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Evaluating wetland health using Odonata diversity and seasonal shifts in Tulshi Reservoir, Maharashtra, India

Rahul S. Kamble[1*], Gajanan K. Sontakke[1] and Sagar A. Vhanalakar[2]

[1]Department of Zoology, Vivekanand College (Empowered Autonomous), Kolhapur 416 003, Maharashtra, India.
[2]Department of Zoology, Karmaveer Hire Arts, Science, Commerce and Education College, Gargoti, Kolhapur 416 209, Maharashtra, India.
Email: rahulkamble3470@gmail.com, drgksontakke@gmail.com, sagarayan36@gmail.com

ABSTRACT: The study assesses species composition and seasonal variation of odonates at Tulshi Reservoir in Kolhapur district, northern Western Ghats, Maharashtra. Field surveys were carried out during pre-monsoon, monsoon, and post-monsoon seasons through direct observations and photographic documentation. A total of 32 species belonging to two suborders (Anisoptera and Zygoptera) and four families (Libellulidae, Gomphidae, Platycnemididae, and Coenagrionidae) were recorded, with Libellulidae being the most dominant. Species richness peaked in the post-monsoon season, likely due to improved water quality and enhanced aquatic vegetation. Generalist taxa such as *Trithemis aurora* (Burmeister, 1839) and *Pseudagrion decorum* (Rambur, 1842) occurred throughout the year, whereas certain species, including *Amphiallagma parvum* (Selys, 1876), appeared only in specific seasons. These findings emphasize the ecological importance of Tulshi Reservoir in sustaining odonate diversity and support the use of these insects as effective indicators of wetland health.

KEY WORDS: Freshwater ecosystem, species composition, richness, seasonal variation, Western Ghats

INTRODUCTION

Freshwater ecosystems, though covering a small fraction of the Earth's surface, support exceptionally rich biodiversity and deliver essential ecological services. Among aquatic insects, dragonflies and damselflies (Order- Odonata) are widely recognized as bioindicators because of their biphasic life cycle, habitat specificity, and sensitivity to environmental changes (Choudhary and Ahi, 2015; Kulkarni and Subramanian, 2015). Larvae respond to water quality variables such as dissolved oxygen, pH, and nutrient levels, while adults reflect riparian and terrestrial habitat conditions (Husband, 2022). Their visibility, ecological role, and ease of identification make them effective tools for monitoring freshwater health.

Worldwide, insect communities are undergoing significant changes, with Odonata frequently highlighted in biodiversity assessments for their responsiveness to environmental pressures (Van Klink *et al.,* 2020; Jähnig *et al.,* 2021). In India, freshwater habitats are increasingly threatened by urbanization, agricultural intensification, and climate variability. The Western Ghats, a global biodiversity

* Author for correspondence

hotspot, supports diverse odonate assemblages, including many endemic species (Koparde *et al.,* 2015; Vincy *et al.,* 2016). Artificial wetlands such as reservoirs, despite being human-made, can provide important refuges and dispersal corridors for aquatic fauna in modified landscapes (Deacon *et al.,* 2019).

Seasonal changes strongly influence odonate abundance and species composition, with patterns linked to rainfall, temperature, and vegetation dynamics (Pattanayak *et al.,* 2019; Dutta Saha, 2022; Aghade and Saraf, 2023; Olambe *et al.,* 2024). However, data on reservoir habitats in Kolhapur district remain scarce. This study documents the diversity and seasonal variation of Odonata at Tulshi Reservoir, providing baseline information for conservation planning and highlighting the role of artificial wetlands in sustaining freshwater biodiversity in the Western Ghats.

MATERIALS AND METHODS

The study was conducted at the Tulshi Reservoir, located in the Kolhapur district of Maharashtra state, India, in the northern Western Ghats. The reservoir lies at approximately 16.2°N ; 74.2°E, at an approximate elevation of 700m above sea level. The study site is a man-made freshwater reservoir covering a catchment area of 34.12 km² (135 ha), surrounded by a varied landscape of farmland, semi-deciduous forest patches, and rural villages. The area experiences a tropical monsoon climate, with distinct pre-monsoon (February to May), monsoon (June to September), and post-monsoon (October to January) seasons. The reservoir receives inflow from local streams and retains water throughout the year creating a stable aquatic environment suitable for both lentic and riparian biodiversity (Fig. 1).

From January 2022 to December 2023, odonate surveys were conducted across the region's three seasons: pre-monsoon, monsoon, and post-monsoon. Sampling was carried out fortnightly during two daily intervals, from 7.30 am to 11.30 am and 4.00 pm to 6.00 pm, under favourable weather conditions. These timeframes were selected to align with peak adult odonate activity, thereby maximizing the accuracy of species detection and identification.

