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Assessing the diversity and abundance of dragonflies and damselflies in selected sites of Saranda Forest, Jharkhand, eastern India

Md Abu Imran Mallick,[1] Sima Paik[2]

[1]Jamshedpur Forest Division, Jamshedpur, Jharkhand; [2]Department of Zoology, University of Calcutta, Kolkata, West Bengal, India

Abstract

Odonates are well studied globally, yet studies from Jharkhand remain limited. Urbanization-induced habitat modification—such as wetland loss, altered hydrology, water pollution, and removal of riparian vegetation—directly affects Odonata breeding habitats, larval development, and community composition, demonstrating their sensitivity to landscape-level disturbance. The present study documents the diversity and community structure of odonates across seven sites in Saranda Forest, Jharkhand, from March 2024 to March 2025. A total of 61 species belonging to two suborders, Anisoptera (35 species; 57%) and Zygoptera (26 species; 43%), were recorded. Dragonflies (Anisoptera) dominated the assemblage, with *Brachythemis contaminata*, *Crocothemis servilia*, and *Brachydiplax sobrina* emerging as the most abundant taxa, while the damselfly *Agriocnemis pygmaea* (Zygoptera) was also recorded among the dominant species. Species richness and abundance varied across sites, with Ligirda (28 species) and Karampada (27 species) supporting the highest richness, while Thalkobad (82 individuals) and Beside Koina River (75 individuals) recorded the greatest abundance. Libellulidae was the most dominant family, followed by Coenagrionidae, whereas other families such as Aeshnidae, Gomphidae, and Macromiidae were sparsely represented. Diversity indices revealed high Shannon (2.6-3.2) and Simpson (>0.85) values across sites, indicating well-balanced communities with low dominance. Ligirda exhibited the highest diversity and evenness, while Beside Koina River showed lower evenness due to dominance by a few species. Species accumulation curves suggested sufficient sampling and revealed distinct site-level assemblages influenced by habitat heterogeneity. Analysis of variance confirmed significant variation in abundance across families, with Libellulidae significantly more dominant than other groups, whereas site-level abundance differences were statistically non-significant. The findings underscore the ecological importance of Saranda Forest as a reservoir of odonate diversity, with family-level dominance patterns and habitat heterogeneity shaping community structure.

Key words: abundance, conservation, diversity indices, ecological indicator, habitat heterogeneity, Odonata, Saranda Forest.

Correspondence to: Md Abu Imran Mallick, Jamshedpur Forest Division, Jamshedpur – 831001, Jharkhand, India.
E-mail: imranmallick708@gmail.com

Introduction

Odonata, a distinctive order of winged insects, comprises two major suborders, Zygoptera (damselflies) and Anisoptera (dragonflies), and represents one of the earliest radiations of winged insects (Subramanian & Babu, 2017; May, 2019). Characterized by two pairs of membranous wings and large compound eyes (Bybee *et al*., 2008), odonates exhibit strong flight capability (Vilela *et al*., 2017) and are commonly associated with aquatic habitats such as lakes, ponds, streams, and wetlands, as well as surrounding terrestrial ecosystems, including agricultural landscapes and forests (Villalobos-Jimenez *et al.*, 2016; Paulson, 2019). They occur worldwide except Antarctica (Dijkstra, 2025), with approximately 6407 species documented globally (Siddiqui *et al*., 2024; Dolai & Mallick, 2025). The South Asian region supports nearly 588 taxa (Kalkman *et al*., 2020; Beatty *et al*., 2022), of which around 504 species belonging to 157 genera and 17 families are recorded from India (Kalkman *et al*., 2020; Subramanian & Babu, 2024). About 175 species are endemic to India, primarily concentrated in the Western Ghats and Northeast India (Subramanian & Babu, 2024). While traditional classifications recognize three suborders (Zygoptera, Anisoptera, and Anisozygoptera), modern taxonomic consensus generally treats extant Odonata as comprising two principal suborders, Zygoptera and Anisoptera, with Anisozygoptera often considered a relict lineage or incorporated within Anisoptera (Epiprocta) (Subramanian & Babu, 2024; Dolai & Mallick, 2025). Jharkhand contributes to this diversity with approximately 72 recorded species, highlighting its regional ecological importance (Subramanian & Babu, 2024).

The life cycle of odonates is closely linked to freshwater ecosystems, comprising an aquatic larval stage and a terrestrial adult phase (Stoks & Córdoba-Aguilar, 2012; Seifert & Scheu, 2012). Larvae inhabit water bodies such as ponds, streams, and wetlands and are highly sensitive to changes in water quality and habitat structure (Tippler *et al*., 2014; Villalobos-Jimenez *et al*., 2016; Rana & Bhatia, 2025), while adults are relatively easy to detect in the field (Bybee *et al*., 2016; Okude *et al*., 2021). These characteristics make odonates effective bio-indicators of freshwater ecosystem health (Choudhary & Ahi, 2015; Chakraborty *et al*., 2023; Landmann *et al*., 2023). Odonates also play key ecological roles as both predators and prey in aquatic and terrestrial food webs (Bried *et al*., 2007; Kietzka *et al*., 2019; Sentis *et al*., 2023; Verma *et al*., 2023), and contribute to biological control of pest insects in natural and agricultural ecosystems (Verma *et al*., 2023). However, odonate populations face increasing threats from habitat degradation, wetland loss, deforestation, and climate change-driven alterations in hydrological regimes (Clausnitzer *et al*., 2009; Harabiš & Dolný, 2012; Hughes, 2017; Dolný *et al*., 2021; Epele *et al*., 2025).

In Jharkhand, previous studies by several workers (Prasad & Ghosh, 1988; Emiliyamma *et al*., 2002; Mitra, 2002; Kesharia *et al*., 2013; Sajan *et al*., 2014; Keshari, 2024) have contributed to understanding regional odonate diversity. Despite these efforts, comprehensive assessments remain limited for many ecologically significant landscapes, including the Saranda Forest of West Singhbhum district. No consolidated checklist or systematic evaluation of species composition currently exists for this region. Therefore, the present study aims to assess and document the diversity and community structure of Odonata in the Saranda Forest, providing baseline information to improve regional biodiversity knowledge and support conservation planning in eastern India.

Materials and Methods

Study area

The Saranda Forest Division, situated in Jharkhand's West Singhbhum district, was the primary study area for documenting odonate diversity from March 2024 to March 2025. Bounded by latitudes 22.10246°N to 22.33333°N and longitudes 85.16667°E to 85.37033°E, it covers 858.82 km^2 with elevations ranging from 185 m to 938 m above mean sea level, forming a topographically varied landscape (Figure 1). The tropical climate features annual rainfall between 945 mm and 1297 mm, with temperatures fluctuating from 6°C in winter to 47°C during peak summer.

