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Odonata diversity of the Kuruva Islands, southern India, with notes on the ecology of *Disparoneura apicalis* (Fraser, 1924) (Odonata: Platycnemididae)

Ayikkara Vivek Chandran
Aqua Research Lab, Department of Geology and Environmental Science, Christ College (Autonomous), Irinjalakuda, Thrissur, the University of Calicut, Thenhipalam, Kerala, India [1]; *Society for Odonate Studies, Vellooparampil, Kuzhimattom PO, Kottayam, Kerala, India* [2].
avivekchandran2@gmail.com *https://orcid.org/0000-0003-2149-2502*

Puthukudy Kunjamu Muneer
Ferns Nature Conservation Society, PB No. 28, Mananthavady, Wayanad, Kerala, India.
muneerputhukudy@gmail.com *https://orcid.org/0000-0001-6486-8982*

Maran Madhavan
Ferns Nature Conservation Society, PB No. 28, Mananthavady, Wayanad, Kerala, India [1]; *Tholpetty eco-development committee, Wayanad Wildlife Sanctuary, Kerala 670646, India* [2].
madhavantholpetty@gmail.com *https://orcid.org/0000-0001-6486-8982*

Subin Kaniyamattathil Jose
Aqua Research Lab, Department of Geology and Environmental Science, Christ College (Autonomous), Irinjalakuda, Thrissur, the University of Calicut, Thenhipalam, Kerala, India.
josesubin@gmail.com *https://orcid.org/0000-0003-4784-2312*

ABSTRACT. Odonata diversity of the Kuruva Islands in Wayanad, a part of the Western Ghats Biodiversity Hotspot in southern India, was studied for a year using transect counts. A total of 59 species were recorded of which 7 are endemic to the Western Ghats. Herb cover, shrub cover, open space, water pH, air temperature, and a composite water chemistry variable incorporating conductivity, TDS, and salinity emerged as the most important predictors of Odonata diversity. The distribution of the endemic and Vulnerable *Disparoneura apicalis* (Fraser, 1924) in the islands is influenced by particular species of plants that act as their perching posts and ovipositing sites. It is recommended that the tourists visiting the Kuruva Islands be sensitized about the importance of the place as an odonate habitat. The highly range-restricted *D. apicalis* can be made a flagship species for the conservation of this unique ecosystem.

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INTRODUCTION

Odonates (dragonflies and damselflies), being freshwater insects, are helpful indicators of freshwater as well as terrestrial habitat conditions. It is known that odonate species richness and/or community composition changes in response to habitat degradation, suggesting their potential as bioassessment tools (Šigutová et al., 2019). Several studies worldwide have identified shade, water speed, water permanence (Oppel, 2005), altitude (Harabiš & Dolný, 2010), water quality, and vegetation structure (Perron et al., 2021) as factors driving Odonata diversity. In India, there have only been scarce attempts to understand the determinants of Odonata diversity. Koparde et al. (2015) showed that canopy cover and area of water on the transect drive species assemblages in the northern Western Ghats. Although the

Corresponding author: Ayikkara Vivek Chandran, *avivekchandran2@gmail.com*

Indian odonate fauna is well described in terms of adult taxonomy, their ecology and distribution remain understudied (Subramanian & Babu, 2020). The greatest diversity and endemism of Odonata in the Western Ghats have been reported from the Nilgiri–Wayanad–Kodagu region and Anaimalai Hills (Subramanian et al., 2018). In a systematic study of the odonates of the southern Western Ghats by the Zoological Survey of India, rare species such as *Chlorogomphus campioni* (Fraser, 1924) and *Idionyx saffronatus* Fraser, 1924 were collected from Wayanad (Emiliyamma, 2014). Another independent study recorded 59 species from various locations in the district (Susanth & Anooj, 2020). From the Wayanad Wildlife Sanctuary, 85 species of odonates, including 14 endemics of the Western Ghats were recorded. The ponds in the sanctuary were the most species-rich, while the streams hosted the greatest number of endemics (Muneer et al., 2023). In this study, we have prepared an inventory of the odonates of the Kuruva Islands of Wayanad for the first time. We have repeated the odonate monitoring protocol in five seasons to record all species and understand how odonate diversity varies with seasons. Having a species inventory and the knowledge of how diversity varies according to the seasons of a year is a prerequisite for any conservation action in a habitat. We have also explored if odonate diversity varies in different locations within the Kuruva Islands. Most importantly, we have studied which habitat parameters determine Odonata diversity in the Kuruva Islands.

Disparoneura apicalis (Fraser, 1924) is a damselfly of the Family Platycnemididae and is endemic to the Western Ghats of India. It is currently known only from two localities in the tributaries of river Cauvery, one of which is the Kuruva Islands in Wayanad, and the other is its type locality near Coorg in Karnataka. It is listed as 'Vulnerable' in the IUCN Red List of Threatened Species and tourist activity in its habitat has been identified as a potential threat to its existence (Kakkassery, 2011). This study is a focused attempt to document the diversity of Odonata of the Kuruva Islands, understand the habitat parameters that drive it, and explore the status of *D. apicalis* in this unique habitat.

MATERIAL AND METHODS

Study area. Kuruva is a river island system formed by the Kabini River, a major tributary of the river Cauvery in the Wayanad district of Kerala, India. It is a well-known ecotourism destination nestled in the Western Ghats of India (Binoy, 2017). The riparian flora of the island group is semi-evergreen with clumps of bamboo interspersed in between. The Kuruva Island is located in a mosaic landscape of forests and agricultural farms. Paddy is the main crop grown in this region. It hosts rich biodiversity including megafauna like the Asian Elephant and the Bengal Tiger. It has an area of 3.8 km² and falls under the jurisdiction of South Wayanad Forest Division of Kerala Forests & Wildlife Department. However, an area of 20 hectares is managed by the Kerala Tourism Department and receives a heavy influx of tourists from October to May every year (Anjana & Mathews, 2017). Presently, the area falls under the 'Reserved Forest' category where certain human activities like grazing and logging may be permitted and hence does not receive full protection as in Wildlife Sanctuaries and National Parks (Anonymous, 2023).

Sampling design. Full-width belt transects were used for monitoring adult odonates of the Kuruva Islands (Darshetkar et al., 2023). For this, the observer walked along the transect for 20 metres and counted odonates seen in a band of 5 metres on both sides of the transect. Twelve such transects were chosen, ensuring spatial coverage of the island chain. Eleven of these transects were along the banks of streams and one was along the banks of one of the two ponds in the island. The distance between the closest transects was 500 metres. Of these 12 transects, 4 were located in areas tourists were allowed to visit (Fig. 1). All transects were walked between 9 AM and 2 PM in fair weather. Odonates were photographed using a Sony® a7 III digital camera (Sony Group Corporation, Tokyo, Japan), a Tamron® 150–500 mm telephoto lens (Tamron Co., Ltd., Saitama, Japan) and a Sony 90 mm macro lens. Odonates that were difficult to identify were caught using an aerial net, examined, and released. Along each transect, sampling pickets were fixed at 5-meter intervals such that each transect had 5 sampling pickets for recording the following habitat parameters:

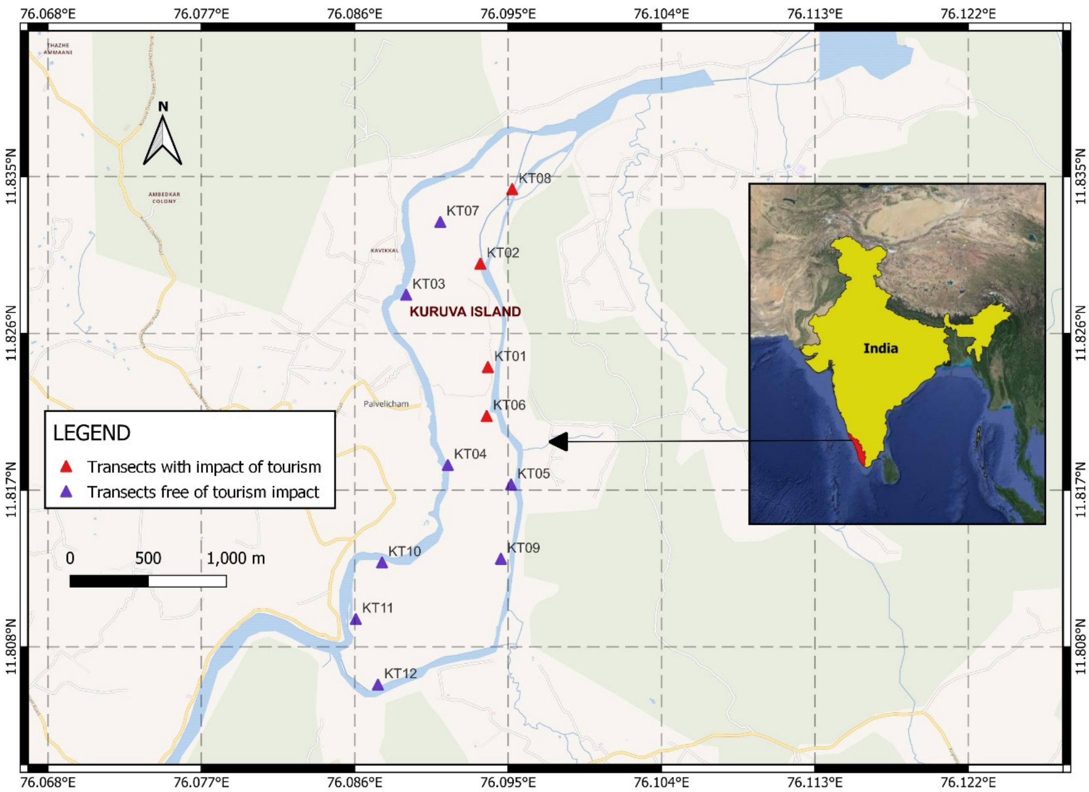

Figure 1. Map of the Kuruva Islands showing the location of transects.

i) Canopy cover: Using a spherical densiometer; ***ii)*** Ground cover: At each sampling picket along the transect, herb cover, shrub cover, grass cover, tree cover, open ground cover, and water spread were measured using the point intercept technique with a meter tape. For this, a meter tape was stretched out from the sampling picket in both directions, and the vegetation type/ground cover was recorded at 1-meter intervals along the tape for a total of 5 meters; ***iii)*** Water quality parameters: At each sampling picket, pH, Oxidation-Reduction Potential (ORP), Dissolved Oxygen Saturation Percentage (DO%), dissolved oxygen concentration, conductivity, Total Dissolved Solids (TDS), salinity, and water temperature were measured using a portable water quality meter (Hanna Instruments, model HI98194). Water depth was measured using a meter tape and water flow was measured using a flow probe (Xylem Global Water FP111). Turbidity of water was measured using a Secchi disk. These were averaged to get the measures for the whole transect. The nature of the substrate in water (sand, silt, clay, rock, litter) was also noted. ***iv)*** Weather parameters: Atmospheric temperature, windspeed, and relative humidity were recorded in each sampling picket using a pocket weather meter (Kestrel 3500). These were averaged to get the measures for the whole transect (Table 1).

The study period was divided into 5 seasons, Pre-monsoon (April–May), Monsoon (June–August), Post-monsoon (September–November), Winter (December–January), and Summer (February–March). All 12 transects were sampled in each season, giving a total of 60 transect walks. The open-source software PAleontological STatistics (PAST ver. 4.03) and R Package (ver. 4.3.0) were used for data analysis. Quantum GIS ver. 3.22.14 was used to prepare a study area map.

Data analysis. The identities of the species were confirmed by referring to taxonomic monographs (Fraser, 1933, 1934 & 1936) and field guides (Subramanian, 2009; Kiran & Raju, 2013; Jose & Chandran, 2020). A checklist was prepared using systematic arrangement and taxonomy according to Kalkman et al. (2020). Species richness, Shannon diversity index, and Simpson diversity index were calculated for each season and represented as boxplots. These measures were tested for normality using the Shapiro-Wilk test. The appropriate test was run for all three diversity measures to see if odonate diversity varies significantly in different seasons.

Table 1. List of habitat parameters measured for each transect.

Sl no	Habitat parameter	Unit
1	Canopy cover	%
2	Ground cover	%
3	Herb cover	%
4	Shrub cover	%
5	Grass cover	%
6	Tree cover	%
7	Open ground	%
8	Water spread	%
Water quality		
9	Depth	cm
10	Flow	m/s
11	pH	-
12	ORP	mV
13	Dissolved Oxygen saturation	%
14	Dissolved Oxygen concentration	mg/L
15	Conductivity	muS/cm
16	TDS	Ppm
17	Salinity	PSU
18	Water temperature	°C
19	Turbidity	cm
Weather		
20	Air temperature	°C
21	Relative humidity	%
22	Windspeed	m/s

Odonata diversity between transects. For each transect, the Shannon diversity index, Simpson index and species richness were calculated for all seasons. The Shapiro-Wilk test for normality was performed on the Shannon index values. A quantile-quantile plot (Q-Q plot) was drawn to supplement this. The Levene's test was run to check for homogeneity of variance. This was followed with a one-way ANOVA to check if there were significant differences in diversity between transects while accounting for the variability introduced by seasonal changes. A Non-metric Multidimensional Scaling (NMDS) plot was made to visualize the differences in species composition between the transects. The dataset included odonate abundances and 22 associated habitat variable measures for 60 transect walks. The dataset was checked for missing values. A Detrended Correspondence Analysis (DCA) was performed to choose between redundancy analysis (RDA) and canonical correspondence analysis (CCA). Multicollinearity was assessed for the habitat parameters and highly correlated variables were removed/replaced. With the remaining variables, CCA was used to explore the relationships between species occurrences and habitat variables. Permutation tests were conducted to evaluate the significance of the overall CCA model, individual axes, and specific habitat parameters.

Ecology of Disparoneura apicalis. Whenever the species of special interest in the islands, *D. apicalis* was encountered, notes were made on its behaviour, and its reproductive activities were timed using a stopwatch. Since *D. apicalis* appeared to have an association with the grass-like herb *Cryptocoryne retrospiralis* Engler, 1879 (Family Araceae), a score ranging from 0 to 10 was assigned to each transect during the summer, when the herb exhibited its maximum growth. A score of 0 indicated the absence of the herb, while a score of 10 represented a 100% spread of the herb within the transect area. To facilitate comparison, both the scores representing the herb's spread and the abundance of *D. apicalis* in each transect were converted into ordinal ranks. This means that, instead of using the raw scores or abundance counts, each transect was ranked relative to the others based on the spread of *C. retrospiralis* and the abundance of *D. apicalis*. This approach simplified the comparative analysis between transects. A Spearman correlation was performed to test if the percentage cover of *C. retrospiralis* and the abundance of *D. apicalis* were correlated.

RESULTS

Diversity. A total of 59 species of odonates were recorded from the Kuruva Islands during the study period, of which 32 were anisopterans (dragonflies) and 27 were zygopterans (damselflies) (Table 2). Of these, 7 species are endemic to the Western Ghats and 5 to India. 46 species were recorded in the transects, and the rest 13 were recorded while traversing between the transects. Of the species recorded, *Disparoneura apicalis* and *Protosticta sanguinostigma* Fraser, 1922 are classified as Vulnerable in the IUCN Red List of Threatened Species. *Elattoneura tetrica* (Laidlaw, 1917) and *Burmagomphus pyramidalis* Laidlaw, 1922 are rare insects with very few occurrence records in Peninsular India (Figs 2A–D). In the transect survey, *Prodasineura verticalis* was the most abundant odonate species (n = 171), while 8 species were recorded only once. *Zygonyx iris* Selys, 1869 was the most abundant anisopteran (n = 44). Although in the number of species recorded, anisopterans marginally surpassed zygopterans (24 anisopterans and 22 zygopterans), in terms of abundance, zygopterans (n = 512) dominated anisopterans (n = 141) (Fig. 3).

Seasonality. While species richness peaked in winter (Fig. 4A), the diversity indices, Shannon index (Fig. 4B), and Simpson index (Fig. 4C) showed maximum values in the post-monsoon season. The monsoon season had the lowest species richness and diversity measures. The Shapiro-Wilk test showed that the Shannon index had a normal distribution ($W = 0.97609, p > 0.05$), while the species richness ($W = 0.91032, p < 0.05$) and Simpson index ($W = 0.78922, p < 0.05$) violated normality. A one-way ANOVA (analysis of variance) was performed on the Shannon indices and a non-parametric Kruskal Wallis test was performed on the species richness values and Simpson indices to see if there was a statistically significant difference in odonate diversity in different seasons.