Dragonflies and damselflies were identified primarily through visual observation using 10×42 binoculars and high-resolution digital photography (Nikon D5600 DSLR with a 70–300mm lens). Where required for species-level confirmation, representative specimens were captured using insect sweep nets and handled carefully to avoid damage. Captured individuals were placed briefly in insect collection tubes, examined in the field under hand lenses, and released at the point of capture.

Identification and Taxonomic Validation:Odonate species were identified using a combination of morphological keys, field guides, and regional checklists specific to South Asia and India. Primary identification references included Fraser (1931, 1933, 1934, 1936), Subramanian and Sivaramakrishnan (2007), Subramanian *et al.* (2018), Kalkman *et al.* (2020), Nair *et al.* (2021) and Subramanian and Babu (2024).

Diversity Analysis: Diversity indices, including species richness, Shannon–Wiener, Simpson's dominance, and evenness, were calculated using PAST software (version 4.03).

Dragonfly Biotic Index (DBI): The ecological quality of the study sites was assessed using the Dragonfly Biotic Index (DBI) (Clark and Samways, 1996; Samways and Steytler, 1996). Field surveys were undertaken to record dragonfly species, which were identified using standard field guides and taxonomic keys (Fraser, 1933–1936; Subramanian, 2005). Each species was assigned a DBI score ranging from 0 to 9, derived from three attributes: (i) Geographical Distribution (0–3), with widespread species scoring 0–1, moderately restricted 2, and endemic or highly restricted 3; (ii) Habitat Sensitivity (0–3), with tolerant or generalist species scoring 0–1, moderately sensitive 2, and habitat specialists 3; and (iii) Threat Status (0–3), based on IUCN Red List categories, where Not Threatened = 0, Near Threatened = 1, Vulnerable = 2, and Endangered/Critically Endangered = 3. The DBI of each species was obtained by summing these values:

$DBI_{(species)}$ = Distribution + Sensitivity + Threat Status

Two indices were then calculated for each site: (a) Total DBI, the sum of DBI scores for all recorded species, and (b) Mean DBI, calculated as:

$$DBI_{(mean)} = \frac{DBI\ (Total)}{Number\ of\ Species}$$

Interpretation followed Clark and Samways (1996): low DBI values indicate habitats dominated by widespread, tolerant taxa and thus ecological degradation, while high DBI values reflect the presence of restricted, sensitive, or threatened species, signifying healthier, less disturbed ecosystems (Subramanian *et al.,* 2008).

RESULTS AND DISCUSSION

A total of 32 species of Odonata were recorded at Tulshi Reservoir, representing two suborders, Anisoptera (dragonflies) and Zygoptera (damselflies), distributed across four families: Libellulidae, Gomphidae, Platycnemididae, and Coenagrionidae. The suborder Anisoptera accounted for 17 species, with Libellulidae being the most dominant family, comprising 15 species (Fig. 3). Notable species such as *Trithemis aurora* (Burmeister, 1839), *Trithemis kirbyi* (Selys, 1891), *Rhodothemis rufa* (Rambur, 1842), *Brachythemis contaminata* (Fabricius, 1793), and *Lathrecista asiatica* (Fabricius, 1798) were observed consistently throughout the year, indicating their adaptability to changing seasonal conditions. Several species, including *Pantala flavescens* (Fabricius, 1798), *Hydrobasileus croceus* (Brauer, 1867), *Trithemis pallidinervis* (Kirby, 1889), *Diplacodes trivialis* (Rambur, 1842), Orthetrum *sabina* (Drury, 1770), *Macrodiplax cora* (Kaup, 1867), and *Urothemis signata* (Rambur, 1842), were exclusive to the monsoon and post-monsoon seasons, suggesting a strong seasonal emergence pattern. The family *Gomphidae* was represented by a single species, *Ictinogomphus rapax* (Rambur, 1842), *Paragomphus lineatus* (Selys, 1850) recorded only during the monsoon and post-monsoon periods (Fig. 3).

A total of 17 species were evaluated, with DBI values ranging between 2 and 4 (Table 3). The majority of species, such as *Trithemis aurora*, *T. kirbyi*, *Diplacodes trivialis*, and *Crocothemis servilia*, scored 2, indicating their widespread distribution and generalist nature. Species including *Orthetrum pruinosum*, *Rhodothemis rufa*, *Urothemis signata*, *Macrodiplax cora*, *Tholymis*