Saranda's forests are dominated by Sal (*Shorea robusta*), supported by associated species such as *Anogeissus latifolia*, *Bauhinia semla*, *Bombax ceiba*, *Terminalia alata*, and *Syzygium cumini*, which sustain wildlife including elephants, butterfly fauna, and diverse avifauna. Indigenous tribes such as Munda, Oraon, Ho, and Santhal maintain traditional agro-forest relationships, reflected in nature-centric festivals like Sarhul.

Seven sampling locations—Thalkobad (22.13765°N, 85.18248°E), Karampada (22.06103°N, 85.22675°E), Beside Koina River (22.23777°N, 85.31444°E), Kiriburu (22.10789°N, 85.29019°E), Toiba (22.090309°N, 85.39970°E), Ligirda (21.90964°N, 86.44607°E), and Gua (22.20878°N, 85.37594°E)—represented diverse habitat types. Thalkobad and Karampada consisted of narrow forest streams (≈2-4 m width) with dense canopy

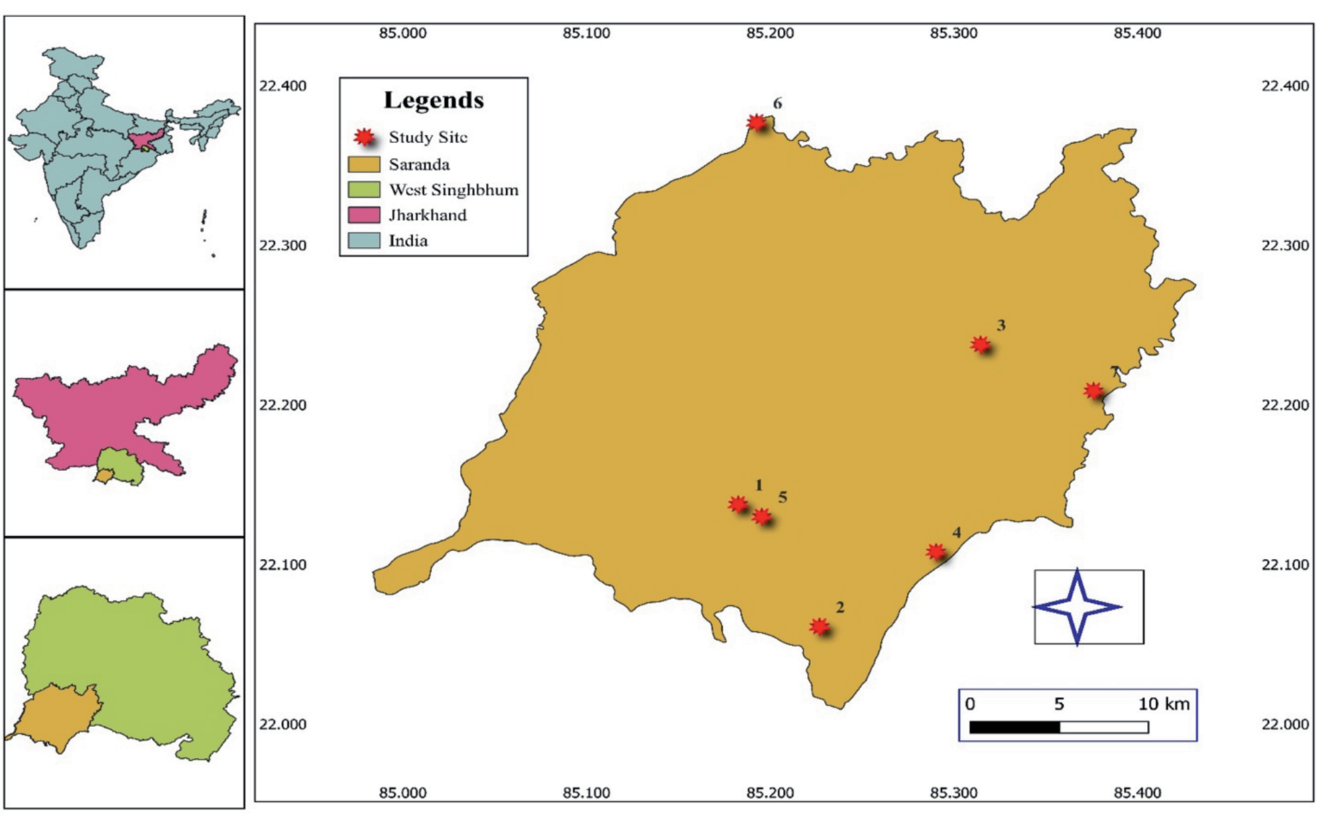

Figure 1. Map of the study area showing the selected survey sites in the Saranda region of West Singhbhum district, Jharkhand, India. The inset maps represent the location of Jharkhand within India, West Singhbhum within Jharkhand, and the Saranda Forest region within West Singhbhum. Red star symbols indicate the specific study sites where odonate surveys were conducted.

cover and low disturbance. The Koina River site comprised a wider riparian habitat (≈6-8 m width) with moderate canopy cover and minimal anthropogenic pressure. Kiriburu represented open grassland–forest edge habitats with sparse canopy and moderate disturbance. Toiba included hilltop woodland with seasonal seepages and partial canopy cover. Ligirda consisted of shaded forest streams with dense riparian vegetation and low disturbance, while Gua represented mixed woodland with medium-width streams and moderate anthropogenic influence. These heterogeneous freshwater-associated habitats, including streams, riparian zones, hilltop seepages, and forest edges, provide suitable ecological conditions for sustaining diverse dragonfly and damselfly assemblages, highlighting the ecological aptness of Saranda Forest for supporting odonate populations and their interactions.

Odonata sampling methods

Odonate data collection in the Saranda Forest study area was carried out through systematic monthly surveys conducted twice per month from March 2024 to March 2025, resulting in a total of 24 surveys. The methodological framework employed full-width belt transects to systematically monitor adult odonates. Observers walked 200 m along each of seven strategically positioned transects, recording individuals within a 3-m band on either side. Transect placement included six sites adjacent to streams and one site near a pond, ensuring broad spatial representation across the study area. To minimize overlap, inter-transect distances were maintained at more than 500 m. Notably, five transects were located in areas accessible to tourists, thereby allowing assessment of potential anthropogenic influences. All surveys were conducted between 8:00 AM and 5:00 PM under fair weather conditions to optimize detection efficiency and reduce environmental variability.

