The Effect of Land-use Changes on Odonate Assemblages in the Central Western Ghats

by

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Dissertation Thesis

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in
Wildlife Science

Under the supervision of

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भारतीय वन्यजीव संस्थान
Wildlife Institute of India

AcSIR

JULY 2024

DECLARATION

I hereby declare that the work conducted under the thesis entitled **“The Effect of Land-use Changes on Odonate Assemblages in the Central Western Ghats”,** is a record of original and independent research work done by me and subsequently submitted for the award of the degree of **Master’s in Wildlife Science** at the **Academy of Scientific and Innovative Research**. This research work has been carried out under the guidance and supervision of **Ritesh Kumar Gautam**, **Scientist- C**, and co-supervision of **Dr. J A Johnson**, **Scientist- F** of Wildlife Institute of India, Dehradun. The work has not formed the basis for the award of any other degree, diploma, or any other qualification. I also declare that the thesis embodies my own work, analysis, observation, understanding and the particulars given in it are true to the best of my knowledge.

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Place: Dehradun
Date: 31-07-2024

31/07/2024

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Supervisor

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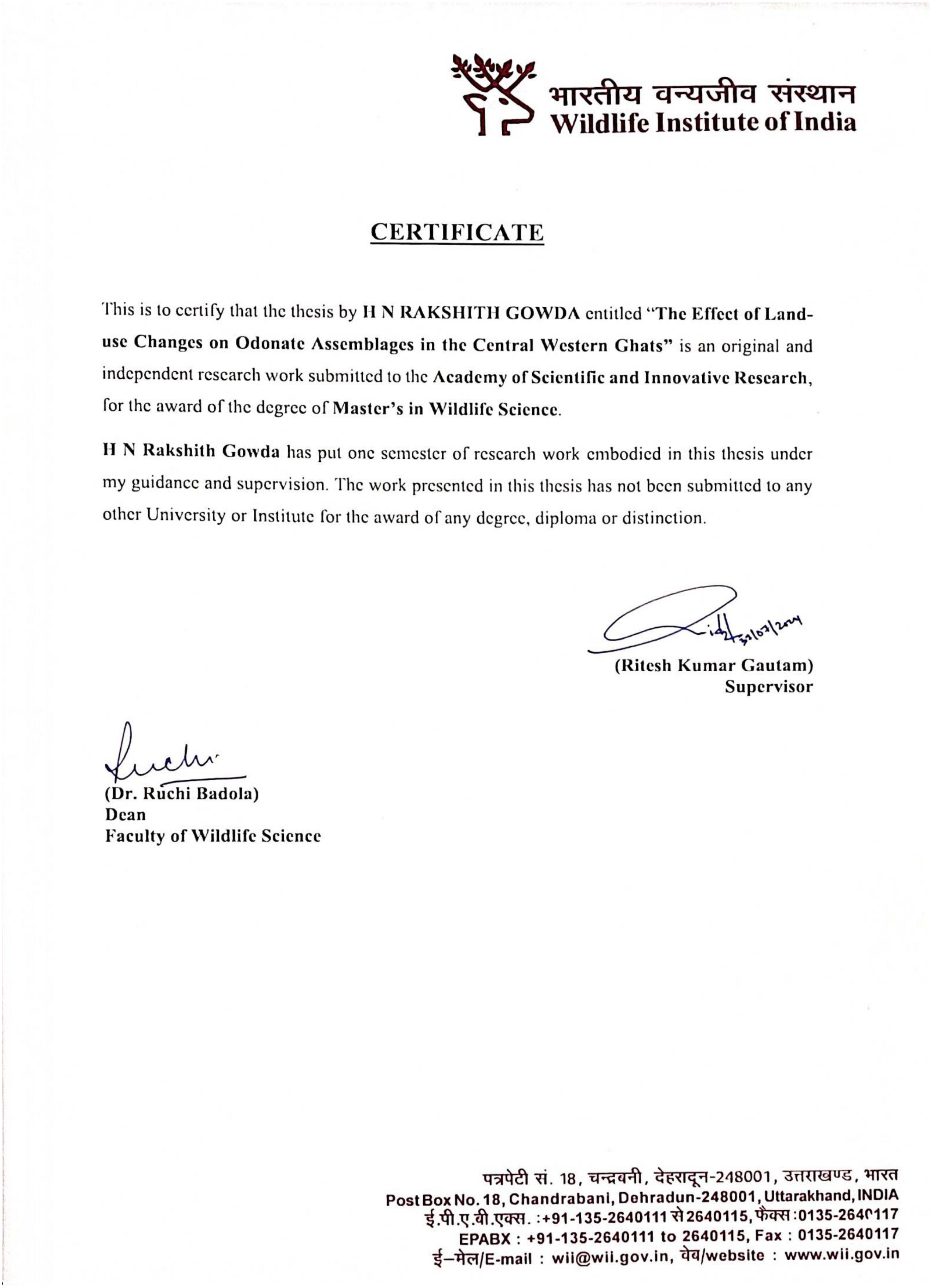

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CERTIFICATE

This is to certify that the thesis by **H N RAKSHITH GOWDA** entitled **"The Effect of Land-use Changes on Odonate Assemblages in the Central Western Ghats"** is an original and independent research work submitted to the **Academy of Scientific and Innovative Research**, for the award of the degree of **Master's in Wildlife Science**.

H N Rakshith Gowda has put one semester of research work embodied in this thesis under my guidance and supervision. The work presented in this thesis has not been submitted to any other University or Institute for the award of any degree, diploma or distinction.

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1. PROJECT SUMMARY

Odonata, the only apex insect predator in both terrestrial and aquatic life forms, are widely used as biological indicators of the health of aquatic ecosystems across the globe. The Riparian land uses such as commercial plantations negatively impact the Odonata assemblages, causing the homogenisation of habitats with generalist species and the extinction of specialist species. These land uses affect the riparian vegetation, habitat structure, and water quality parameters, which are crucial for Odonates to complete their life cycle. To understand the impact of commercial plantations on stream-associated Odonata assemblages at the sub-order level, three treatments comprising a combination of forest and areca plantations on either bank of streams were selected. The habitat variables, such as ambient temperature and canopy cover, along with stream parameters like flow and water quality parameters such as pH and water temperature, significantly influenced the Odonate assemblages. The sub-orders, Dragonflies and Damselflies, differed in their response to altered (Areca plantations and plantation-forest edge) and preserved sites (forested sites). These outcomes highlight the importance of the dependency of Odonata on particular sets of variables and the consideration of suborders of Odonata separately as indicator groups for the quality of aquatic ecosystems.

2. INTRODUCTION

The major challenge in science and conservation is understanding the rate at which biodiversity is affected by anthropogenic disturbances (Manel et al., 2000; Miserendino et al., 2011). Anthropogenic disturbances and environmental changes often occur more rapidly than scientific understanding could comprehend within the given time frame (Vitousek et al., 1997; Ribeiro et al., 2021). However, there is an urgent need to develop tools that identify, evaluate, and monitor the effects of these environmental changes on biodiversity (Ribeiro et al., 2021). The most effective way to address this challenge is through rapid assessments, in which the bio-indicator taxa are used to expedite the decision-making process in conservation (Caro & O'Doherty, 1999; Ribeiro et al., 2021; Miguel et al.,2017). The aquatic macroinvertebrates are often used as bio-indicators because of their characteristics and taxonomic familiarity (Whittaker et al., 2005; Resh, 2007; Vorster et al., 2020; Ribeiro et al.,2021). Although macroinvertebrates in their aquatic stages are preferred as bioindicators, due to their impracticalities of collecting, sorting, and identification, their use in rapid assessments is limited (Fennessy et al., 2007; Kutcher & Bried, 2014). Therefore, the adult life forms of macroinvertebrates are used as a proxy for the aquatic life stage to be used as bioindicators because they perform the role of energy transformation from aquatic to terrestrial ecosystem and exhibit sensitivity to land use practices (Simaika & Samways, 2011; Kutcher & Bried, 2014). Order Odonata is one such taxa that is mainly preferred to monitor or assess the impact of environmental changes on freshwater ecosystems (Corbet, 1999; Chovanec & Waringer, 2001; Fennessy et al., 2007; Kutcher & Bried, 2014; Clausnitzer et al., 2009).

Odonates are predatory insects whose distribution is primarily linked to the presence of water sources (Andrew et al., 2008). These insects follow an amphibious life cycle, depositing their eggs in specific aquatic habitats (Andrew et al., 2008). The larvae develop in the water, feeding on aquatic invertebrates, tiny tadpoles, and fish. Adults are terrestrial predators with specialised morphologies adapted to their way of life (Subramanian, 2012).