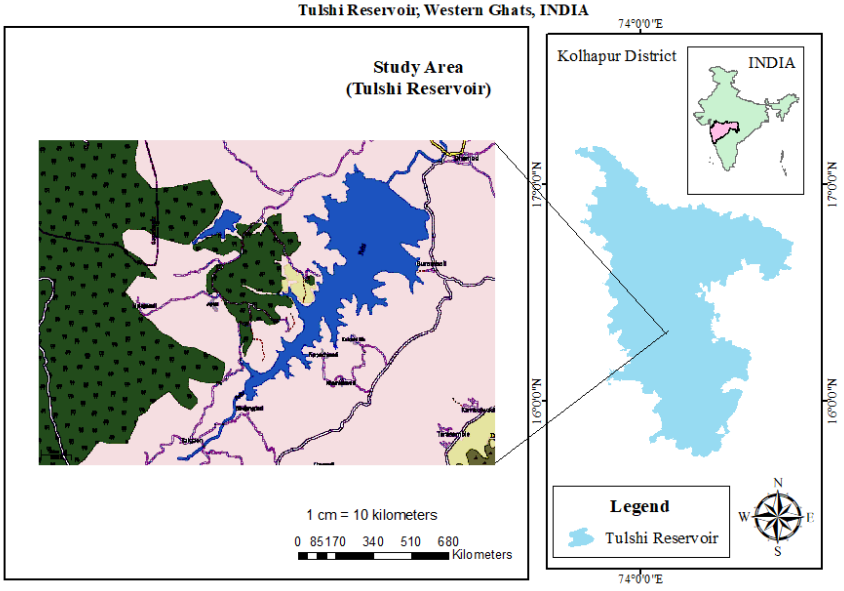

Fig. 1 Study area: Tulshi Reservoir, Maharashtra, India

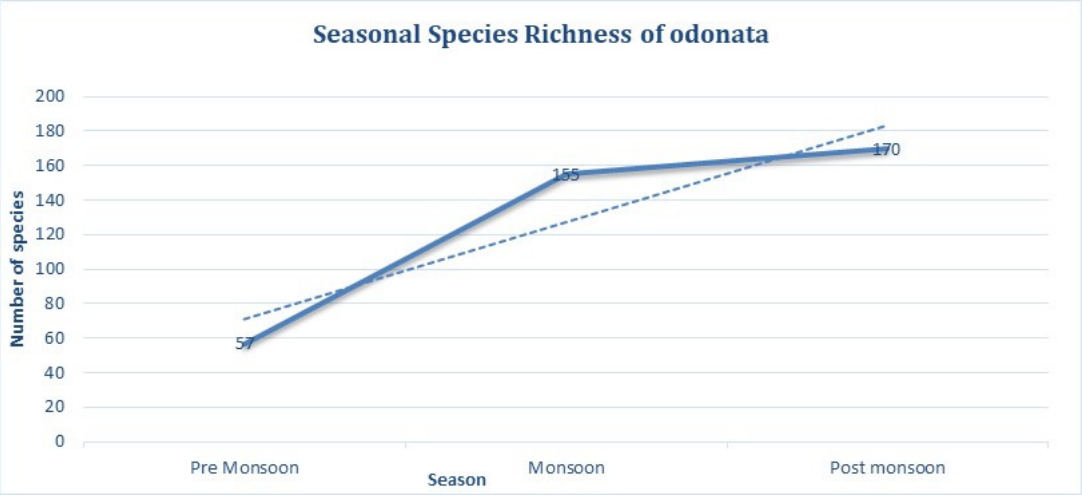

Fig. 2 Seasonal species richness of odonata

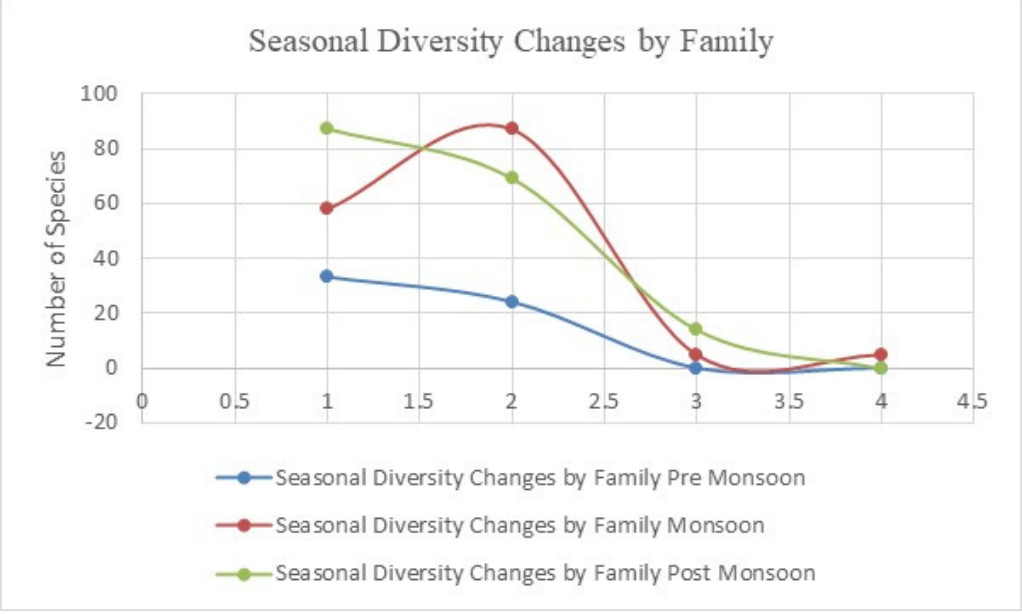

Fig. 3 Familywise seasonal diversity changes

tillarga, *Lathrecista asiatica*, and *Paragomphus lineatus* showed slightly higher DBI values (3), reflecting moderate habitat sensitivity and restricted distribution. The highest DBI score (4) was recorded for *Hydrobasileus croceus* and *Ictinogomphus rapax*, suggesting their greater ecological significance as sensitive taxa with relatively limited distribution. The absence of threatened or endangered species kept threat scores uniformly low (0), highlighting the dominance of common and regionally distributed taxa in the assemblage. Overall, the DBI analysis indicates that the Tulshi Reservoir supports a moderately diverse odonate community with species of both generalist

Table 1. Distribution of Odonata species at Tulshi reservoir during different periods, indicating presences (+) and absences ()

Common Name	Suborder/Family/Scientific Name	Pre	M	Post
	Suborder—Anisoptera/ Family-*Libellulidae*			
Crimson Marsh Glider	*Trithemis aurora* (Burmeister, 1839)	+	+	+
Kirby's Drop wing	*T. kirbyi* (Selys, 1891)	+	+	+
Green Marsh Hawk	*Orthetrum sabina* (Drury, 1770)	-	+	+
Crimson-tailed Marsh Hawk	*O. pruinosum* (Burmeister, 1839)	+	+	+
Ground Skimmer	*Diplacodes trivialis* (Rambur, 1842)	-	+	+
Scarlet Skimmer	*Crocothemis servilia* (Drury, 1773)	+	+	+
Wandering Glider	*Pantala flavescens* (Fabricius, 1798)	-	+	+
Long-legged Marsh Glider	*T. pallidinervis* (Kirby, 1889)	-	+	+
