis festiva* (Rambur, 1842) female; Site: S5; Date: 09 June 2019

Figure 123: *Trithemis pallidinervis* (Kirby, 1889) male; Site: S9; Date: 03 November 2018

Figure 124: *Trithemis pallidinervis* (Kirby, 1889) female; Site: S9; Date: 02 July 2021

Figure 125: *Urothemis signata* (Rambur, 1842) male; Site: S9; Date: 28 October 2018

Figure 126: *Urothemis signata* (Rambur, 1842) female; Site: S9; Date: 24 June 2020

Figure 127: *Zyxomma petiolatum* Rambur, 1842 male; Site: S5; Date: 13 May 2018

Figure 128: *Zyxomma petiolatum* Rambur, 1842 female; Site: S5; Date: 11 Augst 2020

Figure 129: *Epopthalmia vittata* Burmeister, 1839 male; Site: S9; Date: 09 May 2019

Figure 130: *Macromia cingulata* Rambur, 1842 male; Site: S8; Date: 25 June 2020

Figure 131: *Macromia flavicincta* Selys, 1874 male; Site: S9; Date: 09 October 2020

Figure 132: *Macromia flavicincta* Selys, 1874 female; Site: S9; Date: 23 June 2020

Of the ten heterogeneous study sites surveyed, the area around Durgapur Barrage on the Damodar River (S8) proved to be the most diverse, closely followed by a rural habitat (S5) and another riverine habitat (S4). The sites S10 and S6 were found to be least diverse, with both areas being forested and lacking perennial flowing water. Despite heavy anthropogenic and industrial pollution of the Damodar River, the rich diversity profile of S8, including the presence of a few endemic gomphids, indicates the potential for environmental recovery if proper immediate conservation measures are initiated. The presence of species such as *Libellago indica*, *Microgomphus torquatus*, *Disparoneura quadrimaculata*, and *Prodasineura verticalis* Selys, 1860 in the comparatively undisturbed and rather less polluted habitats of the Silabati riverbed (S4) and the nearby Kadma village (S5) is a prominent indicator that the undisturbed, unpolluted riverine habitats in this region provide an ideal habitat to odonate species known to be present primarily across the Indian Peninsular Plateau.

Status and abundance of Odonata

Odonate diversity of the different sites of this district helps to visualize the habitat heterogeneity as well as the health of the freshwater ecosystems (Subramanian et al., 2008; Golfieri et al., 2016). The Taxa_S count (Fig. 6; Table 4), indicating the number of species, clearly indicates high species diversity in S8 (55 species), S5 (52 species) and S4 (51 species). Site S5 led in the highest diversity of damselflies (zygopterans) and closely follows site S8 in terms of total odonate diversity.

The diversity of site S5 can be attributed to the occurrence of a wide range of mixed, unpolluted habitat in a rural setting, ranging from ponds, tanks, irrigation canals, and marshy agricultural fields to remnants of dry deciduous forests, mixed vegetation, and fruit orchards in that area. Sites S4 and S8 both represent riverine habitats but they differ considerably from one another. While a barrage has been created in S8 on the Damodar River leading to a formation of reservoir on the upstream (S9), the heterogeneity of sandy riverbed downstream and the extensive marshlands and grasslands formed as a result has proved to be a treasure house for odonate diversity, especially for gomphids, and macromiids (Table 3). The Damodar River reaches the S8 site after traversing through industrial and coalfield towns, and hence suffers from anthropogenic pollution of heavy metallic industrial affluents (Dey et al., 1985; Banerjee and Gupta, 2013; Seal et al., 2022). However, while the Damodar River at the barrage showed highest diversity at S8, the diversity has declined rapidly to site S7, located only 21 km downstream. This decline in diversity can be attributed to the industrial pollution– the heavy metallic effluents being deposited by its tributary, the Tamla River (Banerjee and Gupta, 2013), evident by higher surface water temperature, quite low dissolved oxygen and increased BOD (Dutta et al., 2021). Thus, while variation of vegetation around S8 is a key factor to diversity, pollution of rivers is also a key factor to the odonate diversity given the industrialization, urbanization, and mining activities around the Damodar River basin (Chakraborty et al., 2021). However, the unpolluted fast-flowing Silabati River traverses through dissected highlands of the Chhotanagpur Plateau, characterized by rill and gully formations giving rise to badland topography (Mahala, 2019). The observed diversity of site S4 on the Silabati River and nearby at site S5 can be largely attributed to this lack of pollution and anthropogenic interference.