Taxonomic identification of encountered odonates drew upon esteemed published literature (Fraser, 1933-1936; Mitra, 2002; Nair, 2011; Subramanian and Babu 2017; Nair *et al.,* 2021), underpinning accurate species delineation. Complementing field identifications, photographic documentation was undertaken using a Samsung Galaxy A13 (SM-A135F/DS) smartphone camera, furnishing a visual catalogue of species encountered. This structured data collection regimen facilitated rigorous documentation of odonate diversity within Saranda Forest, shedding light on species assemblage patterns and their associations with varied habitats, thereby enriching the understanding of local ecological dynamics.

Analysis methods

The relative abundance of each odonate species was calculated using Eq. 1:

$$\text{Relative abundance (\%)} = \left(\frac{n}{N}\right)\times 100 \qquad \text{[Eq. 1]}$$

where: n is the total number of individuals of a particular species, and N is the total number of individuals of all species combined.

To assess the diversity of odonate species in the study area, three indices were used: Shannon Index, Pielou's Evenness Index, and Simpson's Diversity Index.

The Shannon Index (H') measures the diversity of species in an area, taking into account the proportion of each species (Shannon & Weaver 1949). The index is calculated using Eq. 2:

$$H' = -\sum (pi \times \ln(Pi)) \qquad \text{[Eq. 2]}$$

where Pi is the proportion of each species and ln (Pi) is the natural logarithm of Pi.

Pielou's Evenness Index (J') quantifies how evenly the species are distributed in a habitat (Magurran, 2005). The index is calculated using Eq. 3:

$$J' = H'/\ln(S) \qquad \text{[Eq. 3]}$$

where S is the total number of species.

Simpson's Diversity Index (D) measures the diversity of species in an area, considering both the number of species present and their relative abundance (Simpson, 1949). The index is calculated using Eq. 4:

$$D = 1 - \left(\sum n\left(\frac{(n-1)}{N(N-1)}\right)\right) \qquad \text{[Eq. 4]}$$

where n is the number of individuals for each species, and N is the total number of all individuals.

Data analysis was conducted using open-source tools, including PAST (version 4.03) for diversity indices (Hammer & Harper, 2001), R (version 4.3.0) for statistical analyses, and Excel 2013 for data handling. In R, packages such as vegan were used for community ecology analyses, ggplot2 for visualization, and car for testing homogeneity of variances. Before performing analysis of variance (ANOVA), data were tested for normality using the Shapiro-Wilk test and for homogeneity of variances using Levene's test. Additionally, Quantum GIS (version 3.22.14) was employed to create a visual representation of the study area map.

Results

The abundance of odonate species across seven sites in Saranda Forest was assessed, representing two sub-orders: Anisoptera (dragonflies) and Zygoptera (damselflies). A total of 61 species were documented, including 35 (57%) species of dragonflies and 26 (43%) species of damselflies, reflecting the dominance of Anisoptera in the study region. A total of odonate species were recorded in Saranda Forest, with their abundances and relative abundances showing marked variation across taxa. Among the odonate species, *Brachythemis contaminata* was the most dominant species, contributing the highest abundance (46 individuals; 11.30% relative abundance), followed by *Crocothemis servilia* (39; 9.58%), *Agriocnemis pygmaea* (36; 8.85%), and *Brachydiplax sobrina* (29; 7.13%). Other frequently occurring taxa included *Ceriagrion coromandelianum* (23; 5.65%), *Ischnura senegalensis* (17; 4.18%), *Neurothemis fulvia* (15; 3.69%), and *Pantala flavescens* (18; 4.42%). In contrast, a large number of species exhibited very low representation, with relative abundances below 1%. These included taxa such as *Paragomphus lineatus*, *Tramea basilaris*, *Orthetrum luzonicum*, *Vestalis gracilis*, *Aciagrion pallidum*, *Amphiallagma parvum*, *Pseudagrion indicum*, *Pseudagrion decorum,* and *Prodasineura verticalis*, each represented by only a single individual (0.25% relative abundance) (*Supplementary Table 1*).

Among the study sites, Karampada (18 dragonflies, 9 damselflies) and Ligirda (15 dragonflies, 13 damselflies) exhibited comparatively higher species richness. Thalkobad and Beside Koina River showed moderate levels of diversity, while Kiriburu and Gua recorded relatively lower species numbers. In nearly all locations, dragonflies were more abundant than damselflies, with the exception of Ligirda, where the abundance of damselflies (13 species) was nearly comparable to dragonflies (15 species) (Figure 2).

The family-wise distribution of odonate species across the seven study sites in Saranda Forest revealed distinct patterns of dominance. Libellulidae emerged as the most abundant family, with consistently high representation across all sites, peaking at 59 individuals beside Koina River, followed by 56 individuals at Thalkobad and 34 at Kiriburu. This family clearly dominated the assemblage, forming the core of the odonate community. Coenagrionidae represented the second most abundant family, showing relatively even distribution across the sites, ranging from 12 individuals (Beside Koina River) to 22 individuals (Ligirda). This indicates a widespread but moderate abundance of damselfly species belonging to this family. Other families, such as Aeshnidae, Gomphidae, and Platycnemididae, were recorded in low numbers and restricted to certain sites, with counts ranging from 1 to 4 individuals. Similarly, Macromiidae was rare, represented by only a few individuals at Karampada (2) and Ligirda (1). Families Calopterygidae and Chlorocyphidae were recorded in very low abundance, with only 1-2 individuals at scattered sites. Lestidae was the least represented, restricted to Kiriburu with only 2 individuals (Figure 3).