Rufous Marsh Glider	*Rhodothemis rufa* (Rambur, 1842)	+	+	+
Greater Crimson Glider	*Urothemis signata* (Rambur, 1842)	-	+	+
Coastal Glider	*Macrodiplax cora* (Kaup, 1867)	-	+	+
Amber-winged Marsh Glider	*Hydrobasileus croceus* (Brauer, 1867)	-	+	+
Coral-tailed Cloudwing	*Tholymis tillarga* (Fabricius, 1798)	+	-	+
Asiatic Blood Tail	*Lathrecista asiatica* (Fabricius, 1798)	+	+	+
Ditch Jewel	*Brachythemis contaminata* (Fabricius, 1793)	+	+	+
	Family-*Gomphidae*			
Common Clubtail	*Ictinogomphus rapax*(Rambur, 1842)	-	+	+
Lined Cocktail	*Paragomphus lineatus* (Selys, 1850)	-	+	+
	Suborder—ZYGOPTERA			
	Family-*Coenagrionidae*			
Red-tipped Dartlet	*Argiocnemis rubescens* (Selys, 1877)	-	+	+
Olive Marsh Dart	*Ceriagrion olivaceum* (Laidlaw, 1914)	-	+	+
Pygmy Dartlet	*Agriocnemis pygmaea* (Rambur, 1842)	+	-	+
Variable Dartlet	*Agriocnemis femina* (Brauer, 1868)	+	-	+
Aurora Bluetail	*Ischnura aurora* (Brauer, 1865)	-	+	+
Senegal Golden Dartlet	*Ischnura senegalensis* (Rambur, 1842)	+	+	+
Coromandel Marsh Dart	*Ceriagrion coromandelianum* (Fabricius, 1798)	+	+	+
Orange Marsh Dart	*Ceriagrion cerinorubellum* (Brauer, 1865)	+	+	+
Saffron-faced Blue Dart	*Pseudagrion rubriceps* (Selys, 1876)	+	+	+
Blue Grass Dart	*Pseudagrion microcephalum* (Rambur, 1842)	+	+	+
Azure Dartlet	*Amphiagrion parvum* (Selys, 1876)	-	+	+
Abor Marsh Dart	*Mortonagrion aborense* (Laidlaw, 1914)	-	+	+
Three-lined Dartlet	*Pseudagrion decorum* (Rambur, 1842)	+	+	+
Western Golden Dart	*Ichnura rubilio* (Selys, 1876)	-	+	-
	Family: Platycnemididae			
Blue Bush Dart	*Copera vittata* (Selys, 1863)	-	+	-

Pre - Pre-monsoon; M – Monsoon; Post - Post-monsoon

and sensitive ecological categories.