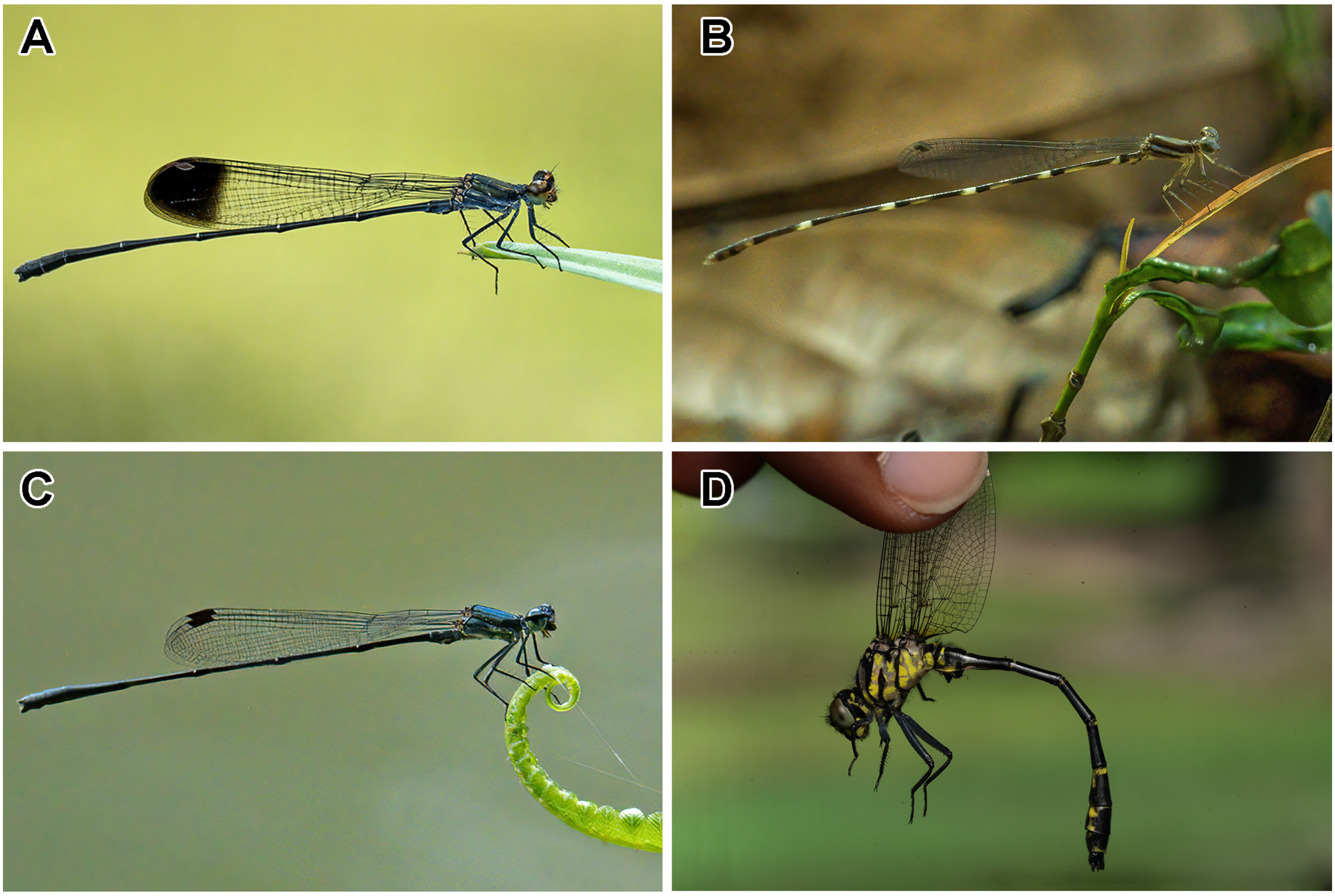

Figure 2. Adult male odonata from the Kuruva Islands. **A.** *Disparoneura apicalis* (Fraser, 1924); **B.** *Protosticta sanguinostigma* Fraser, 1922; **C.** *Elattoneura tetrica* (Laidlaw, 1917); **D.** *Burmagomphus pyramidalis* Laidlaw, 1922. (Photo credits: A–C., by A. Vivek Chandran; D., by Reji Chandran).

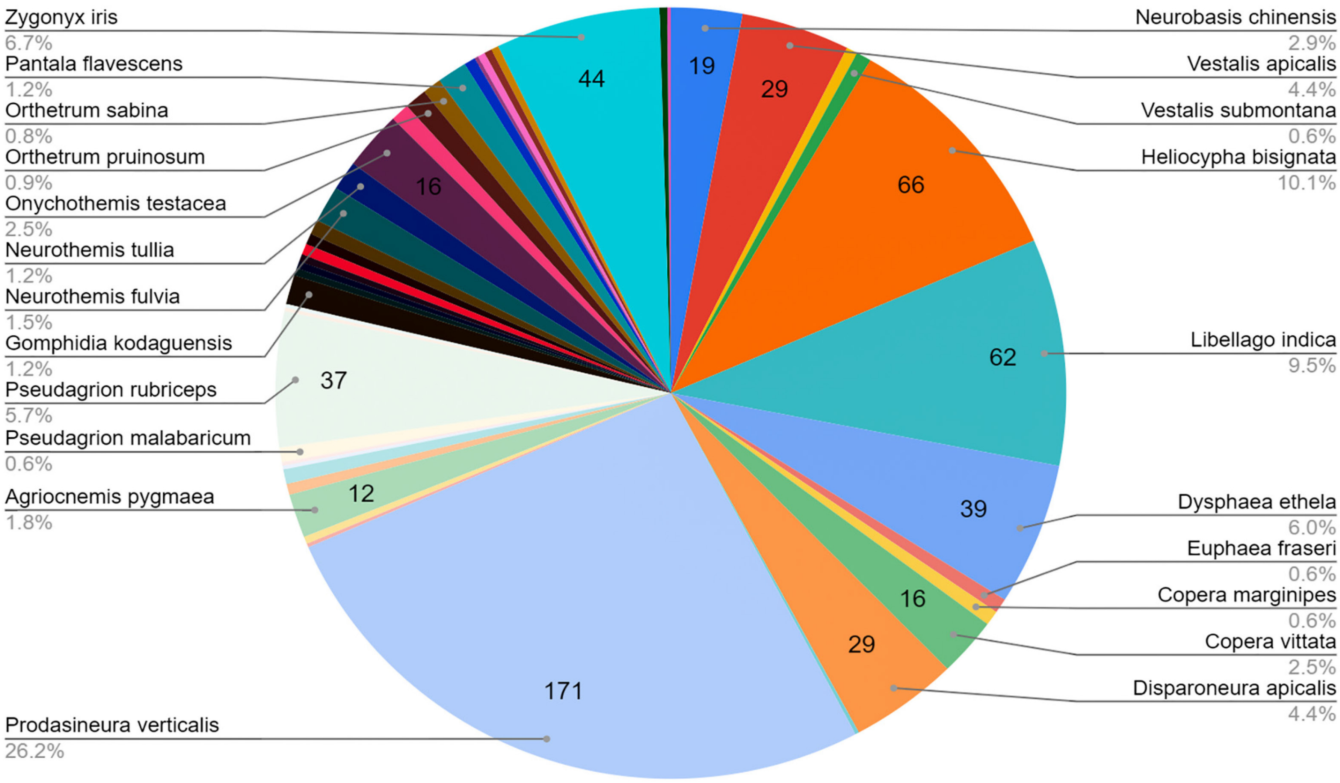

Figure 3. Pie-chart showing the abundance of odonate species recorded in the study from the Kuruva Islands.

There is a considerable difference in species richness in different seasons ($H = 10.108, p < 0.05$). However, the seasonal differences in the Shannon index ($F = 1.77, p > 0.05$) and the Simpson index ($H = 9.0969, p > 0.05$) were not statistically significant.