The Taxa_S index also showed least species richness at site S10, closely followed by S6 and S1. S10 represents a rural fragmented forest with only an irrigation canal drawn from the Sali River, with no perennial flowing river in the habitat. It is presumably the least species rich site with only 27 odonate species recorded. Site S6 with 30 species and S1 with 32 species recorded are slightly more species richness. Both forests also lack a perennial flowing water channel, though there is a feeble seasonal stream in site S6. Of the two types of freshwater habitats studied herein, the results indicated more odonate diversity in lotic (running) freshwater environments and lower species richness in lentic (standing) water bodies.

Lotic environments have been known to provide heterogeneous and favorable habitats for diverse zygopteran species (Corbet and May, 2008), evident by the finding of *Agriocnemis splendidissima* Laidlaw, 1919 only in S6 (seasonal stream), regular sightings of a large colony of 25–30 individuals belonging to *Libellago indica* (Fraser, 1928), and the year-round sightings of around 15–20 individuals of *Prodasineura verticalis* (Selys, 1860), both only from S4. Until now, S4 is the only known locality of the latter species from West Bengal.

Distinctive characteristics of newly recorded odonates

A single individual female of *Ischnura rufostigma* Selys, 1876 was observed at S8 on 7 March 2015. It is characterized by a bright reddish-orange abdomen marked with black. The legs are pale yellow with black short spines. It can be clearly differentiated from the very similar and far more common *Ischnura nursei* (Morton, 1907) by a dorsal black spot shaped like a trident on the 1st segment of the female abdomen (Fraser, 1933). It was previously reported from the adjoining Paschim Bardhaman district on the opposite bank of the Damodar River (Nayak and Roy, 2016). Its distribution was known from parts of West Bengal, undivided Bihar, Madhya Pradesh in central India (Fraser, 1933). Dawn (2021) reported it from Koch Bihar, Jalpaiguri districts of northern West Bengal.

Prodasineura verticalis (Selys, 1860) is known to oviposit on vegetation or on submerged roots in shallow running water (Fraser, 1924; Nair, 2011). Thus, the mouth of a shallow canal shrouded with mixed shrubs and herbs near its confluence with the Silabati River provides the ideal habitat.

Disparoneura quadrimaculata (Rambur, 1842), a flagship damselfly of the rocky terrain and badland characteristic of the plateau, was commonly found in the rocky riverbed of fast-flowing Silabati River at site S4.

It is known to perch on rocks and boulders on streams and rivers (Subramanian, 2005; Nair, 2011). While S6 has been relatively low in terms of species diversity, the presence of *Agriocnemis splendidissima* Laidlaw, 1919, an uncommon species in the region, is worth mentioning. It can be distinguished by the characters mentioned by Laidlaw (1919) in its original description. It was observed at a typical seasonal puddle inside the forest, which is typical of its habitat (Nair, 2011). *Anax ephippiger* (Burmeister, 1839), a migratory species, common in Western India, but uncommon in Eastern India (Nayak, 2020), is also an interesting find. It is known to breed only in stagnant waters (Fraser, 1924) and also was observed to lay eggs in a pond in site S5.

Ictinogomphus kishori Ram, 1985 has been observed several times by the authors. A male was first observed by the first author at a stagnant marshy area on 07 July 2014 from S8. Males and females have subsequently been sighted by all the three authors from S4, S5, S7, S8 and S9. However, for long, these individuals were misidentified as *Ictinogomphus distinctus* Ram, 1985 which was described from three males collected from Howrah district in West Bengal. In the recently published annotated odonate checklist of West Bengal (Dawn, 2021) too, *I. kishori* was not listed.