The suborder Zygoptera included 15 species, belonging to the Coenagrionidae and Platycnemididae families (Fig. 3). This group showed a marked increase in species richness during the monsoon and post-monsoon season (Fig. 2). Species such as *Pseudagrion decorum* (Rambur, 1842), *Pseudagrion rubriceps* (Selys, 1876), *Ceriagrion cerinorubellum* (Brauer, 1865), *Pseudagrion decorum* (Rambur, 1842), and *Ischnura senegalensis* (Rambur, 1842) were present in all three seasons, indicating wide ecological tolerance (Table 1). In contrast, species like *Amphiallagma parvum* (Selys, 1876), *Mortonagrion aborense* (Laidlaw, 1914), *Ischnura aurora* (Brauer, 1865), and *Ceriagrion olivaceum* (Laidlaw, 1914) were recorded in the monsoon and post-monsoon periods, possibly due to favorable habitat conditions such as increased aquatic vegetation and stable water levels. Additionally, *Ichnura rubilio* (Brauer, 1865) and *Copera vittata* (Selys, 1863) species were exclusively observed during monsoon season (Table 1).

The post-monsoon season showed the highest odonate diversity, indicating rich ecological conditions at the reservoir (Fig. 2). Stable water levels and dense aquatic vegetation likely supported adult emergence and activity. The monsoon season was also important, offering suitable conditions for breeding and larval development. High humidity, rainfall, and flooded habitats favoured early life stages. These findings highlight the role of odonates as reliable indicators of wetland health (Table 1).

Table 2 Seasonal variation in abundance and diversity indices of odonates assemblages at Tulshi Reservoir, Western Ghat, India

No.	Diversity indices	Pre-monsoon	Monsoon	Post-monsoon
1.	Individuals	57	155	170
2.	Dominance_D	0.265	0.2599	0.2592
3.	Margalef	4.223	5.578	5.147
4.	Simpson_1-D	0.735	0.7401	0.7408
5.	Evenness_e^H/S	0.406	0.3207	0.3439
6.	Menhinick	1.967	1.874	1.681
7.	Brillouin	1.896	2.189	2.211
8.	Shannon_H	2.143	2.359	2.367

The analysis of seasonal variation in odonate diversity at Tulshi Reservoir demonstrated clear differences among the three sampling periods (Table 2). The number of individuals increased steadily from 57 in the pre-monsoon to 155 during the monsoon and reached a maximum of 170 in the post-monsoon. Indices of species richness showed notable variation, with Margalef's index rising from 4.223 in pre-monsoon to 5.578 in monsoon, followed by a slight decline in post-monsoon (5.147). Menhinick's index followed a decreasing trend (1.967–1.681), reflecting the effect of higher abundance on richness values. Diversity indices such as Shannon–Wiener (H2) and Brillouin indicated a gradual increase from pre-monsoon (2.143 and 1.896, respectively) to post-monsoon (2.367 and 2.211), suggesting enhanced heterogeneity in species composition with seasonal progression. Simpson's index (1–D) remained relatively stable across seasons (0.735–0.7408), pointing to a balanced community structure throughout. Dominance (D) showed a slight reduction from 0.265 to 0.2592, indicating lower single-species dominance in later seasons. Evenness (e^H/S) was highest in the pre-monsoon (0.406), declined during the monsoon (0.3207), and marginally improved in the post-monsoon (0.3439), showing that individuals were more evenly distributed before the rains. These results highlight that monsoon conditions favoured species richness and abundance, while pre-monsoon conditions supported more equitable distribution among species.

The present study documented 32 odonate species from Tulshi Reservoir, encompassing two suborders and four families, with marked variation across seasons. The overall patterns demonstrate the influence of hydrological fluctuations and habitat heterogeneity on community composition, trends that are consistent with observations from other parts of the Western Ghats and peninsular India (Gaikwad, 2021; Nair *et al.,* 2021; Vijayakumaran *et al.,* 2025).