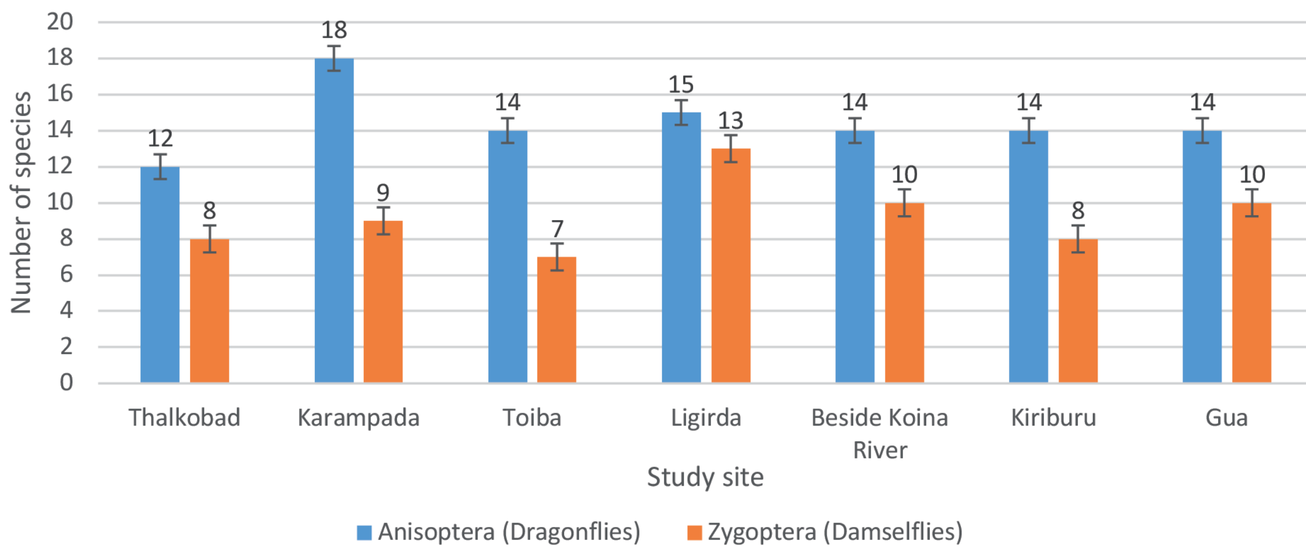

Figure 2. The sub-order-wise abundance of odonate species across seven sites in Saranda Forest.

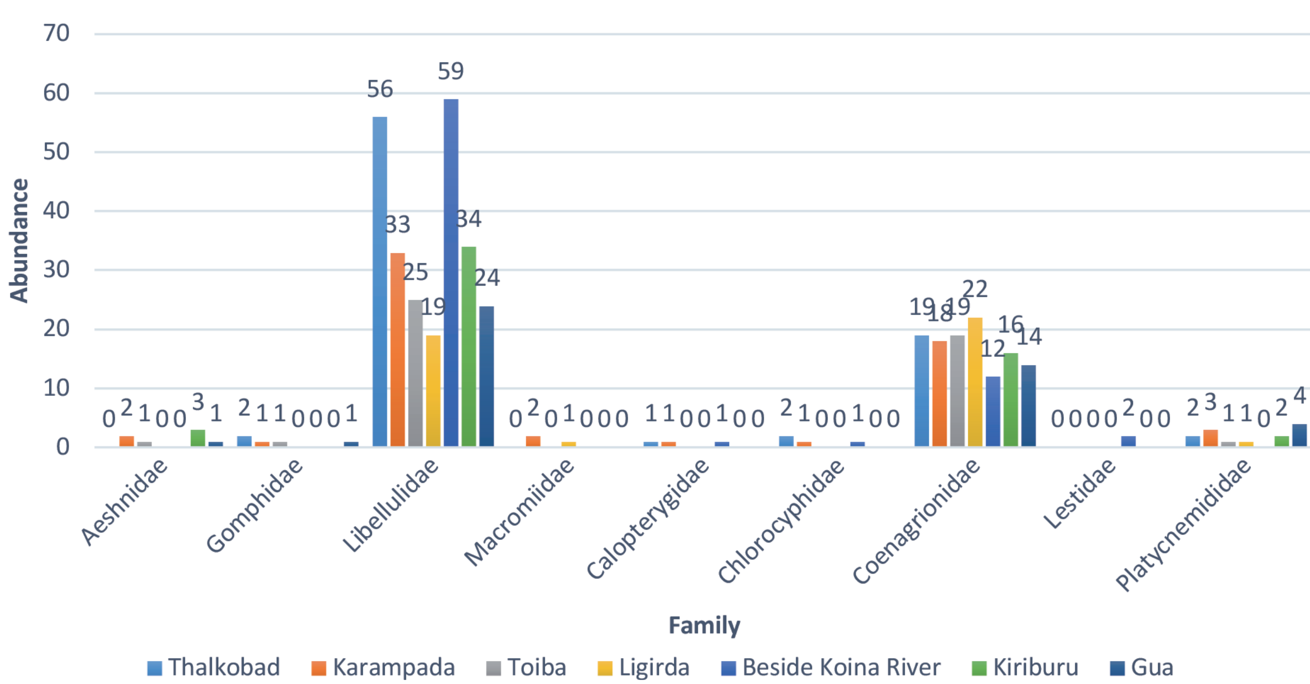

Figure 3. Family-wise odonate distribution across study sites in Saranda Forest.

The abundance of odonate species varied notably across the seven study sites of Saranda Forest (Figure 4). Thalkobad recorded the highest number of individuals (82) despite having relatively fewer taxa (20), indicating a concentration of individuals within fewer species. Karampada followed with 61 individuals across 27 taxa, reflecting both high abundance and richness. Besides, the Koina River also showed considerable abundance (75 individuals) but with only 24 taxa. In contrast, Ligirda exhibited the highest species richness (28 taxa) but relatively lower abundance (43 individuals), suggesting a more even distribution of species with fewer individuals per species. Toiba (21 taxa, 47 individuals) and Gua (24 taxa, 44 individuals) showed moderate richness and abundance, while Kiriburu presented the lowest richness (22 taxa) and a modest abundance (55 individuals).

The biodiversity indices of odonate species showed considerable variation across the seven study sites in Saranda Forest (Figure 5). Abundance was highest at Thalkobad (82 individuals) and Beside Koina River (75 individuals), while Toiba and Ligirda recorded relatively lower abundances. In terms of species richness, Ligirda (28 species) and Karampada (27 species) exhibited the highest values, indicating greater species representation, whereas Toiba recorded the lowest richness (21 species). The Shannon diversity index values ranged between ~2.6 and 3.1, with Karampada and Gua showing the highest diversity, suggesting a more balanced distribution of individuals among species at these sites. Simpson's index values were consistently high across all sites (>0.85), reflecting low dominance by single species and a generally equitable community structure. Evenness values were also high (>0.8) at all sites, with Gua and Karampada showing the highest evenness, indicating that species were more evenly distributed in their populations compared to sites such as Ligirda and Beside Koina River, where slight skewness was observed.