Odonata has two suborders, Anisoptera (Dragonflies hereafter) and Zygoptera (Damselflies hereafter), which exhibit distinct ecological preferences and responses to environmental changes. The differences in their distribution and assemblages are determined by their differences in thermal tolerance, body size, and dispersal ability (Silva et al., 2021). Damselflies possess delicate wing structures and limited flight capabilities, making them more reliant on sheltered habitats, where they can forage and reproduce effectively. In contrast, dragonflies are renowned for their robust wing structure and powerful flight capabilities, enabling them to exploit a broader range of habitats. Their superior dispersal abilities make them less reliant on specific habitat types and more resilient to habitat disturbances. Given their differences in habitat selection, Suborders Zygoptera and Anisoptera should be considered separately while assessing aquatic ecosystems' habitat quality or health (Monteiro-Júnior et al., 2013; Nagy et al., 2019).

Due to their close association with aquatic ecosystems as larval habitat, breeding, and foraging sites (Nagy et al., 2019), Odonates are preferred for monitoring or assessing the effects of disturbances, such as fragmentation or destruction of natural habitat by land use changes, along freshwater ecosystems like tropical streams (Samways, 2008; Kutcher & Bried, 2014; Clausnitzer et al., 2009).

The variables influencing the distribution and diversity of odonates in an aquatic ecosystem can be broadly grouped into three categories.

1. Riparian vegetation structure
2. Stream structure
3. Water quality parameters

Vegetation provides adults with perching structures for thermoregulation (Carvalho et al., 2013), foraging, territory defence, mate attraction, copulation, nocturnal roosting, and protection from adverse weather (Buchwald, 1992; Wildermuth, 1993; McKinnon & May 1994; Rouquette & Thompson, 2007), thereby potentially affecting their density and diversity (Remsburg & Turner, 2009). Hence, variables such as the structural intactness of different vegetation strata, such as trees, shrubs, and grasses, play an essential role along with the canopy cover and density. Stream structure characteristics such as stream width, substrate complexity, and flow rate are crucial as available micro-habitats to support different species. Water quality parameters indirectly influence the fitness and survival of the larval stage, which emerges as adults (Hofmann & Mason, 2005). Apart from biological interactions such as inter-specific competition and prey abundance, these variables shape the species composition and determine the abundance of species found in a particular area. These variables are often correlated and interactive.

The changes in these variables over time or space directly result from land-use changes along the stream habitats (Davidson, 2004). The disturbance in the riparian vegetation negatively affects the structure and function of streams (Nessimian et al., 2008; Price & Leigh., 2006). It reduces the available micro-habitat features essential for survival and successful breeding of Odonata (Juen& De Marco, 2007). This further impacts the odonate assemblages, which depend on the streams to complete their lifecycle. Hence, it is necessary to understand the variables influencing the richness and abundance of odonate assemblages in areas more prone to land-use change.

Apart from agriculture and urbanisation, one of the significant land-use changes affecting biodiversity is the expansion of commercial plantations (Fitzherbert et al., 2008; Koh & Wilcove, 2008; Gibson et al., 2011; Clough et al., 2016). Substantial evidence indicates that commercial plantations and agroforestry practices negatively impact biodiversity across various taxa (Daniels et al., 1990; Johns, 1992; Thiollay, 1995; Raman et al., 1998; Raman & Sukumar,2002). These impacts include the reduction of habitat complexity, the displacement of native species, and the alteration of ecosystem functions. For instance, plantations often replace diverse natural forests with monocultures (Areca nut, silver oak, eucalyptus, etc,.), leading to significant losses in species richness and ecosystem resilience.

However, an alternative perspective suggests that these pocket plantations can serve as refuges for wildlife inhabiting remnant forests and as critical landscape connectivity elements. They can provide essential habitats and movement corridors for wildlife, thereby aiding in the conservation of biodiversity in fragmented landscapes (Perfecto & Vandermeer, 2008; Sreeja et al., 2021). The plantations, particularly those incorporating native species and maintaining structural complexity, can support a variety of wildlife species and contribute to broader conservation objectives (Mudappa & Raman, 2012; Anand et al., 2010). This dual role of plantations underscores the complexity of their impact on biodiversity, highlighting the need for tools that assess the changes caused by the expansion of plantations and the degree to which the indicator species are affected by plantations. Moreover, viewing the plantations and agroforestry practices as interconnected components within a system specifies their importance for biodiversity conservation (Gardner et al., 2009; Anand et al., 2010). Hence, this study aims to understand the effect of commercial plantations in a protected landscape on Odonate assemblages. Further, understanding its impact on vegetation structure, stream characteristics, and water quality parameters.

2.1 Indian scenario and Importance of the present study in the current scenario:

Despite their importance as indicators of water quality and integrity of the freshwater ecosystems, studies related to the ecology of Odonates in India still need to be more comprehensive (Subramanian et al., 2008). Most studies in India on Odonates focus on documenting diversity and distribution and creating checklists for wetlands and other habitats. Though the well-documented taxonomic information is valuable for further studies, the less studied insects' habitat association and ecological roles are crucial for effective biodiversity conservation. Only a few studies have attempted to assess species habitat associations by correlating various habitat variables and water quality parameters to Odonate assemblages (Subramanian et al., 2008; Koparde et al., 2015). Most macroinvertebrate studies lack consideration of Odonate-specific variables due to their taxonomic difficulty. Due to constraints such as sampling difficulty, limited taxonomic expertise, and time- and labour-intensive requirements, larval sampling for odonates in India receives relatively low priority.

The Western Ghats, a global biodiversity hotspot, face challenges such as forest fragmentation due to the spread of commercial plantations such as Coffee, tea, cardamom, areca nut, etc. (Raman, 2006) in the past three decades (Bawa et al., 2007; Latha & Sabu, 2019). The region's mosaic landscape, with commercial plantations occupying 18.3% of the total Western Ghats area, highlights the complexity of interactions between protected areas and human-modified landscapes (Cincotta et al., 2000; Reddy et al., 2016). The highly diverse rivers and their adjoining area of these mosaic Western Ghats landscape are highly prone to disturbances because of human-induced changes in land use (Mohan et al., 2021; Rao et al., 2014). Further, this causes a threat to the freshwater species that depend on these aquatic habitats for the completion of their lifecycle. The changes that anthropogenic disturbances cause in freshwater ecosystems can be best monitored or evaluated through bio-indicator species such as Odonates (Subramanian et al., 2008).

As Odonates are highly habitat-specific, their compositional changes in assemblages give more insight into developing conservation strategies for freshwater ecosystems in the landscape. Thus, understanding the species-habitat association is crucial for effective biodiversity conservation in this landscape (Jere et al., 2020).

3.0 AIM OF THE STUDY:

The present study aims to understand the effect of commercial plantations on Odonate assemblages. Additionally, it aims to compare the compositional difference between forested and plantation sites among two suborders, Dragonflies and Damselflies.

3.1 Objectives:

1. To evaluate the influence of vegetation structure, stream structure, and water quality parameters on the richness and abundance of Odonate assemblages

Research question:

What essential variables influence the richness and abundance of Odonate across treatments?

2. To understand the differences in the composition of Dragonflies and Damselflies between the three treatments

Research question:

How does the pattern of composition differ between Dragonflies and Damselflies?

4.0 METHODOLOGY

4.1 Study site

Someshwara Wildlife Sanctuary, Karnataka

The sanctuary is located in the Udupi and Shivamogga districts of Karnataka State. It is about 88.40 sq. km, with a recent addition of 225.8 sq. km of reserve forests adjoining the Kudhremukh National Park. The sanctuary lies in the Central Western Ghats along the western slopes. It receives annual rainfall of around 3000- 5500mm (Management Plan, January 2011- December 2015-Someshwara Wildlife Sanctuary, Karnataka Forest Department). The major vegetation types include tropical evergreen, semi-evergreen, and moist mixed deciduous forests. The landscape is a mosaic of forest and human settlements with other land uses such as Areca palm Plantation and paddy cultivation. The primary water source in the sanctuary is the river Seethanadi and its tributaries, which flow in an east-west direction.