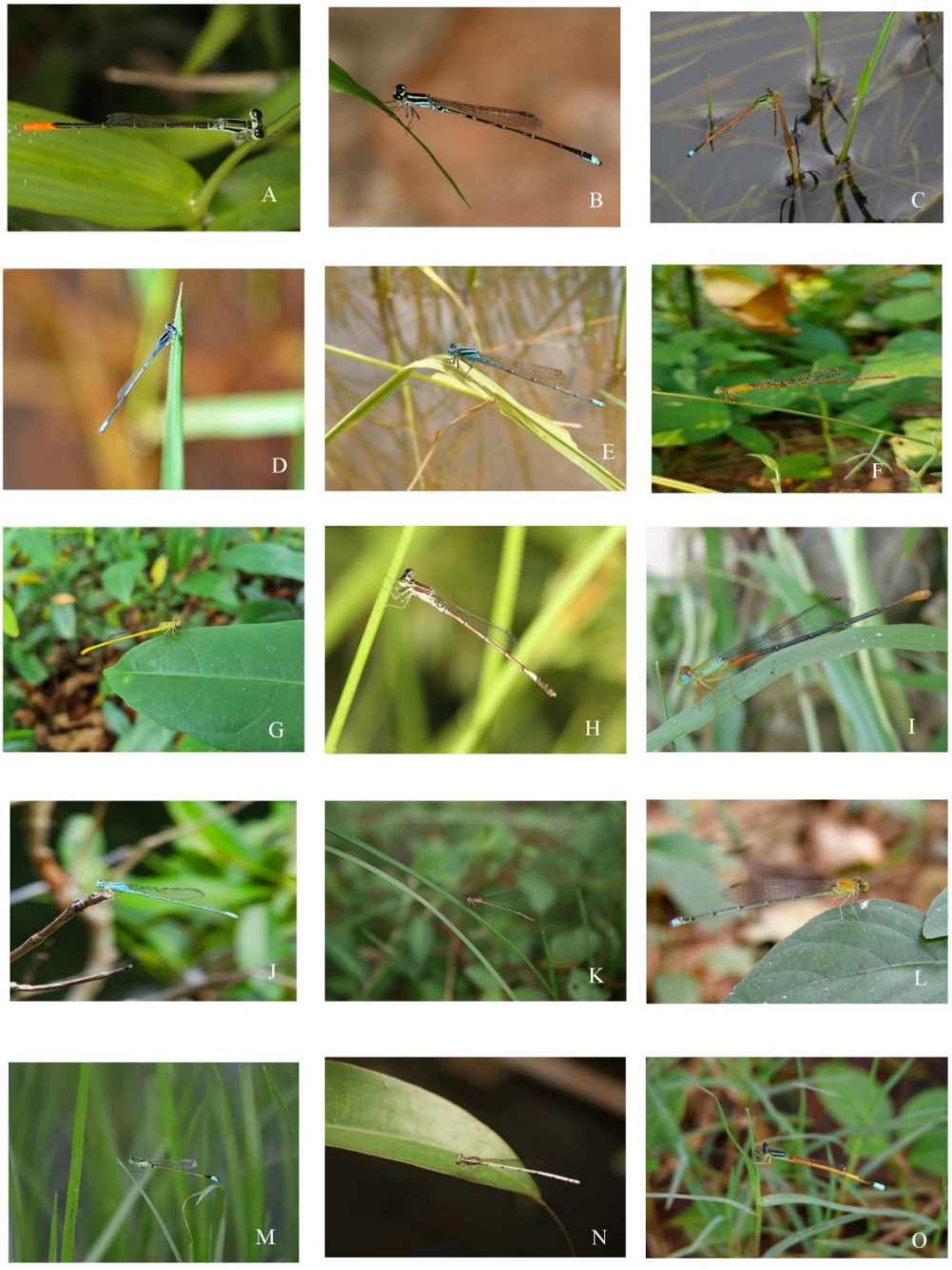

Fig. 4 A to O: Representative damselfly species (Zygoptera) recorded at Tulshi Reservoir, Western Ghats, India A- *Agriocnemis femina;* B- *Argiocnemis rubescens;* C- *Ischnura aurora;* D- *Amphiallagma parvum; E- Pseudagrion microcephalum;* F- *Ceriagrion olivaceum;* G- *Ceriagrion coromandelianum;* H- *Mortonagrion aborense;* I- *Ceriagrion cerinorubellum;* J- *Pseudagrion decorum;* K- *Agriocnemis pygmaea;* L- *Pseudagrion rubriceps;* M- *Ischnura senegalensis;* N- *Copera vittata;* O- *Ichnura rubilio*