The site-wise diversity indices provide insights into richness, abundance, dominance, and evenness of odonate communities across the seven study sites (*Supplementary Table 2*). The highest number of species was observed at Ligirda (28 taxa), followed by Karampada (27 taxa), while the lowest richness was recorded at Thalkobad (20 taxa). In terms of abundance, Thalkobad (82 individuals) and Beside Koina River (75 individuals) supported the highest counts, whereas Ligirda (43 individuals) and Toiba (47 individuals) recorded the lowest. The Simpson's Diversity Index (1-D) and Shannon-Wiener Index (H') indicated the highest diversity at Ligirda (1-D=0.954, H'=3.209), reflecting high species richness and low dominance. In contrast, Beside Koina River (1-D=0.8647, H'=2.576) showed lower diversity, primarily due to higher dominance (D=0.1353; Berger-Parker=0.2933). The evenness (e^H/S) and equitability (J) values were also highest at Ligirda (0.884; 0.963), showing a more balanced distribution of individuals across species. Conversely, Beside Koina River (0.5477; 0.8106) had the lowest evenness, indicating uneven dominance by a few species. The Margalef and Fisher's α indices further highlighted Ligirda as the richest site (Margalef=7.179; Fisher's α=34.81), followed by Gua (Margalef=6.078; Fisher's α=21.61). The Chao-1 estimator also predicted potentially higher species richness, with the maximum value at Toiba (51.33) and Ligirda (49.86), suggesting the possibility of undiscovered or rare species in these areas.

The species accumulation curves for the seven study sites in Saranda Forest showed variation in species richness and sampling efficiency across locations (Figure 6). The curve for Beside Koina River reached the highest asymptote (~28 species), indicating the greatest accumulated richness, followed by Karampada (~27 species) and Ligirda (~24 species). These sites thus represent areas of comparatively high odonate diversity. In contrast, sites such as Toiba and Thalkobad showed lower asymptotic richness (~20-21 species), while Kiriburu (~22 species) and Gua (~24 species) displayed moderate richness.

The one-way ANOVA tested differences in odonate species abundance across sites and families (*Supplementary Figure 1*). Significant variation in species abundance was observed across sites. The highest abundance was recorded at Beside Koina River and Ligirda, while forest-interior sites such as Thalkobad and Karampada supported comparatively lower abundances. This indicates that water-associated habitats sustain richer odonate assemblages than drier forested sites. Among families, Libellulidae was dominant, showing the highest abundance with considerable variability across sites, followed by Coenagrionidae and Chlorocyphidae. Families such as Aeshnidae, Gomphidae, and Macromiidae were comparatively less represented.

One-way ANOVA results showed no significant variation in odonate species abundance across the seven study sites ($F=0.1502$, $p=0.9883$), indicating relatively uniform species abundance among sites (*Supplementary Table 3*). In contrast, ANOVA across odonate families revealed highly significant variation ($F=35.44$, $p<0.001$), suggesting that species abundance differed markedly among families. The large sum of squares between families (8396.51) compared to residual variation indicates that taxonomic grouping strongly influenced community structure.

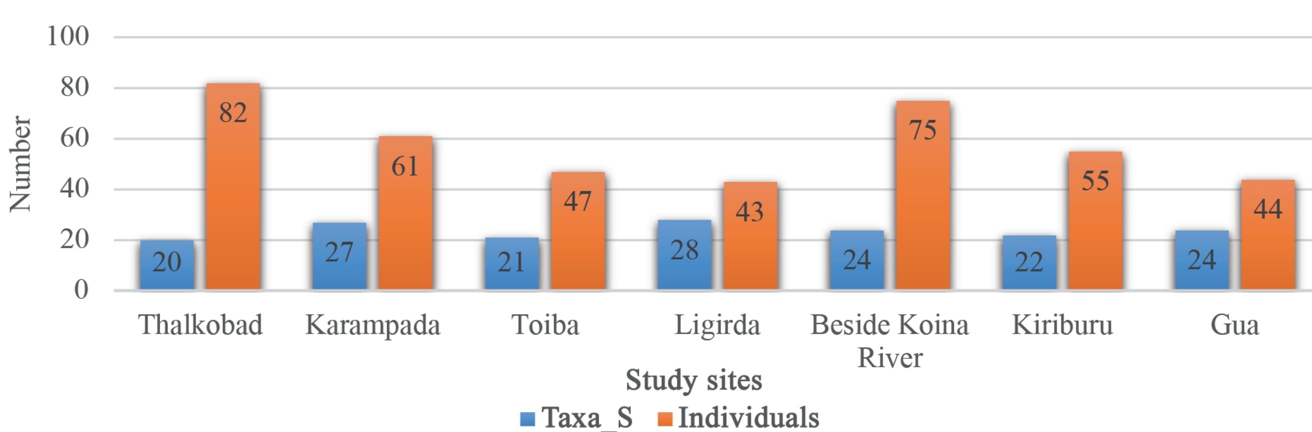

Figure 4. Abundance across the seven study sites in Saranda Forest.

Tukey's HSD test indicated significant differences in odonate abundance among families (*Supplementary Figure 2*). Libellulidae showed the highest abundance and formed a distinct group ("c"), while Coenagrionidae formed an intermediate group ("b"). The remaining families (Aeshnidae, Calopterygidae, Chlorocyphidae, Gomphidae, Lestidae, Macromiidae, and Platycnemididae) were grouped together ("a"), indicating no significant differences among them. In contrast, all study sites belonged to the same group ("a"), confirming no statistically significant differences in odonate abundance between sites, despite slightly higher counts at Thalkobad and Beside Koina River.

The analysis showed that mean abundance values across the seven sites (Thalkobad, Karampada, Toiba, Ligirda, Beside Koina River, Kiriburu, and Gua) ranged between 4.78 (Ligirda) and 9.12 (Thalkobad). However, all sites fell within the same Tukey group "a" (ANOVA F=0.16, p=0.98), indicating no statistically significant differences in species abundance across sites. This suggests that odonate abundance is relatively evenly distributed among the surveyed locations. In contrast, significant differences were observed among families (ANOVA F=35.45, p<0.001). The Libellulidae family had the highest mean abundance (35.72) and was grouped separately into "c", highlighting its strong dominance. The Coenagrionidae family showed intermediate abundance (17.15) and formed group "b". All other families, including Aeshnidae, Calopterygidae, Chlorocyphidae, Gomphidae, Lestidae, Macromiidae, and Platycnemididae, had low mean abundances (≤ 1.86) and were grouped into "a", showing no significant differences among themselves. This indicates that family-level patterns, rather than site-level variation, drive the observed differences in odonate abundance, with Libellulidae emerging as the most dominant contributor to community structure (*Supplementary Table 4*).