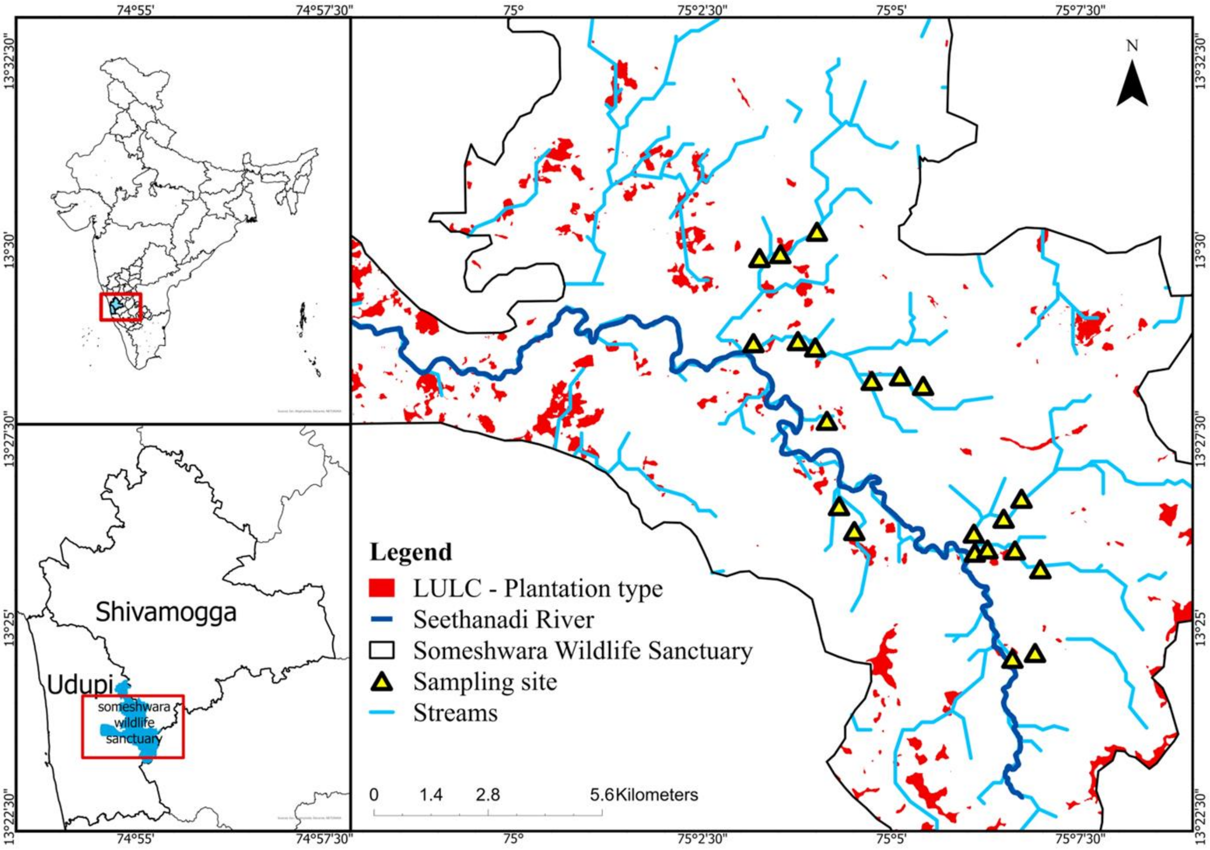

Figure 1: Map of study area extent- Streams of River Seethanadi in Someshwara Wildlife Sanctuary, Karnataka

4.2 Site selection

Preserved sites- Forested streams

The streams flow through tropical evergreen forests in the streams' lower reaches, joining the River Seetha Nadi. All the locations chosen were at least 300m from the nearest human-modified land use (areca plantations) ((Appendix II).

Altered sites

1. Plantation streams

Areca palm plantations dominate the human-settled areas in the region. All the locations selected for sampling were located in mosaic with forested habitats of Someshwara Wildlife Sanctuary. A minimum distance of 300m was maintained between the plantations and the forest.

2. Edge streams- Plantation and forest

The streams located along the boundaries of the areca nut plantations and forest were selected as the third treatment for this study. The minimum distance of 300m was maintained away from other land use.

4.3 Odonate sampling and identification

The species are sampled in full-width belt transects of 100m in length and 10m in width (Figure 2). Full-width belt transects have proven more feasible for sampling Odonates in tropical streams (Darshetkar et al., 2023). Compared to other methods like full-circle point count, half-circle point count, and half-width belt transact, the full-width belt transects efficiently capture new species per unit area sampled (Darshetkar et al., 2023). The individuals were photographed and identified using appropriate field guides.

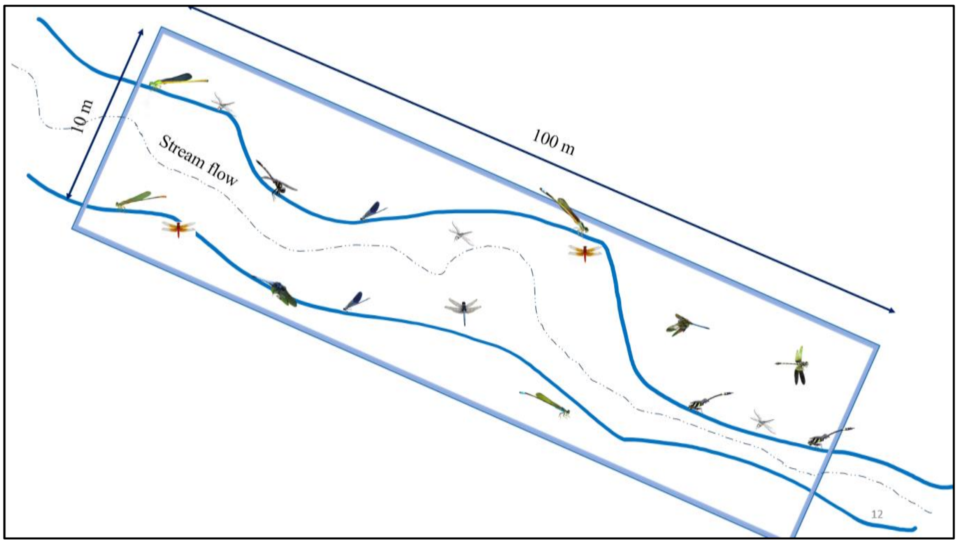

Figure 2: Sampling design for Odonata sampling

4.4 Factors Influencing Odonates

4.4.1 Vegetation parameters

The parameters related to riparian vegetation were visually estimated in 3 circular plots with a radius of 5m every 25 meters from starting the transect on both sides of the streams (Figure 3). Each parameter was ranked or scored as mentioned in Table 1 (Johnson et al., 2020).

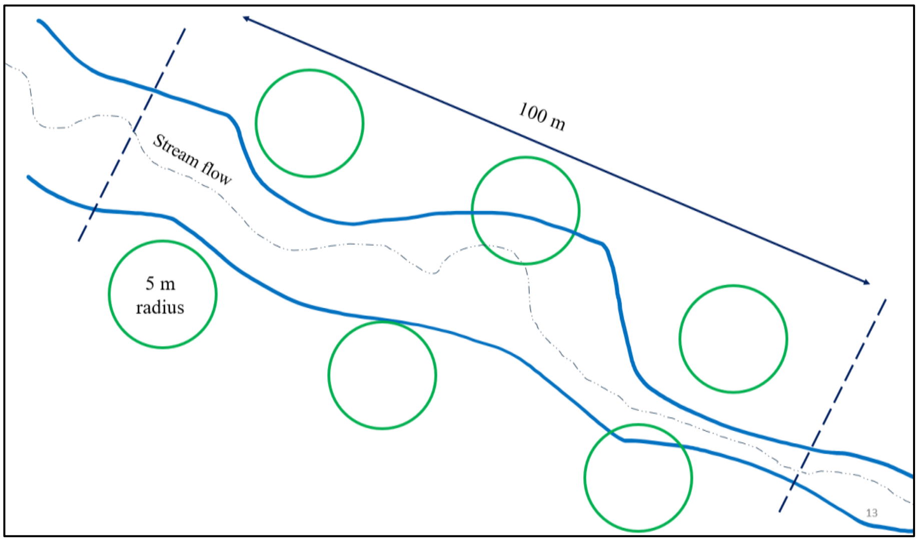

Figure 3: Sampling design for vegetation attributes sampling

Table 1: Parameters of vegetation structure and their categorisation

Sl. No.	**Parameter**	**Scoring**				
1	The extent of canopy cover	0-20%	20-40%	40-60%	60-80%	80-100%
		VL	L	M	H	VH
		0	2	4	6	8
2	Structural intactness of Tree species (SI)	Continuous	Clumped	Scatted	Sparse	
		3	2	1	0	
3	Structural intactness of shrubs (SI2)	Continuous	Clumped	Scatted	Sparse	
		3	2	1	0	
5	Structural intactness of grasses (SI3)	Continuous	Clumped	Scatted	Sparse	
		3	2	1	0	
6	Recruitment index (dominant sp. present by biomass)	% cover	0-40%	40-80%	>80%	
		rate	H	M	L	
		Score	3	2	1	

4.4.2 Stream structure and Water quality parameters

The transect was divided into five segments of 20m each (Figure 4), and the total stream width, wet stream width, flow and depth, and water quality parameters were measured in each segment. The proportion of habitat (run, rifle, pool and cascade) and substrate type (sand, silt, clay, pebble, cobble, boulder, and bedrock) were visually estimated in each segment. The canopy cover on the transact was measured using a Densiometer at the end of each segment at the centre of the stream. The flow and depth were measured using a flow meter attached to the depth finder. The water temperature (℃), pH, Electrical conductivity (mS/cm), Total Dissolved Solvents (ppm), Dissolved Oxygen (mg/L), and Oxidation-Reduction Potential (mV) were measured using an aqua probe attached to an aqua meter at the centre of each segment.