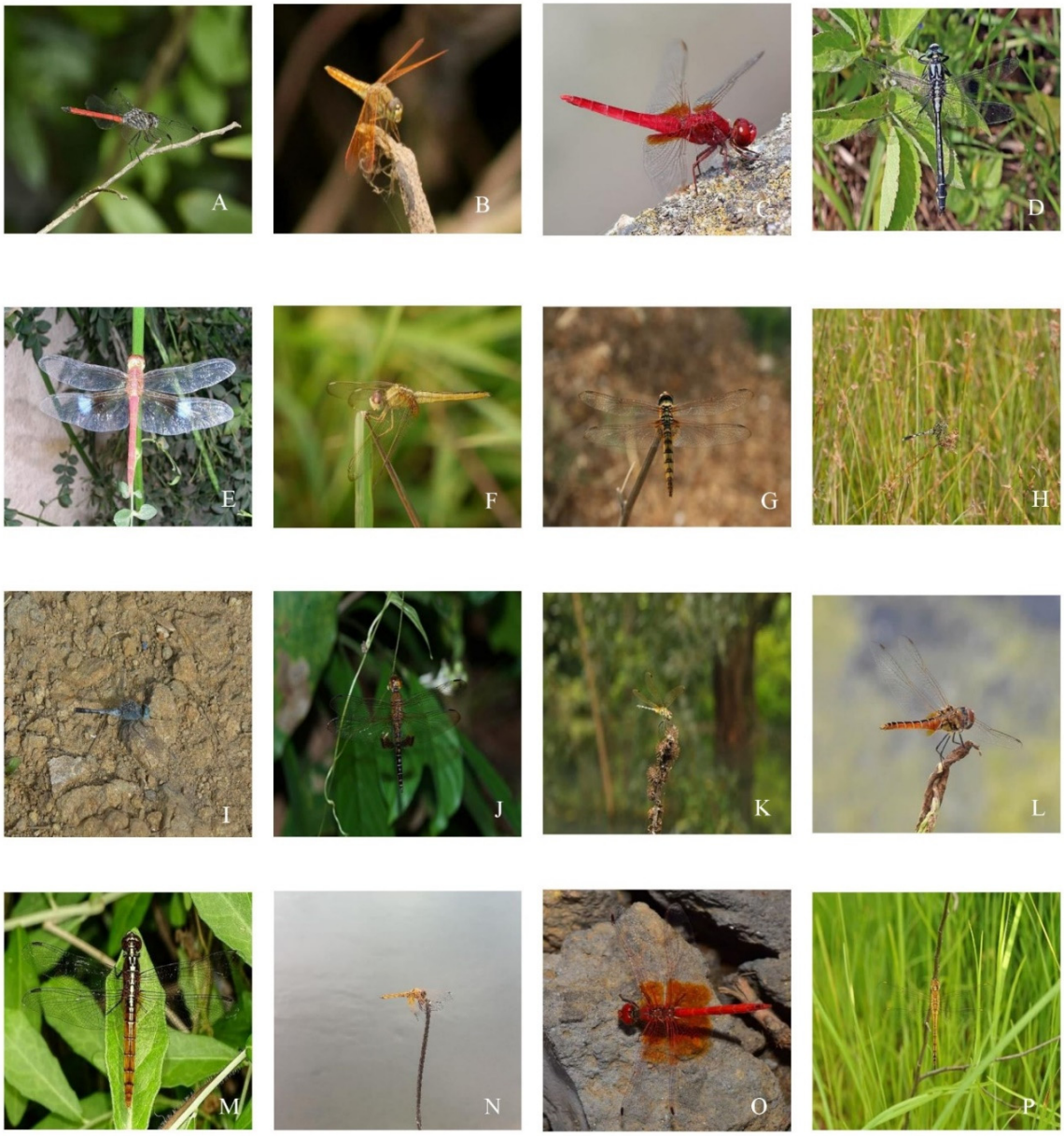

Fig. 5 A to P: Representative Dragonfly species (*Anisoptera*) recorded at Tulshi Reservoir, Western Ghats, India. A- *Lathrecista asiatica;* B- *Brachythemis contaminata;* C- *Crocothemis servilia;* D- *Ictinogomphus rapax; E- Tholymis tillarga;* F- *Orthetrum pruinosum;* G- *Urothemis signata;* H- *Orthetrum sabina;* I- *Diplacodes trivialis;* J- *Hydrobasileus croceus;* K- *Trithemis pallidinervis;* L- *Macrodiplax cora;* M- *Rhodothemis rufa;* N- *Trithemis aurora;* O- *Trithemis kirbyi;* P- *Pantala flavescens*

Table 3. Dragonfly Biotic Index (DBI) scores of the species recorded from the Tulshi Reservoir, Maharashtra, India

Name of the species	S	G	T	DBI
Trithemis aurora (Burmeister, 1839)	1	1	0	2
T. kirbyi (Selys, 1891)	1	1	0	2
T. pallidinervis (Kirby, 1889)	1	1	0	2
Orthetrum sabina (Drury, 1770)	0	2	0	2
O. pruinosum (Burmeister, 1839)	1	2	0	3
Diplacodes trivialis (Rambur, 1842)	0	2	0	2
Crocothemis servilia (Drury, 1773)	0	2	0	2
Pantala flavescens (Fabricius, 1798)	0	3	0	3
Rhodothemis rufa (Rambur, 1842)	2	1	0	3
Urothemis signata (Rambur, 1842)	2	1	0	3
Macrodiplax cora (Kaup, 1867)	1	2	0	3
Hydrobasileus croceus (Brauer, 1867)	2	2	0	4
Tholymis tillarga (Fabricius, 1798)	1	2	0	3
Lathrecista asiatica (Fabricius, 1798)	1	2	0	3
Brachythemis contaminata (Fab, 1793)	0	2	0	2
Ictinogomphus rapax (Rambur, 1842)	2	2	0	4
Paragomphus lineatus (Selys, 1850)	2	1	0	3