Supplementary Figure 3 shows Gaussian fit plots for biodiversity indices at the Gua site. Richness and abundance display near-normal distributions, centered at 35-40 and 12-16, respectively, indicat-

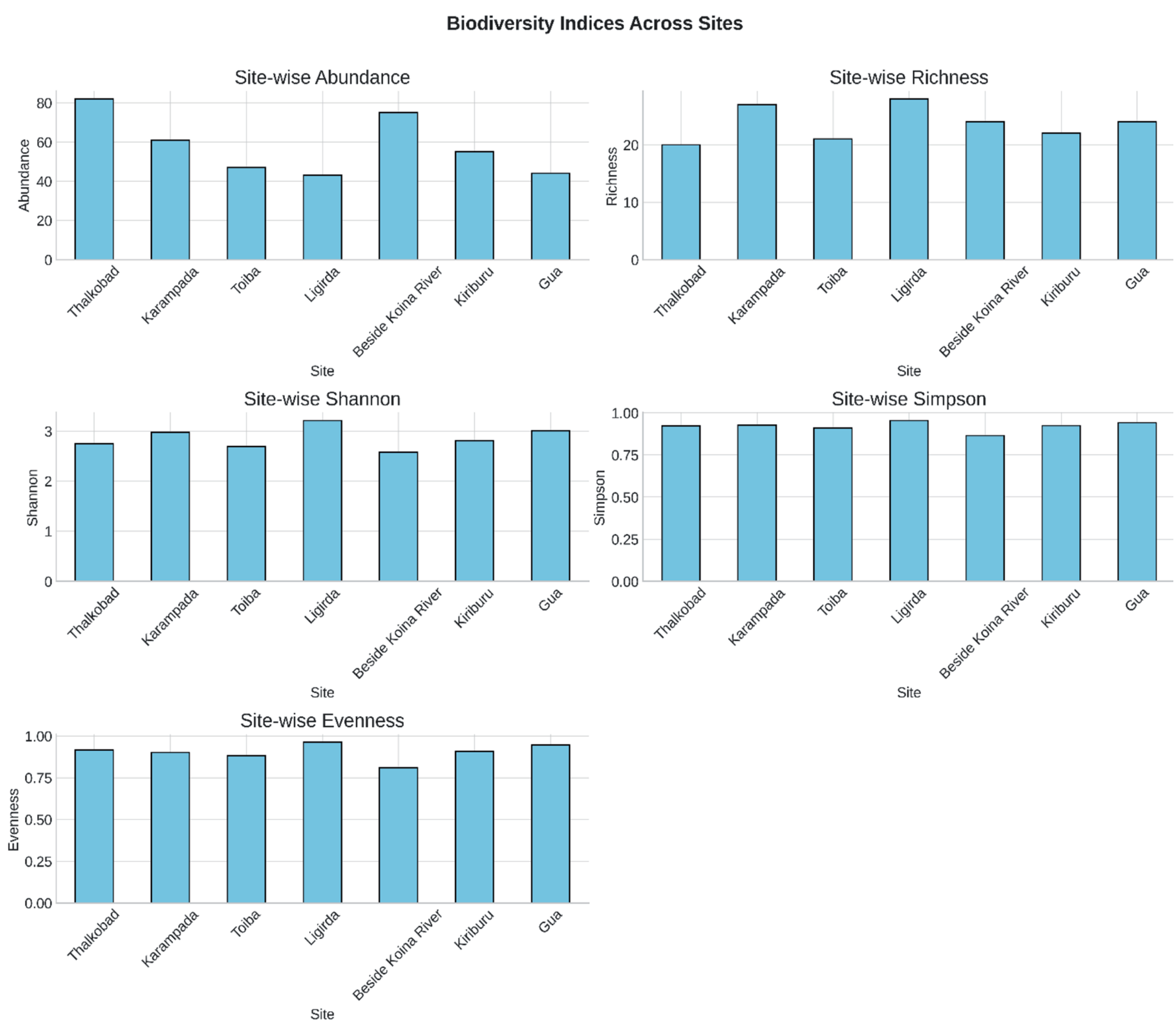

Figure 5. The biodiversity indices of odonate species showed considerable variation across the seven study sites in Saranda Forest.

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ing balanced species occurrence. Dominance shows moderate fit with slight skewness, suggesting no single species dominates. Evenness and both diversity indices follow normal-like distributions with peaks at intermediate values. The odonate community at Gua exhibits stable structure with moderate richness and diversity, and no strong skewness in dominance or abundance.

Supplementary Figure 4 presents Gaussian fit plots for biodiversity indices at the Karampada site. Species richness shows a near-normal distribution peaking at 15-20, while abundance centers at 18-22, indicating moderate to high odonate presence. Dominance fits a bell-shaped curve with moderate values, with no extreme single-species dominance. Evenness spans 25-35, reflecting a fairly uniform species distribution. Shannon and Simpson indices peak at 34-38 and 30-35, respectively, indicating stable diversity. Overall, Karampada supports a balanced odonate community with moderate to high richness and abundance.

Supplementary Figure 5 shows Gaussian fit plots for biodiversity indices at the Kiriburu site. Species richness is moderately skewed, centered at 18–22, while abundance follows a bell-shaped distribution peaking at 30–35, indicating consistent populations. Dominance peaks at moderate values of 10-15, with no strong single-species dominance. Evenness ranges from 8-16, suggesting moderate variability but overall balance. Shannon and Simpson indices peak at 40-45 and 32-38, respectively, reflecting stable diversity. Kiriburu supports a healthy odonate community with moderate richness, stable abundance, and limited dominance.

Supplementary Figure 6 presents Gaussian fit plots for biodiversity indices at the Koina River site. Richness shows a bell-shaped distribution centered at 28-35, indicating moderate to high species representation. Abundance peaks at 40-48, reflecting relatively high odonate populations. Dominance clusters at 20-28, suggesting moderate dominance without reducing overall diversity. Evenness ranges from 15-22, showing somewhat balanced species distribution. Shannon and Simpson indices peak at 12-15 and 48-55, respectively, indicating a well-structured community with moderately high diversity and balanced species distribution.

Supplementary Figure 7 shows Gaussian fit plots for biodiversity indices at the Ligirda site. Richness centers at 37-42, indicating moderately high species presence. Abundance peaks at 45-50, reflecting strong odonate density. Dominance clusters at 20-28, with a few species more abundant but not suppressing diversity. Evenness ranges from 40-48, suggesting a balanced species distribution. Shannon and Simpson indices peak at 30-35 and 10-14, respectively, indicating high diversity. Overall, Ligirda supports a stable, diverse odonate community with high abundance and even species distribution.

Supplementary Figure 8 presents Gaussian fit plots for biodiversity indices at the Thalkobad site. Richness centers at 45-50, indicating high species representation. Abundance peaks at 10-15, reflecting moderate population density. Dominance clusters at 35-42, with some species more abundant but no strong single-species skew. Evenness ranges from 40-48, suggesting balanced species distribution. Shannon and Simpson indices peak at 20-25 and 30-35, respectively, indicating moderate to high diversity. Thalkobad supports a diverse, ecologically balanced odonate community with high richness and moderate abundance.