The boxplot for the Shannon index shows how odonate diversity varied in the transects across the five seasons (Fig. 4D). The Shapiro-Wilk test showed that this data conforms to normality ($W = 0.97609, p > 0.05$), further confirmed by the quantile-quantile plot (Fig. 4E). Levene's test showed that the assumption of homogeneity of variances for ANOVA is met ($F = 0.2852, p > 0.05$). The one-way ANOVA performed showed that there was no significant difference in odonate diversity between the 12 transects ($F = 1.92, p > 0.05$). However, a Non-metric Multidimensional Scaling (NMDS) plot based on species composition in the transects showed distinct clustering (Fig. 4F). This analysis was performed after generating a pairwise dissimilarity matrix with the Bray-Curtis dissimilarity measure (Table 3). All transects along the banks of streams, except KT04, KT05 and KT08 clustered together. The seventh transect (KT07) had the most different species assemblage. This transect was along a pond at the island's interior, while all the rest were on the banks of streams/the River Kabini. The following six species were only recorded from the transect KT07 (pond): *Aciagrion approximans krishna* Fraser, 1921, *Agriocnemis splendidissima* Laidlaw, 1919, *Ceriagrion olivaceum aurantiacum* Fraser, 1924, *Pseudagrion malabaricum* Fraser, 1924, *Rhodothemis rufa* (Rambur, 1842) and *Tetrathemis platyptera* Selys, 1878. Twenty species, including *D. apicalis* were unique to the streams, while the majority 40 were shared between streams and ponds (Fig. 5A).

Habitat parameters. Turbidity had to be removed from the analysis as this parameter could not be measured in 25 out of 60 observations due to a field constraint (low water depth curtailed the use of the Secchi disk in some transects). A Detrended Correspondence Analysis (DCA) was run to choose the ordination method for our data. The gradient length of the first DCA axis was 4.8590, which exceeds the threshold of 4.

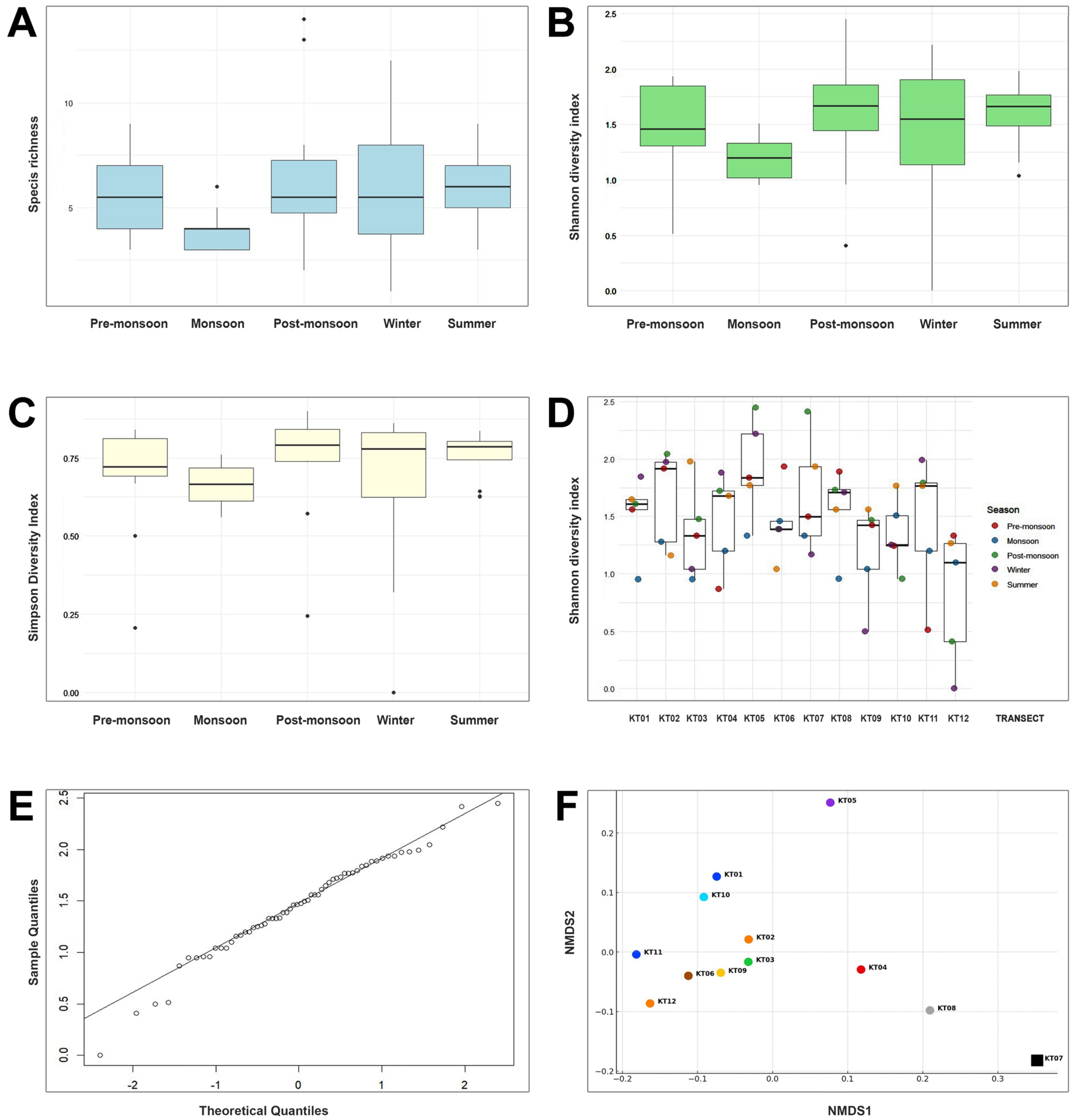

Figure 4. Diversity indices, distribution and species composition of the Odonata in the Kuruva Islands across seasons, transects and habitats. **A.** Species richness; **B.** Shannon diversity index. **C.** Simpson diversity index; **D.** Shannon diversity indices in the 12 transects across 5 seasons; **E.** Quantile-quantile plot showing normal distribution of Shannon diversity values; **F.** NMDS plot showing the clustering of transects according to species assemblages.

This indicates that species in this study likely exhibit unimodal responses to environmental gradients, supporting the use of Canonical Correspondence Analysis (CCA) for further analysis of species-environment relationships. Variance Inflation Factor (VIF) was calculated to assess multicollinearity among the habitat parameters (Table 4). Parameters with VIF > 10 were addressed in the following manner: DO saturation (DO %) was removed from further analysis as it was highly correlated with DO concentration.

Table 2. List of Odonata species recorded from the Kuruva Islands in the study. IUCN Red List status- LC: Least Concern, VU: Vulnerable, NE: Not Evaluated, DD: Data Deficient; Endemicity - EN WG: Endemic to the Western Ghats, EN IND: Endemic to India.