Within Anisoptera, the family Libellulidae was dominant, contributing 15 species. The prevalence of Libellulidae has also been reported in Kerala (Nair *et al.,* 2021), the Bavali River catchments (Vijayakumaran *et al.,* 2025), and Thattekkad wetlands (Varghese *et al.,* 2014), where their ecological plasticity allows them to thrive under fluctuating hydrological regimes. Widespread species such as *Trithemis aurora* (Burmeister, 1839), *Brachythemis contaminate* (Fabricius, 1793), and *Orthetrum sabina* (Drury, 1770) were observed in all three seasons, reflecting their tolerance to changing conditions, a pattern also highlighted in Kolhapur wetlands by Gaikwad (2021). Conversely, post-monsoon exclusives like *Pantala flavescens* (Fabricius, 1798) and *Macrodiplax cora* (Kaup, 1867) indicate synchronization with seasonal emergence windows, echoing findings from high-altitude habitats of Munnar, where post-monsoon stability facilitated odonate diversity (Krishnanunni *et al.,* 2024).

The Zygoptera, represented by Coenagrionidae and Platycnemididae, showed high richness during post-monsoon. This agrees with studies from Kerala and Tamil Nadu, which documented zygopteran proliferation in habitats with abundant macrophytes and stable water levels (Varghese *et al.,* 2014; Kannagi *et al.,* 2016; Nair *et al.,* 2021). At Tulshi, *Pseudagrion decorum* (Rambur, 1842) and *Ceriagrion cerinorubellum* (Brauer, 1865) occurred consistently across seasons, suggesting broad ecological tolerance, while species such as *Amphiallagma parvum* (Selys, 1876) and *Mortonagrion aborense* (Laidlaw, 1914) were restricted to post-monsoon, likely benefiting from dense aquatic vegetation. Similar habitat-linked associations were reported by Pawar et al. (2024) in organic paddy fields of Satara, where vegetation complexity promoted greater odonate diversity.

The seasonal variation in diversity indices further reinforces these ecological trends. The Shannon–Wiener and Brillouin indices showed gradual increases from pre-monsoon to post-monsoon, reflecting growing heterogeneity, while Simpson's index remained stable, indicating structural consistency in the community. These trends are comparable to those observed by Pawar et al. (2024), who noted stable diversity but fluctuating evenness across cropping cycles, and by Patil and Chougale (2025) and Kolhapur and Gaikwad (2021) in Rankala Lake, where richness was strongly linked to rainfall. The decline in evenness during monsoon at Tulshi suggests dominance by a few abundant species, a phenomenon also observed in deciduous forests of Tamil Nadu (Kannagi *et al.,* 2016). In contrast, the relatively high evenness during pre-monsoon resembles patterns from Sangli, where low water levels constrained species richness but supported more equitable distribution (More, 2024).

Globally, shifts in family ratios, particularly the resilience of Libellulidae compared to other groups, have been associated with environmental change and habitat disturbance (Šigutová *et al.,* 2024). The findings at Tulshi, where libellulidae dominate and zygopterans exhibit seasonal restriction, align with these broader trends, underscoring the sensitivity

of odonate assemblages to both local hydrological cycles and wider climatic influences. The findings from Tulshi Reservoir underline the importance of seasonal hydrological cycles and habitat heterogeneity in maintaining odonate diversity. The dominance of adaptable Libellulidae alongside the seasonal exclusivity of several Zygoptera reflects both resilience and sensitivity within the community. Such patterns not only confirm the role of odonates as bioindicators of freshwater ecosystem health but also stress the need for habitat management that conserves aquatic vegetation, water quality, and seasonal flow regimes. Similar concerns have been highlighted in studies from Kerala, Satara, and the Bavali River catchments, where odonate assemblages responded strongly to environmental changes (Nair *et al.,* 2021; Pawar *et al.,* 2024; Vijayakumaran *et al.,* 2025). In the context of increasing anthropogenic pressures and climate variability in the Western Ghats, protecting reservoirs like Tulshi is critical for sustaining both odonate diversity and the ecological services they support, including mosquito regulation and food-web stability. Long-term monitoring and community-based conservation programs will be essential to ensure the persistence of these keystone insect groups.

A total of 32 odonate species were documented from Tulshi Reservoir, showing distinct seasonal differences in richness, abundance, and community structure. Libellulidae dominated the assemblage, while Zygoptera showed stronger seasonal variation. Species richness peaked during monsoon and post-monsoon, whereas evenness was greater in the pre-monsoon period. These findings confirm the value of odonates as sensitive indicators of freshwater ecosystems and emphasize the need for habitat conservation and long-term monitoring in the Western Ghats.

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