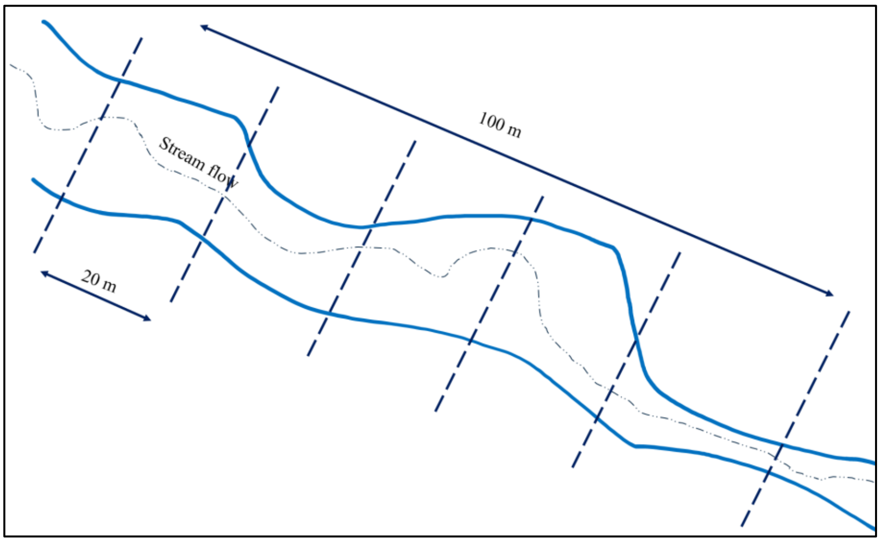

Figure 4: Sampling design for stream attributes and water quality parameters

4.5.0 Statistical methods

The data accumulation and segregation were performed using Microsoft Excel 2021 and R (R Core Team, 2020; Wickham, 2011). Species richness estimates for each land use were derived using classic Chao I estimate for each sample of all three treatment types using EstimateS, v.9.1.0 (Colwell & Elsensohn, 2013). The species accumulation curve was rarefied to double the number of samples for each treatment obtained, and the plots are visualised using ggplot2. Then, all the variables were performed with the Pearson correlation matrix. The variables correlated by less than 60 % and ecologically important were retained for further statistical analysis. Non-metric Multi-Dimensional Scaling (Vegan::metaMDS) based on Bray-Curtis similarity was performed to visualise the compositional differences between the three treatments. The compositional similarity of communities across treatments was checked using an analysis of similarity test (ANOSIM, Vegan::anosim). Canonical correspondence analysis was performed using past software to understand the relationship between all the variables selected and the composition of odonates (Hammer et al., 2001).

5.0 RESULTS

5.1.1 Sampling efficiency and overview

21 transacts, with 7 in each treatment group, were sampled thrice over three months from February to April 2024. Overall, 46 species were recorded, divided among two suborders, Dragonflies and Damselflies, encompassing 22 and 24 species, respectively. The dragonfly species were distributed among two families and comprised 16 genera, whereas the damselfly species were distributed among six families and comprised 14 genera. Pied Paddy Skimmer (*Neurothemis tullia)* is the most abundant species among the Dragonflies, while Stream Ruby (*Heliocypha bisignata)* is the most abundant among the Damselflies. In forest treatment, the Fulvous Forest Skimmer (*Neurothemis fulvia)* is the most prevalent Dragonfly, and the Pied Paddy Skimmer is the most abundant among the other two treatments (Appendix I). The Stream ruby consistently remains the most abundant Zygoptera among all three treatments.

The damselfly assemblages were relatively well sampled in all the treatments, as the rarefied accumulation curves depicted asymptotes in both individual-based and sample-based accumulation curves (Figure 8 and Figure 10). The individual-based rarefied accumulation curves for Dragonfly assemblages were relatively sampled less, with curves for forest and plantation treatment not reaching asymptotes for the total number of individuals sampled per treatment (Figure 7).

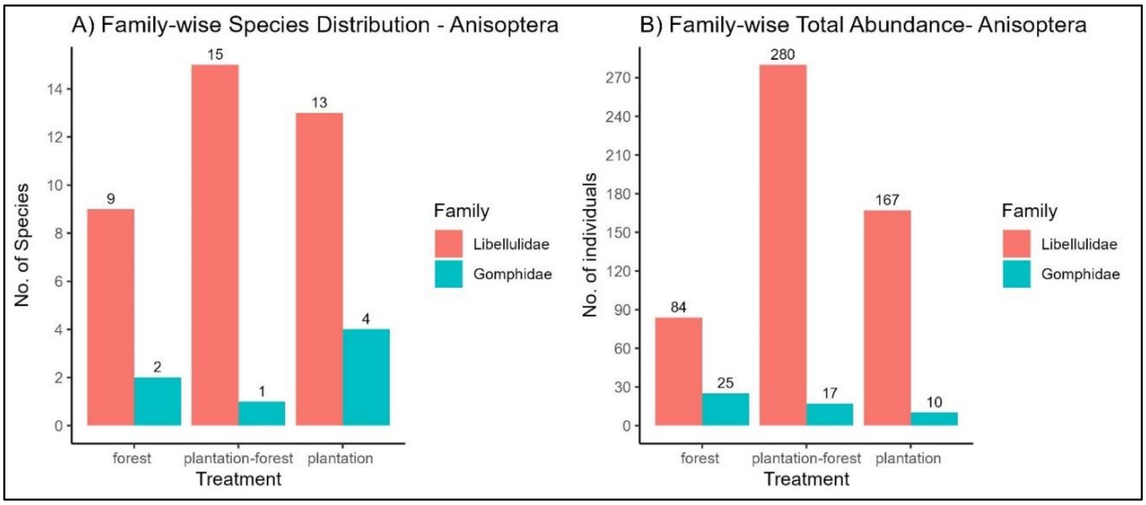

Figure 5: The family-wise species distribution (A) and total abundance (B) of sub-order Dragonflies

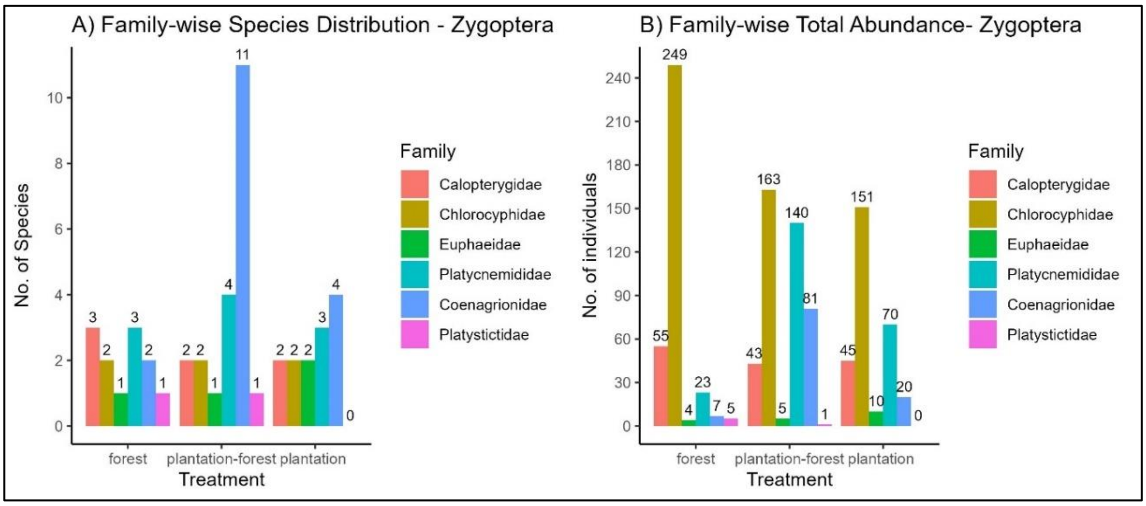

Figure 6: The family-wise species distribution (A) and total abundance (B) of sub-order Damselflies