SL	Scientific Name	Common Name	IUCN	END
Suborder Zygoptera				
Family Lestidae				
1	*Lestes dorothea* Fraser, 1924	Forest Spreadwing	LC	
2	*Lestes elatus* Hagen in Selys, 1862	Emerald Spreadwing	LC	
3	*Lestes nodalis* Selys, 1891	Spotted Spreadwing	LC	
Family Platistictidae				
4	*Protosticta sanguinostigma* Fraser, 1922	Red Spotted Reedtail	VU	EN WG
	Family Calopterygidae			
5	*Neurobasis chinensis* (Linnaeus, 1758)	Stream Glory	LC	
6	*Vestalis apicalis* Selys, 1873	Black-tipped Forest Glory	LC	
7	*Vestalis gracilis* (Rambur, 1842)	Clear-winged Forest Glory	LC	
8	*Vestalis submontana* Fraser, 1934	Montane Forest Glory	NE	EN IND
Family Chlorocyphidae				
9	*Heliocypha bisignata* (Hagen in Selys, 1853)	Stream Ruby	LC	EN IND
10	*Libellago indica* (Fraser, 1928)	River Heliodor	NE	EN IND
	Family Euphaeidae			
11	*Dysphaea ethela* Fraser, 1924	Black Torrent Dart	LC	EN IND
12	*Euphaea fraseri* (Laidlaw, 1920)	Malabar Torrent Dart	LC	EN WG
Family Platycnemididae				
13	*Copera marginipes* (Rambur, 1842)	Yellow Bush Dart	LC	
14	*Copera vittata* (Selys, 1863)	Blue Bush Dart	LC	
15	*Disparoneura apicalis* (Fraser, 1924)	Black-tipped Bambootail	VU	EN WG
16	*Disparoneura quadrimaculata* (Rambur, 1842)	Black-winged Bambootail	LC	EN IND
17	*Elattoneura tetrica* (Laidlaw, 1917)	Black and Yellow Bambootail	LC	EN WG
18	*Prodasineura verticalis* (Selys, 1860)	Black Bambootail	LC	
Family Coenagrionidae				
19	*Aciagrion approximans* krishna Fraser, 1921	Violet-striped Slender Dartlet	LC	
20	*Agriocnemis pieris* Laidlaw, 1919	White Dartlet	LC	
21	*Agriocnemis pygmaea* (Rambur, 1842)	Pygmy Dartlet	LC	
22	*Agriocnemis splendidissima* Laidlaw, 1919	Splendid Dartlet	LC	
23	*Ceriagrion coromandelianum* (Fabricius, 1798)	Coromandel Marsh Dart	LC	
24	*Ceriagrion olivaceum aurantiacum* Fraser, 1924	Rusty Marsh Dart	LC	
25	*Ischnura rubilio* Selys, 1876	Golden Dartlet	NE	
26	*Pseudagrion malabaricum* Fraser, 1924	Jungle Grass Dart	LC	
27	*Pseudagrion rubriceps* Selys, 1876	Saffron-faced Grass Dart	LC	
Suborder Anisoptera				
Family Aeshnidae				
28	*Anax guttatus* (Burmeister, 1839)	Pale-spotted Emperor	LC	
29	*Anax indicus* Lieftinck, 1942	Lesser Green Emperor	LC	
30	*Gynacantha dravida* Lieftinck, 1960	Brown Darner	DD	
31	*Gynacantha millardi* Fraser, 1920	Parakeet Darner	NE	
Family Gomphidae				
32	*Burmagomphus pyramidalis* Laidlaw, 1922	Spotted Sinuate Clubtail	LC	
33	*Gomphidia kodaguensis* Fraser, 1923	Kodagu Clubtail	DD	EN WG
34	*Macrogomphus wynaadicus* Fraser, 1924	Wayanad Bowtail	DD	EN WG
Family Macromidae				
35	*Epophthalmia vittata* Burmeister, 1839	Common Torrent Hawk	LC	
36	*Macromia bellicosa* Fraser, 1924	Militant Torrent Hawk	LC	EN WG
Family Libellulidae				
37	*Acisoma panorpoides* Rambur, 1842	Trumpet Tail	LC	

SL	Scientific Name	Common Name	IUCN	END
38	*Cratilla lineata* (Brauer, 1878)	Emerald-banded Skimmer	LC	
39	*Diplacodes trivialis* (Rambur, 1842)	Ground Skimmer	LC	
40	*Indothemis limbata* (Selys, 1891)	Restless demon	LC	
41	*Lathrecista asiatica* (Fabricius, 1798)	Asiatic Blood-tail	LC	
42	*Neurothemis fulvia* (Drury, 1773)	Fulvous Forest Skimmer	LC	
43	*Neurothemis tullia* (Drury, 1773)	Pied Paddy Skimmer	LC	
44	*Onychothemis testacea* Laidlaw, 1902	Stellate River Hawk	LC	
45	*Orthetrum chrysis* (Selys, 1891)	Brown-backed Red Marsh Hawk	LC	
46	*Orthetrum luzonicum* (Brauer, 1868)	Tri-coloured Marsh Hawk	LC	
47	*Orthetrum pruinosum* (Burmeister, 1839)	Crimson-tailed Marsh Hawk	LC	
48	*Orthetrum sabina* (Drury, 1770)	Green Marsh Hawk	LC	
49	*Palpopleura sexmaculata* (Fabricius, 1787)	Blue-tailed Yellow Skimmer	LC	
50	*Pantala flavescens* (Fabricius, 1798)	Wandering Glider	LC	
51	*Potamarcha congener* (Rambur, 1842)	Yellow-tailed Ashy Skimmer	LC	
52	*Rhodothemis rufa* (Rambur, 1842)	Rufous Marsh Glider	LC	
53	*Tetrathemis platyptera* Selys, 1878	Pigmy Skimmer	LC	
54	*Tholymis tillarga* (Fabricius, 1798)	Coral-tailed Cloud Wing	LC	
55	*Trithemis aurora* (Burmeister, 1839)	Crimson Marsh Glider	LC	
56	*Trithemis festiva* (Rambur, 1842)	Black Stream Glider	LC	
57	*Zygonyx iris* Selys, 1869	Iridescent Stream Glider	LC	
58	*Zyxomma petiolatum* Rambur, 1842	Brown Dusk Hawk	LC	
Taxon incertae sedis				
59	*Macromidia donaldi* (Fraser, 1924)	Dark Daggerhead	LC	

High multicollinearity in water chemistry variables (TDS, Conductivity, and Salinity) was addressed by combining them into a single variable (water_chemistry_pc1) using Principal Component Analysis (PCA). The first principal component (PC1) explains 94.64% of the total variance in the original variables. This is a very high proportion, indicating that PC1 captures most of the information from the original three variables. Hence, a CCA was performed with 17 habitat parameters and species occurrence data. The CCA revealed significant relationships between habitat parameters and odonate species composition in the Kuruva Islands ecosystem ($p = 0.001$). The analysis explained 63.66% of the total variation in species data, indicating a strong influence of measured environmental factors on odonate community structure (Table 5).

The first four CCA axes cumulatively accounted for 32.59% of the species-environment relationship. CCA1 and CCA2, explaining 11.18% and 8.28% of the variation respectively, were the most informative axes. The high species-environment correlations (>0.95 for all four axes) suggest a robust relationship between species distribution and habitat parameters. Examination of environmental variable correlations with CCA axes (Table 6) and the CCA plot (Fig. 5B) reveals key ecological gradients:

1. Water Chemistry Gradient (CCA 1): The strongest correlation with CCA 1 was the water chemistry principal component ($r = -0.6231$), which combines conductivity, TDS, and salinity. This suggests a primary gradient from freshwater to more mineralized conditions.
2. Temperature-Humidity Gradient (CCA 1): Water temperature ($r = -0.5632$) and relative humidity ($r = 0.4231$) also showed strong correlations with CCA 1, indicating a gradient from cooler, humid conditions to warmer, drier environments.
3. Habitat Structure Gradient (CCA 2): CCA 2 was strongly correlated with wind speed ($r = 0.6732$), open areas ($r = 0.6231$), and negatively with water presence ($r = -0.5783$). This axis likely represents a gradient from sheltered, water-rich habitats to more open, wind-exposed areas.
4. Vegetation Complexity (CCA 2): Herb cover ($r = 0.5372$) and shrub cover ($r = -0.0619$) showed contrasting correlations with CCA 2, suggesting a gradient in vegetation structure.