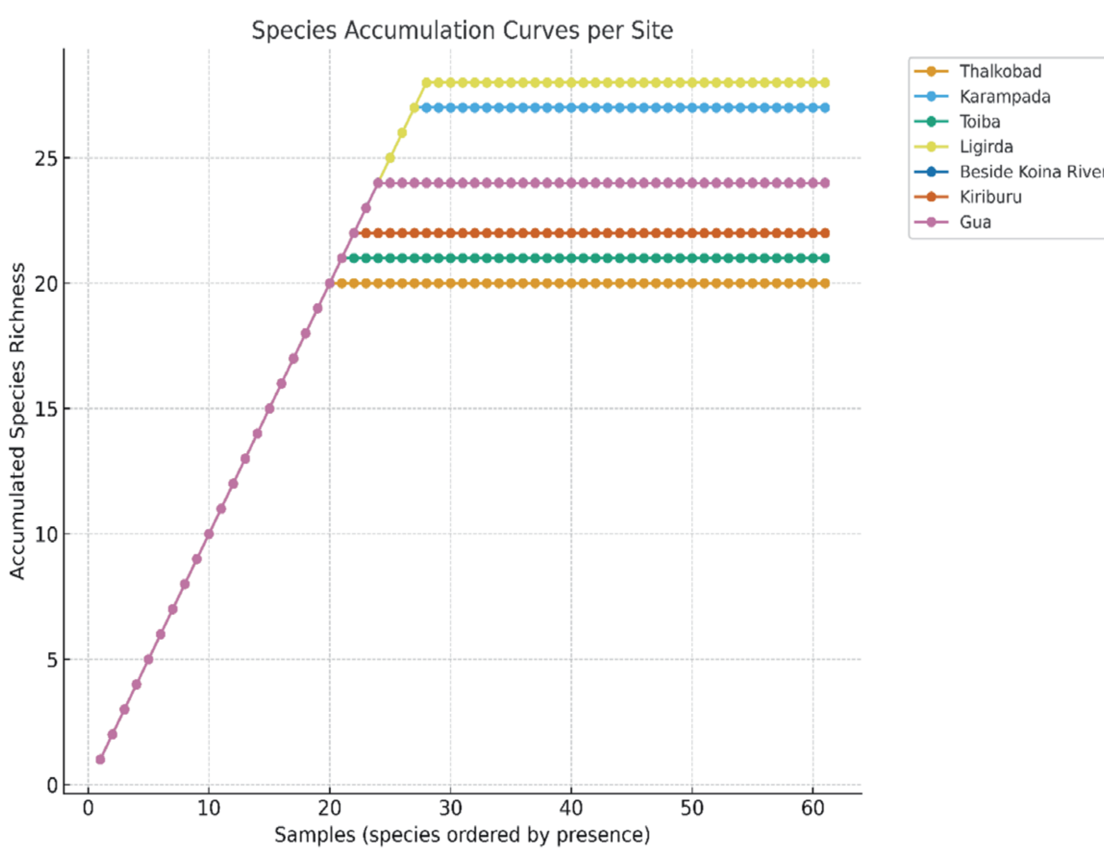

Figure 6. The species accumulation curves for the seven study sites in Saranda Forest.

Supplementary Figure 9 shows Gaussian fit plots for biodiversity indices at the Toiba site. Richness clusters at 28-32, indicating a moderately rich odonate community. Abundance centers around 20, reflecting a stable population. Dominance ranges from 40-50, with a few species contributing more strongly but not overwhelming diversity. Evenness peaks at 40-45, suggesting a relatively balanced species distribution. Shannon and Simpson indices cluster at 30-35 and 35-40, respectively, indicating moderate diversity with fair species balance and moderate dominance.

The heatmap of odonate species abundance across sites provides a clear visualization of species distribution and relative abundance patterns (*Supplementary Figure 10*). Each row represents an odonate species, while each column corresponds to a study site (Thalkobad, Karampada, Toiba, Ligirda, Beside Koina River, Kiriburu, and Gua). The color gradient, from dark purple (low abundance) to yellow (high abundance), highlights variation in species occurrence. The heatmap shows that species distribution is highly heterogeneous across sites. For instance, certain species such as *Cratilla lineata* and *Crocothemis servilia* exhibit high abundances at Ligirda and Beside Koina River, while other species like *Agrionemis pygmaea* and *Ischnura senegalensis* are relatively more widespread across multiple sites but at lower densities. Sites such as Ligirda and Beside Koina River show strong species dominance with concentrated high-abundance taxa, whereas Thalkobad, Kiriburu, and Gua reflect more even but generally lower abundances.

This dendrogram represents the hierarchical clustering of odonate species based on their abundance patterns across different sites, using Ward's method as the clustering algorithm (*Supplementary Figure 11*). The horizontal axis (distance) reflects the degree of dissimilarity between species, while the vertical branches represent the progressive merging of species into clusters. The clustering shows that species with similar abundance and distribution patterns across survey sites are grouped together at lower distances, indicating strong ecological or habitat associations. For example, closely related clusters suggest species that co-occur frequently under similar habitat conditions. Conversely, species that merge at higher distances exhibit more distinct ecological preferences and distribution patterns. The dendrogram reveals two major groups (large clusters separated at higher distances) with multiple sub-clusters nested within them.

This dendrogram shows the hierarchical clustering of sites based on odonate species abundance and distribution, using Ward's method (*Supplementary Figure 12*). The vertical axis (distance) represents dissimilarity among sites, while the horizontal axis lists the surveyed locations. Sites that cluster together at lower distances are more similar in terms of species composition, whereas those that merge at higher distances are more distinct. From the figure, Ligrida and Gua form the closest pair, indicating strong similarity in their species assemblages. These are then clustered with Toiba, suggesting ecological overlap among these three sites. Karamapada and Kiriburu form another pair, moderately similar to the first cluster. In contrast, Thalkobad and Beside Koina River form a separate, distinct group, joining the other sites only at a higher distance level.

Discussion

The present study highlights the Saranda Forest as an important reservoir of odonate diversity in eastern India, documenting 61 species belonging to two suborders. High species richness and varied assemblages indicate the ecological value of this forest landscape, consistent with previous studies demonstrating that odonate diversity reflects freshwater ecosystem integrity and habitat quality (Stoks & Córdoba-Aguilar, 2012; Kietzka *et al*., 2019). The consistent dominance of Libellulidae across sites aligns with global observations that members of this family exhibit broad ecological tolerance and high dispersal ability, enabling them to thrive in both natural and moderately disturbed habitats (Villalobos-Jiménez *et al*., 2016; Dolný *et al*., 2012). In contrast, families such as Aeshnidae, Gomphidae, and Macromiidae were recorded in low abundance, which is commonly associated with narrower habitat preferences and sensitivity to environmental changes (Harabiš & Dolný, 2012).