However, the species can be readily distinguished by comparing the Segment 10, where the citron yellow is broad in *I. distinctus*, but the yellow is reduced to only a spot in *I. kishori* (Ram, 1985). Apart from type locality Azamgarh in Uttar Pradesh, India, it has also been found in the Himalayan country of Nepal (Vick, 1989). While *I. distinctus* was reported earlier from the adjacent Paschim Bardhaman district (Nayak and Roy, 2016), *I. kishori* has also been recorded there (at Dhubchururia village in Andal block) which was previously misidentified as *I. distinctus*. This article thus confirms the presence of *I. kishori* in western part of West Bengal from Bankura and Paschim Bardhaman districts and reports overlapping distribution range of *I. kishori* and *I. distinctus.*

An *Ictinogomphus* sp. female sighted at S8 by the first author on 30 May 2017 however has citron yellow broader (compared to other *I. kishori* females) in Segment 10. However, since the female of the related *I. distinctus* was neither collected nor described and given the variability of end segments in females, the authors suggest further work on the taxonomy and distribution of the genus in the region.

A female individual of *Cyclogomphus heterostylus* Selys, 1854 was observed at site S8. A previous report from the opposite bank of the river in the adjoining Paschim Bardhaman district is known (Nayak and Roy, 2021). Dawn (2021), however, reported it only from Darjeeling district in northern West Bengal. Known to be distributed in central India and Deccan, this species can be differentiated reliably from the very similar and more common *Cyclogomphus ypsilon* Selys, 1854 by an entirely yellow labrum, thicker black band on the lower frons and formation of a distinct second 'Y' on the sides of thorax, while *Cyclogomphus ypsilon* Selys, 1854 has only one 'Y' (Fraser, 1934). The only other similar species with a second 'Y' is *C. gynostylus* Fraser, 1926, which is endemic to the island of Sri Lanka (Kalkman et al., 2020) and can be distinguished from *Cyclogomphus heterostylus* Selys, 1854 only by the male cerci (Jose and Chandran, 2020). This report confirms the presence of this species in the Damodar River Valley. Reported to be endemic only to Western Ghats (Kalkman et al. 2020), this report confirms its presence well beyond the Western Ghats. The findings from the Cooum River (misspelt as the Coomb River) from Chennai (erstwhile Madras) (Fraser, 1934) in the Coromandal Coast were also outside the reaches of the Western Ghats. Thus, the status of *Cyclogomphus heterostylus* Selys, 1854 should be treated as endemic to India (Babu et al. 2013) and should not be considered restricted only to Western Ghats.

An individual of *Microgomphus torquatus* Laidlaw, 1919 was observed to be preyed upon by *Orthetrum sabina* (Drury, 1770) at site S4 on 22 September 2020. A teneral female of the species was again sighted at the same spot on 11 October 2020. The species can be reliably differentiated from its nearest relative *Microgomphus souteri* Fraser, 1924 by the lateral black stripe, which by meeting the finely black upper part of the postero-lateral suture forms a 'Y'-shaped marking (Sélys-Longchamps, 1854). In *Microgomphus souteri* the area between the arms of the 'Y' is filled in to form a broad black stripe expanding above (Fraser, 1924). Since two individuals of the species were sighted in different months, including a teneral female, it is assumed that S4 holds a breeding population of the species. The species was initially known from western parts of Deccan (Fraser, 1934). Rathod et al. (2016) extended range northwards into the Dang district of Gujarat, which is the northernmost extension of Western Ghats. Dawn and Chandra (2014) extended its range to Titirgaon near Jagdalpur in the Bastar district of Chhattisgarh, central India, thereby extending its range outside the Western Ghats. It has also been sighted repeatedly from the Deccan Peninsula in eastern parts of Maharashtra, even outside the Western Ghats (Tiple and Koparde, 2015; Tiple, 2020). This observation thus extends its range northeastwards by 675 km (aerial distance measured by Google Earth). Previously reported only from the Western and Central India, this is the first observation of the species from Eastern India and thus confirms the presence of the species across the Deccan Peninsula. Site S4, where the new observation occurred, is located just beyond the foot of the Chhotanagpur Plateau (the northeasternmost extension of the Deccan Peninsula) in the Silabati River basin. This species has been considered as endemic to the Western Ghats only (Kalkman et al., 2020). The new record results in an updating of the status as endemic more broadly to India.