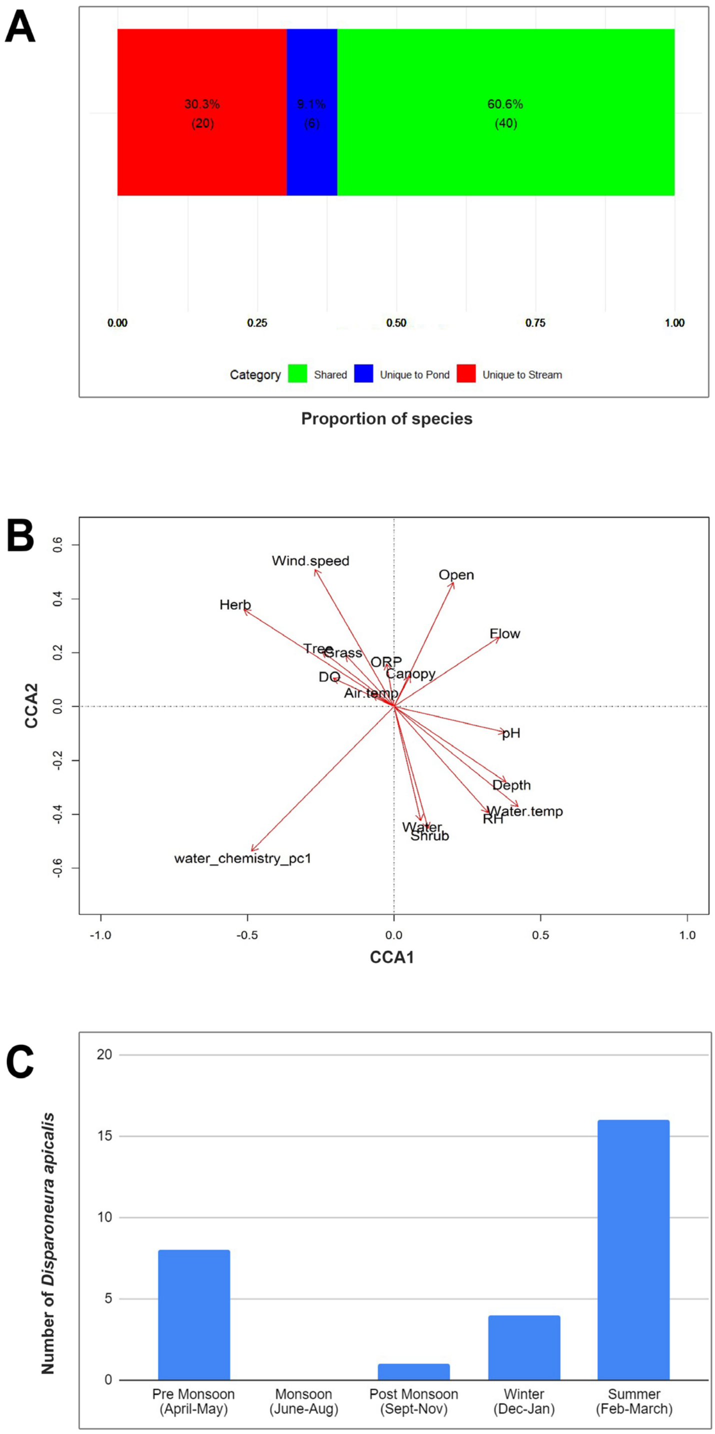

Figure 5. The occurrence of Odonata in the Kuruva Islands. **A.** Plot showing the occurrence of odonate species in the pond and streams of Kuruva; **B.** CCA plot showing the effect of habitat parameters on the Odonate occurrence; **C.** Number of *Disparoneura apicalis* (Fraser, 1924) recorded in each season.

Permutation tests were conducted to evaluate the significance of the overall CCA model, individual axes, and specific environmental variables. The results confirmed that the overall model was highly significant ($p < 0.001$). The first CCA axis was also significant ($p < 0.001$), indicating that it captured the primary gradient in the data. Significant environmental variables included herbaceous cover ($p < 0.001$), shrub cover ($p = 0.041$), open space ($p = 0.005$), pH ($p = 0.019$), air temperature ($p = 0.011$), and the water chemistry PC1 ($p = 0.015$).

Table 3. Dissimilarity Matrix of NMDS of the 12 transects.

Transect	NMDS1	NMDS2
KT01	-0.07444	0.126773
KT02	-0.03192	0.021164
KT03	-0.03231	-0.01655
KT04	0.117735	-0.02946
KT05	0.076825	0.25099
KT06	-0.11216	-0.04002
KT07	0.351982	-0.18205
KT08	0.209449	-0.098
KT09	-0.069	-0.03481
KT10	-0.09158	0.092419
KT11	-0.1814	-0.00405
KT12	-0.16316	-0.08639

Table 4. Variance Inflation Factors for the habitat parameters.

Habitat parameter	VIF
TDS	46.89
Conductivity	31.02
DO.	17.35
DO	16.81
Salinity	9.41
Shrub	8.15
RH	5.81
Open	5.62
Grass	5.42
Air.temp	4.95
Tree	4.73
Water	4.1
Water.temp	2.98
Herb	2.75
pH	2.47
Wind.speed	2.03
Depth	1.77
Flow	1.58
ORP	1.56
Canopy	1.29

Seasonality and breeding and Association of Disparoneura apicalis. In the one-year study period, only 29 individuals of *Disparoneura apicalis* were recorded in the transects. This number was too small to arrive at any significant conclusion. However, the following inferences can be drawn from the year-long observations: Adult *D. apicalis* were encountered in 6 months from November till April. The species remained unrecorded for the rest of the year (Fig. 5C).

Table 5. Summary of Canonical Correspondence Analysis (CCA) results for the habitat parameters.

Statistics	CCA1	CCA2	CCA3	CCA4
Eigenvalues	0.4632	0.3431	0.2837	0.2604
Proportion Explained	11.18	8.28	6.85	6.28
Cumulative Proportion	11.18	19.46	26.31	32.59
Species-Environment Correlations	0.9732	0.9512	0.9613	0.9499
Total Inertia: 4.1446				
Constrained Inertia: 2.6383 (63.66% of total)				
Unconstrained Inertia: 1.5063 (36.34% of total)				
Significance of all canonical axes: $p = 0.001$				

Table 6. Correlations of habitat parameters with CCA Axes.

Environmental Variables	CCA1	CCA2
Canopy	0.2741	0.0893
Herb	0.1632	0.5372
Shrub	-0.3981	-0.0619
Grass	0.1023	0.3425
Tree	0.2134	0.2987
Open	0.0712	0.6231
Water	-0.0231	-0.5783
Depth	0.4231	-0.2134
Flow	0.3612	0.1923
pH	0.1234	-0.0912
ORP	-0.2341	0.1234
DO	0.3421	0.2341
Water temp	-0.5632	-0.3421
Air temp	-0.2341	0.4532
RH	0.4231	-0.3421
Windspeed	0.1234	0.6732
water_chemistry_pc1	-0.6231	-0.1234

The islands were inaccessible in July and August due to the heavy monsoonal rainfall which made traversing the river dangerous. However, since adults of *D. apicalis* were unrecorded in the months immediately preceding and succeeding this period, it can be assumed that the species is only present as eggs/larvae during the monsoon months. Their numbers peaked in summer when all the breeding activities were recorded. Mating and egg-laying were observed in March 2022 ($n = 1$), February 2023 ($n = 6$) and March 2023 ($n = 1$). Adult males were mostly seen perched on the annual herb, *C. retrospiralis* in the shade of riparian trees along the edges of the islets in Kuruva (Fig. 6A). The males showed agonistic behaviour towards conspecific males and males of *Prodasineura verticalis* by flying at them and chasing them away, or by flicking the wings and curling the abdomen (Fig. 6B).

Figure 6. Breeding behaviour of *Disparoneura apicalis* (Fraser, 1924). **A.** A male perched on the herb *Cryptocoryne retrospiralis* Engler, 1879; **B.** A male showing agonistic behaviour towards a male *Prodasineura verticalis* (Selys, 1860); **C.** Copulation; **D.** A pair ovipositing in the submerged roots of the riparian tree, *Calophyllum calaba* Linnaeus, 1753. (Photo credit: A. Vivek Chandran).

However, the species had very small territories and males could be seen perched within a meter of each other. Females were seen only during mating and egg-laying. As soon as a female came near the edge of the water, the male perched closest to it flew towards it and held it in the tandem position. The pair flew around in tandem just above the water surface for half a minute (30 seconds) before the male perched again on *C. retrospiralis*- hanging the female down. In 20 seconds, they attained the wheel position and copulated. Since intra-male sperm transfer was not observed in any of the 8 cases, it is probably done before the male holds the female in tandem. The copulation lasted for a minute (60 seconds), after which the pair again flew in tandem (Fig. 6C). All 8 females were observed ovipositing in the submerged root clumps of *Calophyllum calaba* Linnaeus, 1753, which lined the edges of the islets (Fig. 6D). This riparian tree is endemic to the Western Ghats (Fig. 7A). Oviposition lasted for 2 minutes and the male held the female in tandem in 7 out of the 8 cases observed. In one odd case, the male was seen perched on *C. retrospiralis*, immediately above the ovipositing female. In all the observed cases, the female ended up dipping its abdomen almost completely in water but did not immerse its thorax (Fig. 7B). Within the 2 minutes of egg laying, the pairs changed the ovipositing site once (n = 6) or twice (n = 2), all within a distance of 3 meters, before separating and flying off. After the act, the males continued perching on *C. retrospiralis*, while the females flew into the shrubs further inside the islets. The whole process of mating and egg-laying was completed in 4 minutes. An important association of the target species, *D. apicalis* was with the grass-like herb, *C. retrospiralis* (Family: Araceae) that lined the banks of the River Kabini and its streams in the Kuruva Islands.