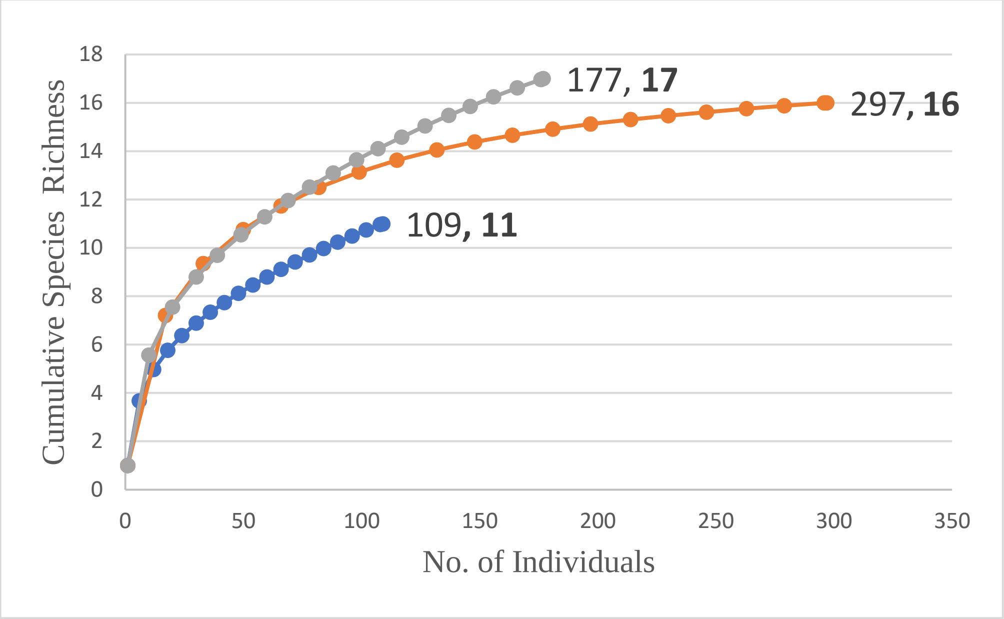

Figure 7: Rarefied Individual-based species accumulation curves for Dragonflies

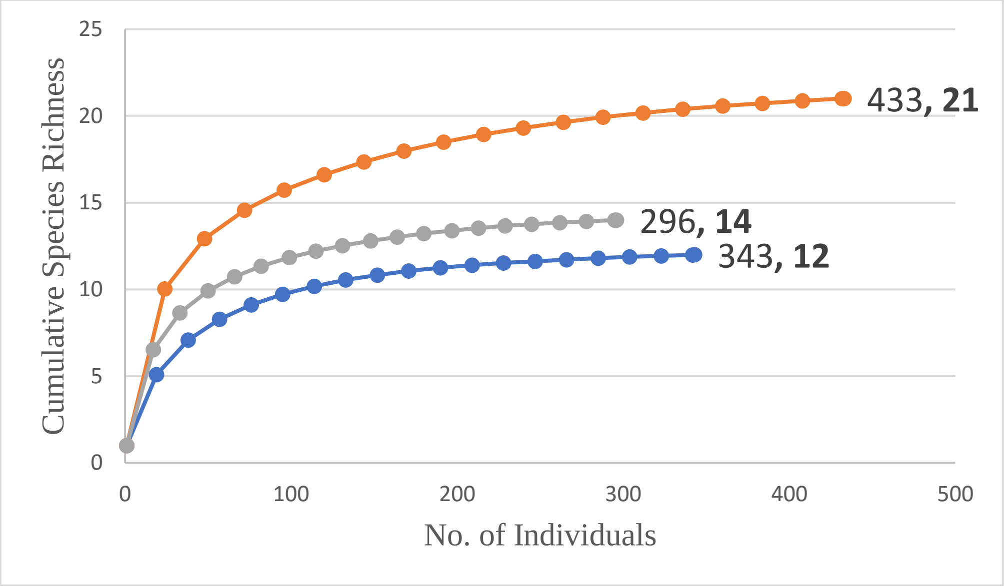

Figure 8: Rarefied Individual-based species accumulation curves for Damselflies

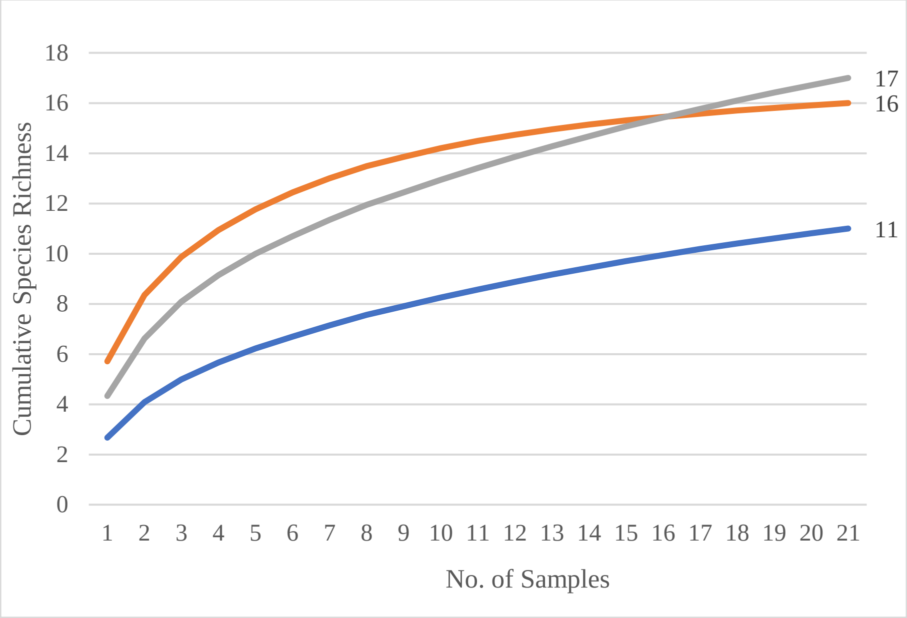

Figure 9: Rarefied Sample-based species accumulation curves for Dragonflies

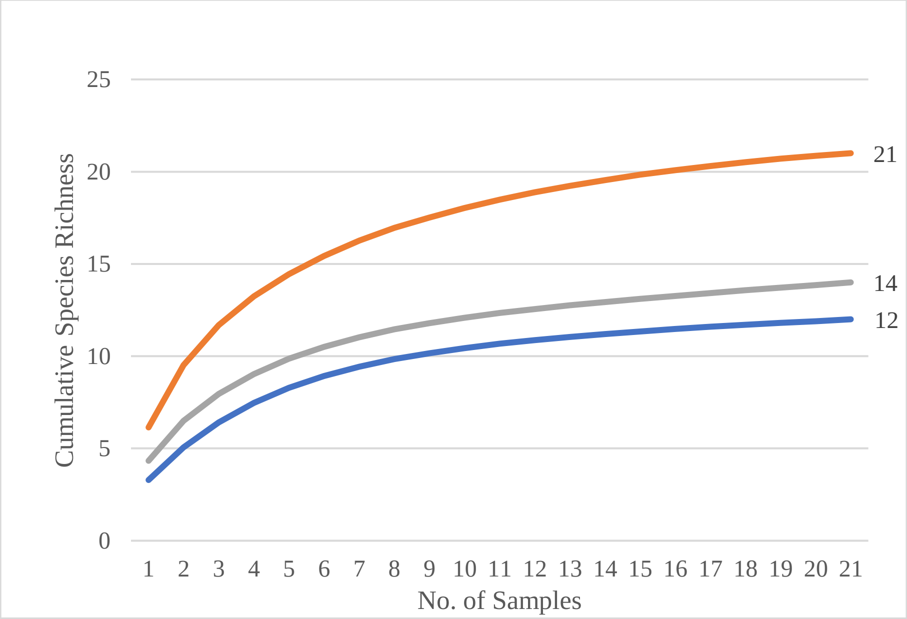

Figure 10: Rarefied Sample-based species accumulation curves for Damselflies

5.1.2 Species richness:

The Chao 1 estimator was used to calculate the species richness for each category, as there were no precise asymptotic accumulation curves for a few treatments (Figures 6 to 10).