Variation in diversity indices among sites suggests the influence of habitat heterogeneity on odonate assemblages. Sites such as Ligirda and Karampada showed higher richness, likely reflecting structurally diverse habitats. Similar patterns have been reported where heterogeneous habitats support both generalist and specialist taxa (Kietzka *et al*., 2019; Villalobos-Jiménez *et al*., 2016). In contrast, sites with high abundance but lower evenness indicate localized dominance by a few species, a pattern commonly observed in odonate communities inhabiting relatively uniform habitats (Dolný *et al*., 2012).

Multivariate analyses (PCA and clustering) revealed site-level assemblage differentiation, suggesting ecological filtering. Although environmental variables were not directly measured, previous studies have demonstrated that odonate community composition is strongly associated with factors such as water availability, riparian vegetation, and habitat structure (Harabiš & Dolný, 2012; Villalobos-Jiménez *et al*., 2016). The absence of significant variation in abundance across sites (ANOVA, $p>0.05$), coupled with significant differences among families, indicates that community structure is shaped more by taxonomic composition than overall species counts. This pattern supports the concept of habitat filtering, where certain families dominate under specific habitat conditions (Kietzka *et al*., 2019).

Odonates are widely recognized as indicators of freshwater ecosystems due to their biphasic life cycle and dependence on aquatic habitats (Stoks & Córdoba-Aguilar, 2012). Studies have shown that variations in odonate abundance and diversity are linked to environmental gradients such as canopy cover, water quality, and hydrological regimes (Harabiš & Dolný, 2012; Villalobos-Jiménez *et al*., 2016). While these variables were not directly measured in the present study, the statistical patterns observed—particularly diversity variation, PCA grouping, and family-level dominance—are consistent with habitat-driven community structuring reported in earlier research.

From a conservation perspective, the dominance of widespread species such as *Brachythemis contaminata* and *Crocothemis servilia* should not overshadow the occurrence of low-abundance taxa. Such species often represent habitat specialists and contribute significantly to overall biodiversity (Kietzka *et al*., 2019). The coexistence of generalists and specialists within Saranda Forest suggests that maintaining habitat heterogeneity, including streams, wetlands, and riparian vegetation, is essential for sustaining odonate diversity. Overall, the statistical analyses combined with observed species composition indicate that odonate communities in Saranda Forest are structured by habitat heterogeneity and family-level ecological adaptations, reinforcing their potential as bio-indicators for assessing ecological health in tropical forest ecosystems under anthropogenic pressure.

Conclusions

The present study provides the first comprehensive assessment of odonate diversity and abundance in the Saranda Forest, Jharkhand, documenting 61 species across seven sites. The findings reveal that dragonflies and damselflies form a well-balanced community, with Libellulidae as the dominant family, while other families such as Aeshnidae, Gomphidae, and Macromiidae remain sparsely represented. Species richness and diversity were strongly influenced by habitat heterogeneity, with sites like Ligirda and Karampada supporting the greatest diversity, whereas Thalkobad and Beside Koina River recorded high abundances but lower evenness due to dominance by a few species. Multivariate analyses highlighted distinct assemblages among sites, reflecting the role of environmental gradients and water-associated habitats in structuring odonate communities. Although overall abundance did not vary significantly across sites, clear differences in family-level composition emphasize the importance of habitat quality in shaping community structure. This study underscores the ecological significance of Saranda Forest as a reservoir of odonate diversity in eastern India and establishes a valuable baseline for future monitoring. Conservation strategies should prioritize maintaining hydrological regimes, riparian habitats, and microhabitat heterogeneity to safeguard both widespread generalists and rare habitat specialists. Protecting this diversity is crucial not only for sustaining odonate populations but also for ensuring the ecological integrity of freshwater ecosystems in the region.

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Online supplementary material:

Supplementary Figure 1. One-way analysis of variance boxplots showing site-wise variation in odonate species abundance (left) and family-wise variation in abundance (right).

Supplementary Figure 2. Tukey's Honestly Significant Difference test showing multiple comparisons of odonate abundance among families and across study sites. Different letters indicate significant differences at $p<0.05$.

Supplementary Figure 3. Gaussian fit distributions of biodiversity indices at the Gua site, including richness, abundance, dominance, evenness, Shannon, and Simpson indices.

Supplementary Figure 4. Gaussian fit distributions of biodiversity indices at the Karampada site, including richness, abundance, dominance, evenness, Shannon, and Simpson indices.

Supplementary Figure 5. Gaussian fit distributions of biodiversity indices at the Kiriburu site, including richness, abundance, dominance, evenness, Shannon, and Simpson indices.

Supplementary Figure 6. Gaussian fit distributions of biodiversity indices at the Koina River site, including richness, abundance, dominance, evenness, Shannon, and Simpson indices.

Supplementary Figure 7. Gaussian fit distributions of biodiversity indices at the Ligirda site, including richness, abundance, dominance, evenness, Shannon, and Simpson indices.

Supplementary Figure 8. Gaussian fit distributions of biodiversity indices at the Thalkobad site, including richness, abundance, dominance, evenness, Shannon, and Simpson indices.

Supplementary Figure 9. Gaussian fit distributions of biodiversity indices at the Toiba site, including richness, abundance, dominance, evenness, Shannon, and Simpson indices.

Supplementary Figure 10. Heatmap of odonate species abundance across study sites (Thalkobad, Karampada, Toiba, Ligirda, Beside Koina River, Kiriburu, and Gua) showing heterogeneous species distribution patterns.

Supplementary Figure 11. Hierarchical clustering dendrogram of odonate species abundance across sites using Ward's method.

Supplementary Figure 12. Hierarchical clustering of sites based on odonate species abundance using Ward's method.

Supplementary Table 1. List of odonate species recorded from the Saranda Forest, Jharkhand, showing their family affiliation, common name, scientific name, International Union for Conservation of Nature conservation status, abundance, and relative abundance.

Supplementary Table 2. Site-wise biodiversity indices of odonate species across seven study sites in Saranda Forest.

Supplementary Table 3. One-way analysis of variance results showing variation in odonate species across study sites and families. Species abundance did not differ significantly among sites ($p>0.05$), whereas significant differences were observed among families ($p<0.001$), indicating family-level variation contributes more strongly to community diversity patterns.

Supplementary Table 4. Tukey's Honestly Significant Difference results showing site-wise and family-wise odonate abundance. Site-wise comparisons revealed no significant differences across sites ($p>0.05$), while family-wise analysis showed strong variation, with Libellulidae significantly more abundant than all other families.

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