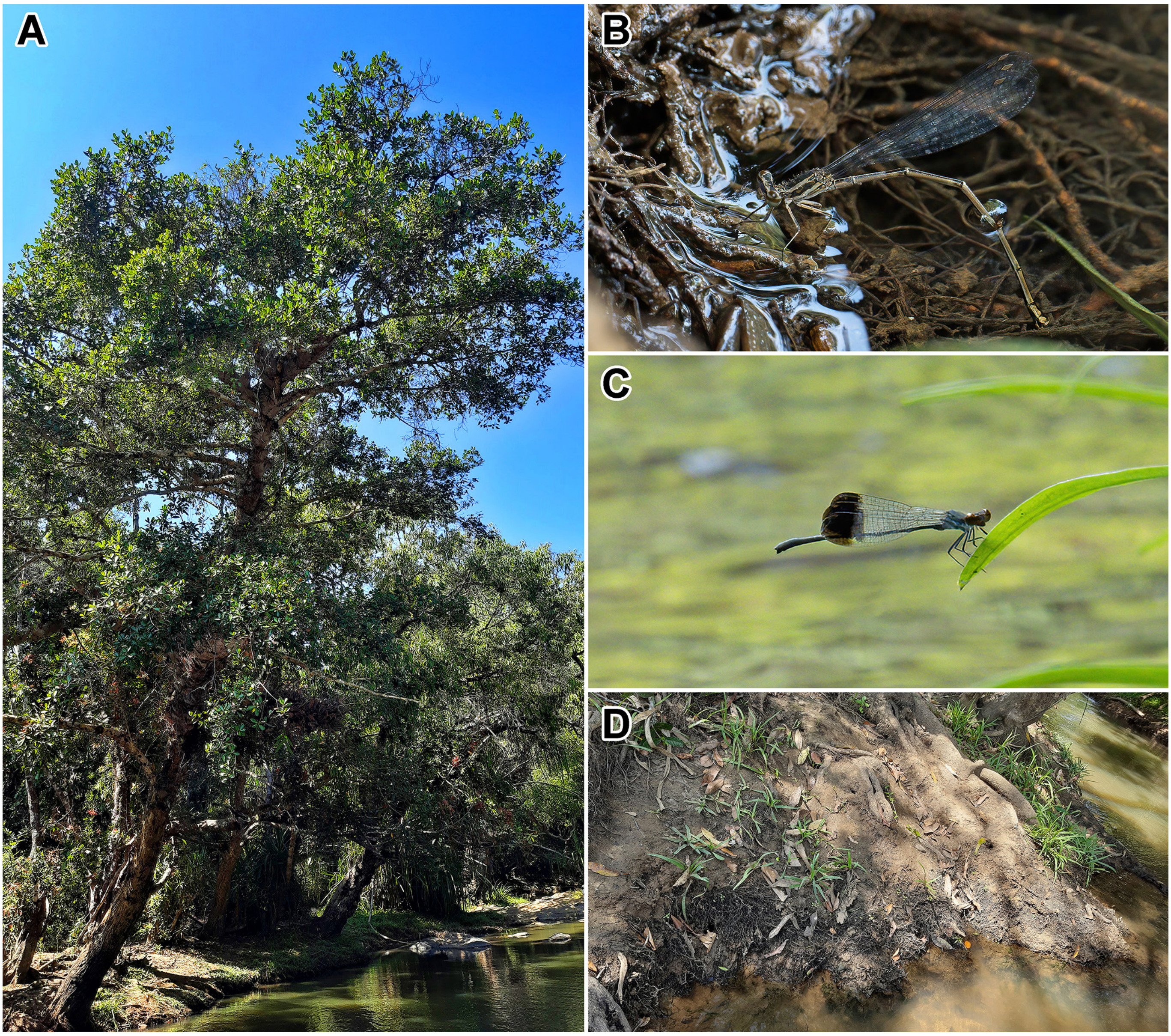

Figure 7. The influence of riparian vegetation on *Disparoneura apicalis* (Fraser, 1924). **A.** The endemic riparian tree, *Calophyllum calaba* Linnaeus, 1753 in the Kuruva Islands; **B.** A female *D. apicalis* ovipositing in the submerged roots of *C. calaba*. **C.** *D. apicalis* perched on *Cryptocoryne retrospiralis* Engler, 1879; **D.** *C. retrospiralis* subjected to trampling by tourists. (Photo credit: A. Vivek Chandran).

All encounters of *D. apicalis* in the study were on *C. retrospiralis* (Fig. 7C). The Spearman correlation showed that there was a significant positive correlation between the percentage cover of *C. retrospiralis* in a transect and the abundance of *D. apicalis* in it ($r = 0.66, p = 0.02$). *Disparoneura apicalis* was seen in 5 of the 12 transects sampled, 4 of which had tourist footfall. The possible impacts of tourism include changes in water quality (by tourists taking baths), direct disturbance to the species, and effects on vegetation. The former two impacts did not seem to affect *D. apicalis*, but disturbance to vegetation was evident. In 3 out of the 4 transects which were open to tourists, severe trampling of *C. retrospiralis*, the favoured perching posts of *D. apicalis* was observed (Fig. 7D). The following remarks on the habitat of *D. apicalis* could be made based on year-long observations: *Disparoneura apicalis* was only seen in the shaded edges of the islets (canopy cover > 80%) where *C. retrospiralis* grew well. Water in the adjacent river/stream was well-oxygenated and had a flow rate ranging from 0.1 to 0.4 m/s. The substrate at the bottom of the river/stream was rocky, sometimes covered with decaying leaf litter.

DISCUSSION

The Kuruva Islands harbour a rich and diverse odonate fauna, with 59 species recorded during this study, including several endemic and threatened taxa. This high diversity underscores the ecological importance of this riverine island ecosystem within the Western Ghats Biodiversity Hotspot. The presence of rare species like *Disparoneura apicalis*, *Protosticta sanguinostigma*, *Elattoneura tetrica*, and *Burmagomphus pyramidalis* further emphasizes the conservation value of this habitat. Our findings reveal significant seasonal variation in odonate species richness, with a peak in winter. The diversity indices show maximum values in the post-monsoon season. This seasonality likely reflects the life cycles of different odonate species and their responses to changing environmental conditions throughout the year. The lower diversity observed during the monsoon season may be due to reduced adult activity or sampling difficulties during heavy rains.

The analysis of habitat parameters provides valuable insights into the ecological factors influencing odonate communities in the Kuruva Islands. Herb cover, shrub cover, open space, water pH, air temperature, and the composite water chemistry measure of TDS, conductivity, and salinity emerged as significant predictors of odonate diversity in the Kuruva Islands. This highlights the complex interplay between vegetation structure, water quality, and climatic factors in shaping these assemblages. This information can guide habitat management strategies aimed at conserving odonate diversity in the region. Our study also underscores the importance of considering multiple habitat types within the Kuruva Islands ecosystem. The distinct odonate assemblages observed in pond versus stream habitats demonstrate the need for a landscape-level approach to conservation that preserves the full range of aquatic habitats present in the island complex. The study's focus on *Disparoneura apicalis*, a highly range-restricted and vulnerable species, offers crucial insights into its ecology and conservation needs. The strong association observed between *D. apicalis* and specific plant species – *Cryptocoryne retrospiralis* for perching and *Calophyllum calaba* for oviposition – demonstrates the importance of maintaining intact riparian vegetation for this threatened taxon. This finding emphasizes the need for targeted conservation efforts that protect not only the odonates, but also their plant associates and overall habitat structure. The observed trampling of *Cryptocoryne retrospiralis* in tourist-accessible areas is concerning, particularly for *D. apicalis*. Trampling of vegetation has been identified as an important, yet overlooked threat to odonate habitats (Goertzen & Suhling, 2013). This highlights a potential conflict between ecotourism and conservation objectives that needs to be carefully managed. Implementing measures to protect sensitive vegetation, such as designated pathways or boardwalks, could help mitigate this impact while still facilitating sustainable tourism. The seasonal pattern of *D. apicalis*, with adults present from November to April and breeding activities concentrated in the summer months, provides valuable information for timing conservation interventions and monitoring efforts. This knowledge can inform management decisions, such as potentially restricting access to critical breeding areas during peak reproduction periods.