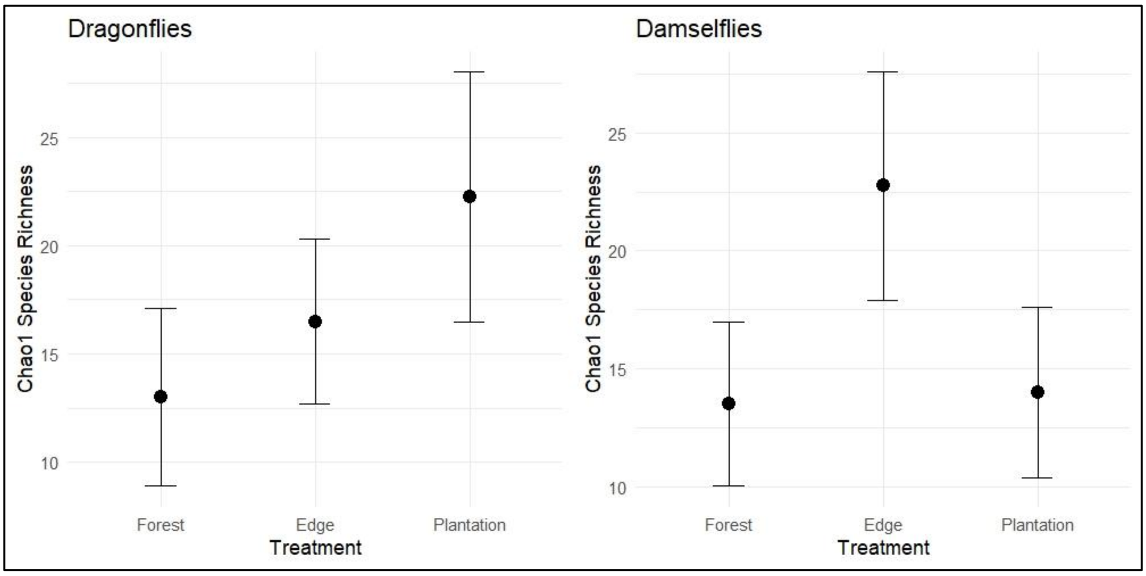

Figure 11: The estimated (Chao1) richness values between treatments among Dragonflies and Damselflies

5.1.3 Rank abundance curves

Dragonflies

The most dominant species across treatments were found to be different in Dragonfly communities. Absolute richness, Shannon diversity, and evenness values were the lowest at the forest sites. However, the values were higher and comparable between Plantation and Edge.

Damselflies

The most dominant species across treatments in Damselfly communities across treatments is the same. The values of absolute richness, Shannon diversity and Shannon evenness were highest for Edge, followed by Plantation and Forest sites.

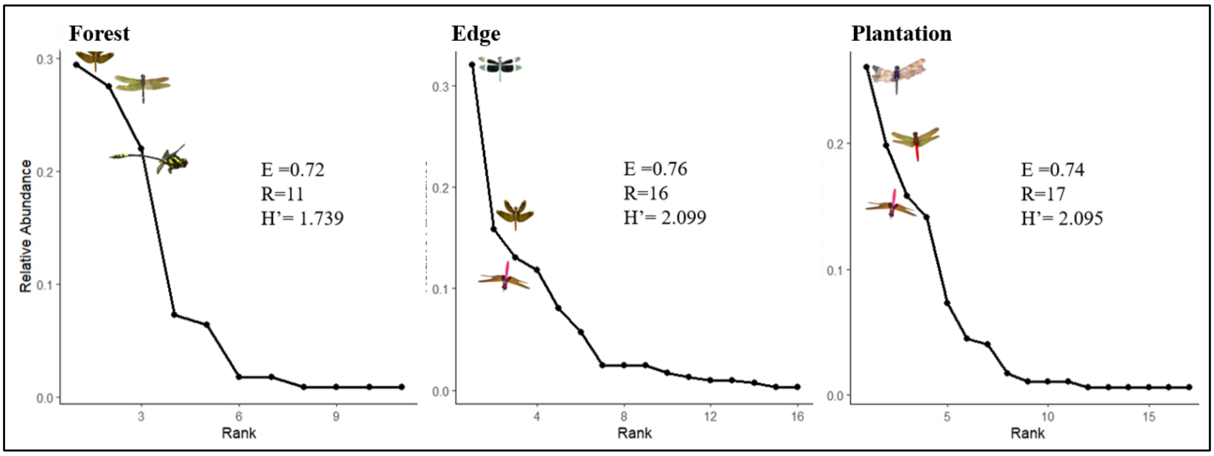

Figure 12: Rank abundance curves of the three treatments with their absolute richness (R), Shannon evenness (E) and Shannon diversity index (H') values for Dragonflies

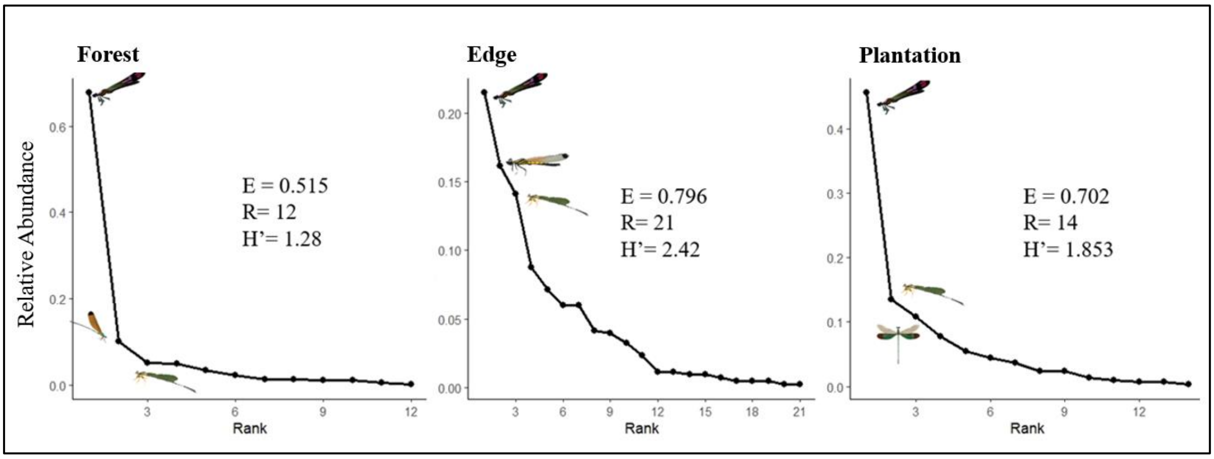

Figure 13: Rank abundance curves of the three treatments with their absolute richness (R), Shannon evenness (E) and Shannon diversity index (H') values for Damselflies

5.2 Compositional differences

Dragonflies

The compositional similarity between the edge and plantation is the maximum compared to the forest community, which has a minor overlap with the other two treatments (Table 7). The minimum overlap is because the two species, Kodagu Tiger and Emerald Cascader, are highly abundant (Appendix I) in the forest community. Four species were unique to plantation sites, whereas only one was unique to Edge sites.

Damselflies

The highest compositional similarity was found between the Edge and plantation sites. However, in contrast to the similar pattern in dragonflies, the compositional similarity between forest and plantation sites is more significant than between forest and edge sites (Table 7). Six species were unique to Edge sites, while no unique species were found in forest and plantation sites.