The identifying characters and previously known distribution status of *Macromia cingulata* Rambur, 1842, *Macromia flavicincta* Selys, 1874, *Pseudagrion australasiae* Selys, 1876 and *Libellago indica* (Fraser, 1928) have been discussed in detail in a previous publication (Nayak and Roy, 2021).

Diversity and abundance of Odonata across sites

The high values of Simpson's 1-D index in S8, S5 and S4, with comparatively lower values in S6 and S10 and S1 correspond to the higher and lower diversity suggested by the Taxa_S values. In accordance with the species diversity indicated by Taxa_S, Sites S8 (2,333 individuals) and S10 (765 indivduals) also showed the highest and lowest abundances of odonate individuals among the study sites respectively, as indicated by the Individuals count (Table 4). Shannon's index, which rises with the number of species and the evenness of their abundance also demonstrates a similar trend. Study site S5 showing the least value of Evenness index can be attributed to the wide range of microhabitats within the rural environment. The high value of Berger-Parker index indicates the lack of diversity and single taxa dominance in S10, which is also the least diverse and least abundant of the study sites. It can be attributed to the abundance of the common species, and lack of findings of uncommon rarities. The value of Evenness Index in S5 being the least points to the diversity and least evenness of the abundance of those species.

Individual rarefaction analysis (Fig. 6) of data plots the number of specimens sampled with probability of taxa number obtained. While S8 and S10 clearly form the upper and lower curves of the plot, it was observed that with an increase in number of specimens sampled, the taxa number of S5 slightly surpasses S4. The α-diversity profile (Fig. 7) indicates species richness, heterogeneity, dominance and evenness. At α= 0, S5 is next only to S8, and is minutely followed by S4, indicating species diversity. At α= 1, S5 also falls below S4 and S9, indicating Shannon's indices. The overlapping of the curves shows that the trends demonstrated by the various α diversity indices are not similar for the study sites.

The UPGMA dendrogram (Fig. 3) demonstrates that the primary forest sites S1 and S6 are most closely related, while closely situated the Damodar Riverbank sites S8 and S9 are closely related.

Conclusion

The Bankura district shows characteristics of both undulating plateau region in the west and Gangetic plains in the east, which is evident by the high global β-diversity in the district. The district suffers from moderate levels of anthropogenic interference, which is particularly very high in the Damodar River on the north due to the presence of many industries and coal mines in the basin, low in the remnant deciduous forests, and moderate in the agricultural plains. Despite the pollution from effluents in the Damodar River, the diversity of Odonata indicates the promise of the district ecosystem as an Odonata hotspot if proper conservation and planned de-polluting measures are initiated. A long-term ecological monitoring scheme needs to be taken up to study the correlation of pollution with diversity and abundance of odonates. Citizen scientists are increasingly contributing to biodiversity monitoring in various parts of the world by reporting species observations in various web portals such as iNaturalist, GBIF, eBird, India Biodiversity Portal, Biodiversity of West Bengal, and DiversityIndia websites and to various unstructured databases such as social media groups. Thorough surveys across the Bankura district and long-term observations by researchers, and documentation from citizen scientists would enrich the information of biodiversity of the district, as well as the state.

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Conflict of interest

The authors declare that there are no conflicting issues related to this research article.

Supplementary files

Supplementary files associated with this article are available for download at https://jad.lu.ac.ir/article-1-168-en.html

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