In the Kuruva Islands, tourism activities are run jointly by the Vana Samrakshana Samiti (a collective of the local communities trained and employed by the Kerala Forests & Wildlife Department) and the District Tourism Promotion Council (DTPC), Government of Kerala. The site, however, remains closed to tourists from June to September because the monsoonal rains make the streams dangerous to navigate. Hence, Kuruva receives maximum tourist footfall in summer when the water level drops and the islets are easily accessible. This coincides with the luxuriant growth of *C. retrospiralis* and the breeding period of *D. apicalis*. To summarize, tourism activities in the Kuruva Islands happen in the prime habitat of *D. apicalis* and the impact is maximum during the breeding period of *D. apicalis*. Daily, a maximum of 1150 tourists are taken to the island via bamboo rafts (Fig. 8A). Once inside the island, they trek through designated routes and play in the waters of the River Kabini and its streams (Fig. 8B). The fact that parts of the Kuruva Islands are open to the public should be treated as an opportunity rather than as a threat. The VSS (Vana Samrakshana Samiti) watchers could be trained in the identification of odonates. These watchers could then act as guides to the tourists and help them appreciate the unique Odonata diversity of the site. Tourists could then be educated to avoid activities like trampling vegetation, which can damage odonate habitats. The highly range-restricted *Disparoneura apicalis* could be made the mascot for conserving this unique ecosystem.

Figure 8. Tourism in the Kuruva Islands. **A.** Tourists being taken into the Kuruva Islands in a bamboo raft; **B.** Tourists playing and bathing in the River Kabini at the Kuruva Islands. (Photo credit: A. Vivek Chandran).

AUTHOR'S CONTRIBUTION

The authors confirm their contribution to the paper as follows: A.V. Chandran, P.K. Muneer, and M. Madhavan: collected primary data and helped in drafting the manuscript. A.V. Chandran and S.K. Jose: curated and analyzed data and wrote the final version of the manuscript. All authors reviewed the results and approved the final version of the manuscript.

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AVAILABILITY OF DATA AND MATERIAL

The specimens listed in this study are deposited in the Research Collections of the Aqua Research Lab, Christ College (Autonomous), Irinjalakuda, and are available from the curator, upon request.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This study only included plants and arthropod material, and all required ethical guidelines for the treatment and use of animals were strictly adhered to in accordance with international, national, and institutional regulations. No human participants were involved in any studies conducted by the authors for this article.

CONSENT FOR PUBLICATION

Not applicable.

CONFLICT OF INTERESTS

The authors declare that there is no conflict of interest regarding the publication of this paper.

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تنوع سنجاقک‌ها در جزایر کورووا، جنوب هند و نکاتی از بوم‌شناسی *Disparoneura apicalis* (Fraser, 1924) (Odonata: Platycnemididae)

آیککارا ویوک چاندران[۱،۲*]، پوتوکودی کُنجامو مونییر[۳]، ماران مادهاوان[۳،۴] و سوبین کانیاماتاتیل خوزه[۱]

۱ آزمایشگاه مطالعات آب‌شناسی، دپارتمان زمین‌شناسی و علوم محیطی، کالج کریست (خودگردان)، ایرینجالاکودا، تریسور، دانشگاه کالیکوت، کرالا، هند
۲ انجمن مطالعات طیاره‌مانندها، وللوپارامپیل، کاتایام، کرالا، هند
۳ انجمن حفاظت از طبیعت فرنز، مانانتواد، وایناد، کرالا، هند.
۴ کمیته توسعه اکولوژیک تولپتی، پناهگاه حیات وحش وایناد، کرالا، هند

* پست الکترونیک نویسنده مسئول مکـاتبه: *avivekchandran2@gmail.com*

| **تاریخ دریـافت:** ۱۰ آذر ۱۴۰۲ | **تاریخ پذیرش:** ۰۴ آبان ۱۴۰۳ | **تاریخ انتشار:** ۱۲ دی ۱۴۰۳ |

چکیــده: تنوع سنجاقک‌ها در جزایر کورووا واقع در وایناد، بخشی از منطقه غنی تنوع زیستی گهات غربی در جنوب هند ، به مدت یک سال با استفاده از شمارش‌های مسیرهای پیشمایش مطالعه شد. در مجموع ۵۹ گونه ثبت شد که از این تعداد ۷ گونه مختص گهات غربی هستند. پوشش گیاهی علفی، پوشش درختچه‌ای، فضای باز، pH آب، دمای هوا و متغیرهای شیمیایی آب شامل هدایت الکتریکی، مواد جامد محلول و شوری به عنوان مهم‌ترین شاخص‌های پیش‌بینی تنوع سنجاقک‌ها شناسایی شدند. انتشار گونۀ بومی و در معرض خطر به نام *Disparoneura apicalis* (Fraser, 1924) در جزایر تحت تأثیر گونه‌های خاصی از گیاهان که از آنها به عنوان مکان استراحت و محل‌های تخم‌گذاری استقاده می‌کند قرار دارد. پیشنهاد می‌شود که گردشگران بازدیدکنندگان جزایر کورووا از اهمیت این مکان به عنوان زیستگاه سنجاقک‌ها آگاه شوند. حوزۀ انتشار گونۀ *D. apicalis* بسیار محدود بوده و می‌تواند به عنوان گونۀ پرچم‌دار برای حفاظت از این اکوسیستم منحصر به فرد معرفی شود.

واژگــان کلیدی: بوم‌شناسی فردی، سنجاقک دنباله‌سیاه، حفاظت، بومی، ویاناد

Authors' Brief Biographical Notes

Ayikkara Vivek Chandran

Department of Geology and Environmental Science, Christ College (Autonomous), Irinjalakuda, Thrissur, affiliated to the University of Calicut, Thenhipalam, Kerala, India.

Email: avivekchandran2@gmail.com

A PhD scholar studying the ecology of Odonata under the supervision of Dr. Subin K. Jose at Christ College (Autonomous), Irinjalakuda, Kerala, India. Vivek is also a member of the General Council of the Society for Odonate Studies (SOS), a non-governmental organization in India, studying and disseminating information about odonates.

https://www.researchgate.net/profile/A-Vivek-Chandran

Puthukudy Kunjamu Muneer

Ferns Nature Conservation Society, PB No. 28, Mananthavady, Wayanad, Kerala, India.

Email: muneerputhukudy@gmail.com

He is a banker by profession and naturalist by choice. He is the prime educator in nature camps conducted by Kerala Forests and Wildlife Department in Wayanad. He is knowledgeable about birds, butterflies and odonates of the Western Ghats.

https://scholar.google.com/citations?user=BfB44WIAAAAJ&hl=en

Maran Madhavan

Ferns Nature Conservation Society, PB No. 28, Mananthavady, Wayanad, Kerala, India.

Email: madhavantholpetty@gmail.com

A forest watcher working in the eco-development committee of Tholpetty, Wayanad Wildlife Sanctuary, and has sound knowledge of the region's birds, mammals, butterflies, and odonates.

https://scholar.google.com/citations?user=uxd6iWsAAAAJ&hl=en&authuser=1

Subin Kaniyamattathil Jose (PhD)

Department of Geology and Environmental Science, Christ College (Autonomous), Irinjalakuda, Thrissur, the University of Calicut, Thenhipalam, Kerala, India.

Email: josesubin@gmail.com

An Assistant Professor (Environmental Science) at Christ College (Autonomous), Irinjalakuda, Kerala, India. His research interests are biodiversity, Geographic Information Systems (GIS) and water quality.

https://www.researchgate.net/profile/Subin-Jose-3