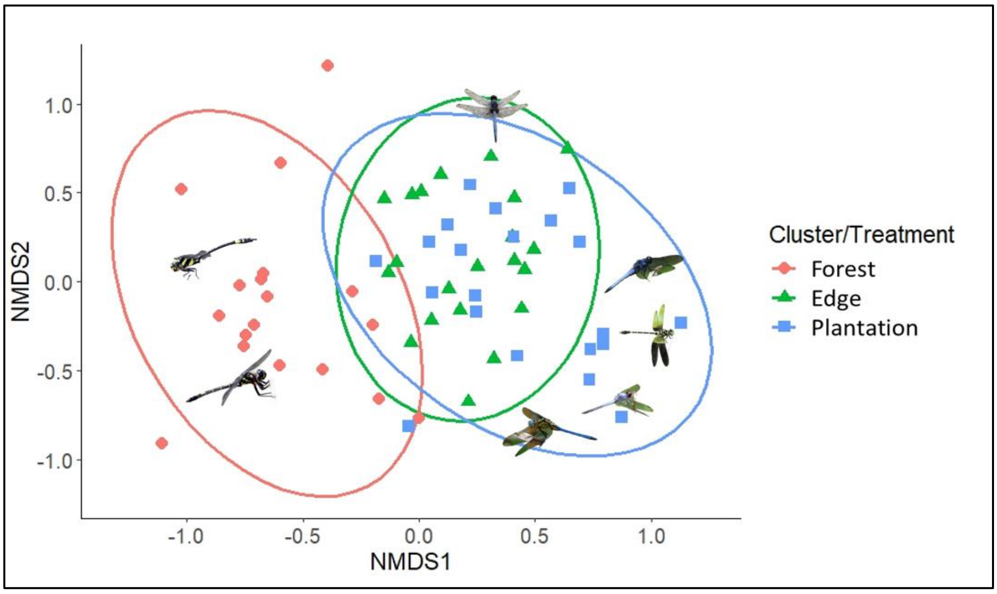

Figure 14: Compositional similarity of Dragonflies using non-metric multidimensional scaling

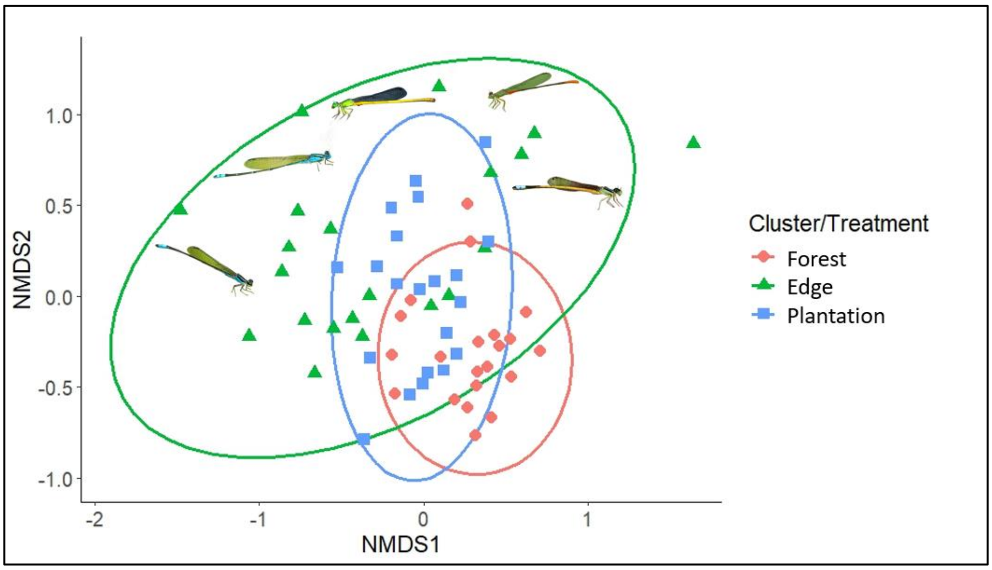

Figure 15: Compositional similarity of Damselflies using non-metric multidimensional scaling

Table 2: Results of ANOSIM test for compositional dissimilarity in Anisoptera

Dissimilarity: Bray Permutation: free Number of permutations: 999	Forest vs. Edge	Forest vs Plantation	Edge vs Plantation
ANOSIM statistic R	0.5235	0.568	0.125
Significance:	0.001	0.001	0.001

Table 3: Results of ANOSIM test for compositional dissimilarity in Zygoptera

Dissimilarity: Bray Permutation: free Number of permutations: 999	Forest vs. Edge	Forest vs Plantation	Edge vs Plantation
ANOSIM statistic R	0.4305	0.2746	0.1511
Significance:	0.001	0.001	0.001

5.3 Relationship between variables and odonate assemblages

Dragonflies

Axis 1 and 2 depicted a cumulative contribution of 56.51% of the overall data (Table 4). There is an apparent clustering of forest sites (towards the right side of Axis 1) away from the clustering of plantation and edge sites, which are mostly diffused at the centre of the two axes (Figure 5). The species clustering is also towards this edge and plantation sites. However, there are few species which are sparsely distributed and far away from the edge and plantation sites clustering, indicating their presence and high abundances in forest sites only.

The variables that had the greatest effect on these assemblages were canopy cover, ambient temperature, flow rate, pH, and habitat diversity. Canopy cover, flow rate, and habitat diversity positively influence the forest community and negatively influence the Edge and Plantation communities. The trend is vice versa for variables such as water and Ambient temperatures.

Damselflies

Axis 1 and 2 depicted a cumulative contribution of 55.40% of the overall data (Table 5). There is an apparent clustering of forest sites (towards the right side of Axis 1), but the Edge and plantation sites are mostly scattered separately (Figure 6). The species are also highly scattered in all four quadrants, but the maximum number of species are scattered towards Edge sites.

Variables that had the greatest effect on these assemblages were canopy cover, ambient temperature, flow rate, pH, and habitat diversity. The canopy cover, flow rate and habitat diversity positively influence the forest community and negatively influence Edge and Plantation communities. The trend is vice-versa for variables, i.e., Water and Ambient temperatures. However, the water and ambient temperatures have maximum influence on Edge sites.

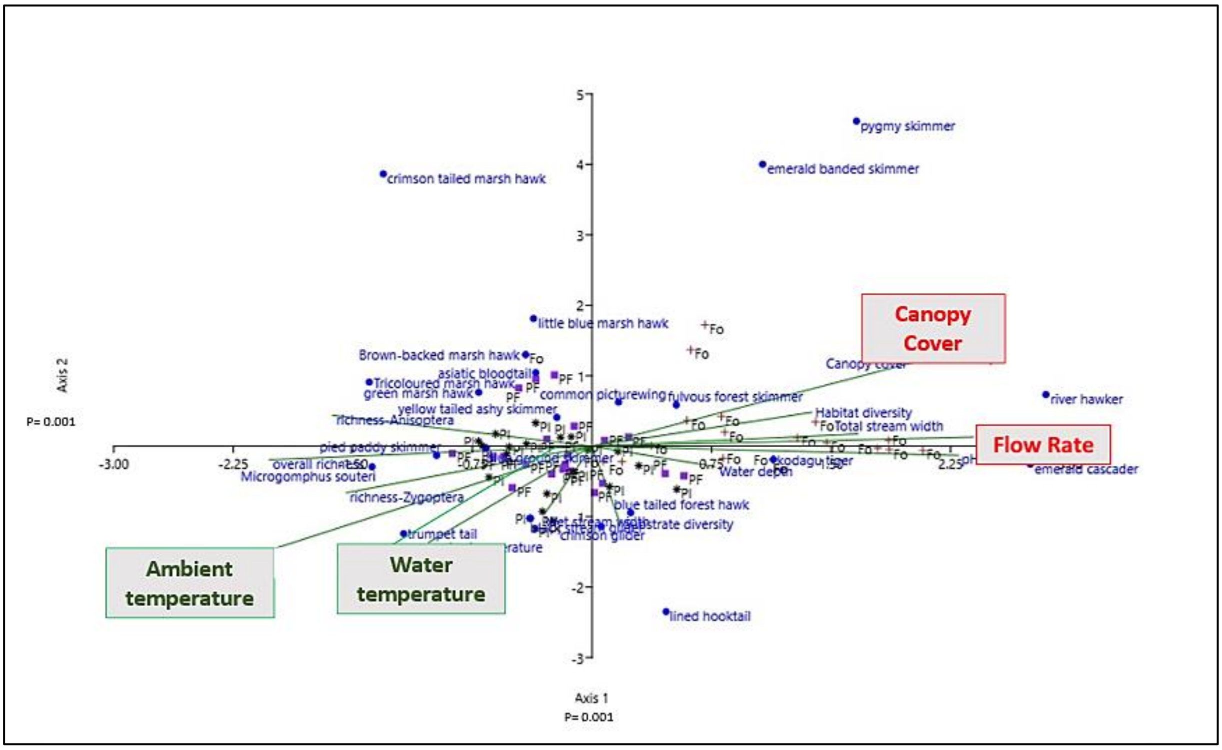

Figure 17: The relationship between the variables influencing Dragonfly assemblages. The variables highlighted in the boxes have the maximum effect on the assemblages. The names with ‘ • ’ indicate different species, the red plus ‘+’ mark indicates forested sites, ‘ ■ ’ indicates Edge, and ‘ * ’ indicates plantation sites.

Table 4: Eigenvalues of variables for axis one and axis 2 influencing Dragonfly assemblages

	Axis 1 (39.09%)	Axis2 (17.43%)
Total stream width	0.417	0.044
Flow rate	0.598	0.033
Habitat diversity	0.344	0.120
Canopy cover	0.503	0.297
pH	0.575	-0.033
water temperature	-0.257	-0.342
ambient temperature	-0.510	-0.372

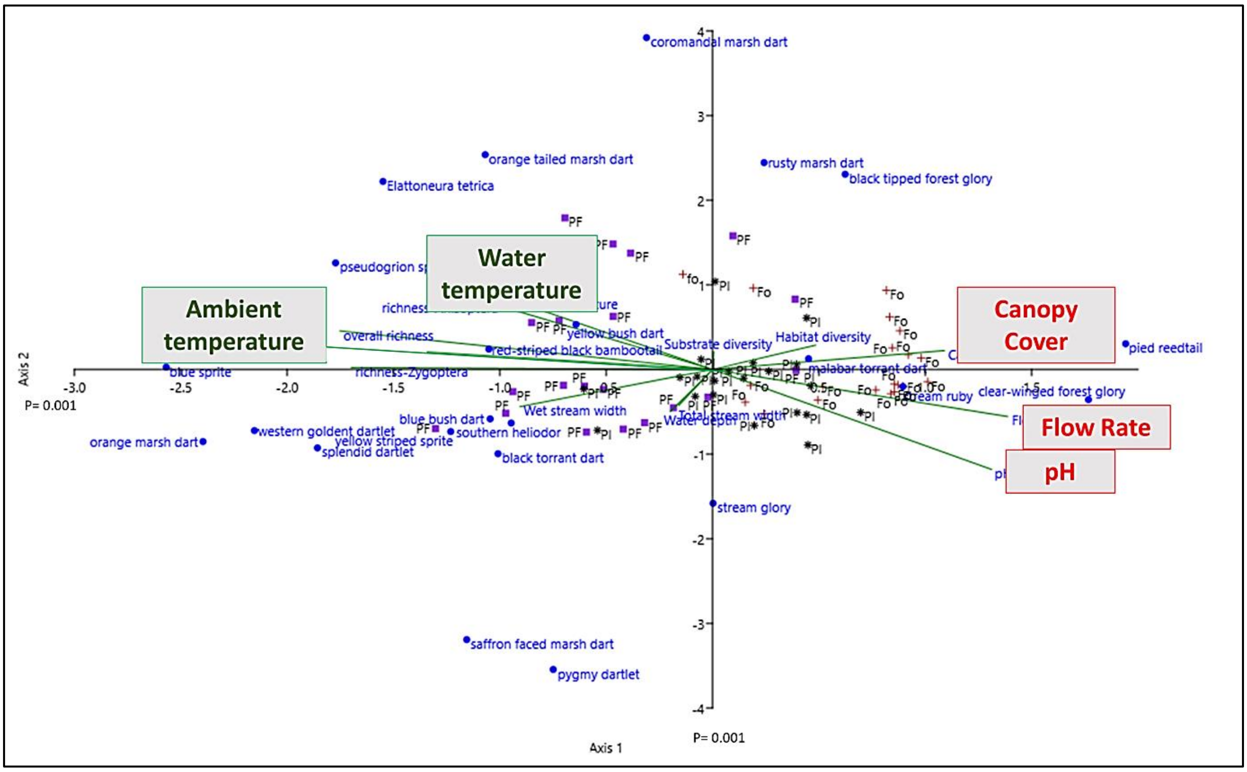

Figure 18: The relationship between the variables influencing Damselfly assemblages. The variables highlighted in the boxes have maximum effect over the assemblages. The names with ‘ • ’ indicate different species, the red plus ‘+’ mark indicates forested sites, ‘ ■ ’ indicates Edge, and ‘ * ’ indicates plantation sites.

Table 5: Eigenvalues of variables for axis one and axis 2 influencing Damselfly assemblages

	Axis1 (37.37%)	Axis2 (18.03%)
Wet stream width	-0.362	-0.175
Flow rate	0.555	-0.222
Canopy cover	0.436	0.089
pH	0.524	-0.472
water temperature	-0.315	0.274
ambient temperature	-0.553	0.085

6.0 DISCUSSION

6.1 Comparison of Richness and Diversity between Treatments

Several studies report that Dragonflies exhibit higher richness in altered sites, whereas Damselflies exhibit higher richness in preserved sites **(**Loiola & De Marco, 2011; Monteiro-Júnior et al., 2013; Carvalho et al., 2013**).** In the present study, the Dragonflies present higher species richness in altered sites, i.e., Plantation (22 ± 3) and plantation-forest edge (17 ± 2), compared to preserved sites, i.e., forest (13 ± 2) (Chao 1 estimator, values rounded off). In the case of Damselflies, the general pattern is contradicted as the altered sites Edge (23 ± 2) and plantation (14 ± 2) have higher species richness than the forested sites (13 ± 2) (Chao 1 estimator, values rounded off). The results of Damselflies suggest potential support for the Intermediate disturbance hypothesis, as the plantation-forest edge exhibits higher species richness than the completely altered (plantation) and preserved site (forest).

In dragonflies, the Shannon diversity index values were comparable between Edge (2.099) and plantation sites (2.095), whereas the value was found to be lowest for forest sites (1.739). In damselflies, the value was found to be maximum for Edge (0.796), followed by plantation (0.702) and forest sites (0.515). The evenness trend between treatments followed the same pattern as Diversity. The observed pattern can be explained by the intermediate disturbance hypothesis, which posits that species richness decreases at both extremes of disturbance while increasing at intermediately disturbed sites (Harabiš & Dolný, 2015). In the present study, among all significant variables influencing the assemblages, canopy cover and ambient temperature play crucial roles due to their importance for the thermoregulation of Odonates. These variables create intermediate conditions suitable for Odonates, leading to the highest richness and diversity of edge sites.

6.2 Compositional difference between Dragonflies and Damselflies between three treatments

Forest communities are more distinct from altered sites (Edge and plantation) in Dragonflies, contradicting their general pattern of high disturbance tolerance due to their more vital dispersal ability and thermal tolerance. The forest communities are well established over the years and present a stable community assemblage than the plantation or edge communities which are dynamic because of frequent disturbances (Brasil et al., 2017).

The results show that the odonate assemblages in preserved sites (Forest) are significantly dissimilar from those in altered sites (Plantation and Edge) (Table 7 and Table 8). It is difficult to explain the species distribution pattern, as the study was not oriented at comparing composition at the landscape level. However, the outcome supports the Nested distribution pattern, in which the species are nested over a spatial continuum or form discrete communities depending upon their ability to disperse and tolerate changes in habitat (De Marco Júnior et al., 2015; Brasil et al., 2017; Patterson & Atmar, 1986; Heino et al., 2009).

6.3 Relationship between variables and Odonate assemblages

Several studies have highlighted the importance and influence of the variables on odonate assemblages that were considered in this study. The variables that had the maximum effect on both Dragonfly and Damselfly assemblages are Canopy cover (de Oliveira-Junior et al., 2015), ambient temperature (Resende, 2002), Water temperature (Seidu et al., 2019; Vilenica et al., 2020), pH ((de paiva Silva et al., 2010) and flow rate (Seidu et al., 2019). Canopy cover, flow rate, and habitat diversity positively influence the forest community and negatively influence the Edge and Plantation communities. The trend is vice versa for variables such as water and Ambient temperatures.

Although few studies (de paiva Silva et al., 2010; de Oliveira-Junior et al., 2015) have reported the relatively lesser importance of water quality parameters on odonate assemblages when compared to other physical parameters, this study highlights the influence of water quality on assemblages of both Dragonflies and Damselflies.

7.0 CONCLUSION

The streams and riverine habitats of the Western Ghats landscape are highly threatened due to habitat fragmentation and deforestation caused by the conversion of forested habitats into commercial plantations and agricultural fields. Since Odonates are closely associated with aquatic ecosystems because of their amphibious life cycle, they are widely used as bio-indicators to assess the health of aquatic habitats. The study aimed to evaluate the impacts of these land-use-driven changes in vegetation structure, stream characteristics, and water quality parameters on odonate assemblages in Central Western Ghats. The assemblages were influenced maximum by habitat variables, i.e., ambient temperature and Canopy cover, stream variables, i.e., flow rate and habitat complexity, and water quality parameters, i.e., pH and water temperature. The relationship between the odonate assemblages and these variables highlights the dependency of odonates on particular sets of habitat requirements. Furthermore, studying these relationships with landscape-level variables might provide a more comprehensive understanding of Odonate habitat associations, aiding in developing effective freshwater conservation strategies.

By comparing the compositional similarity among the treatments between Zygoptera and Anisoptera, it is evident that the suborders of odonates have distinct responsiveness towards changes in their habitat. The forest communities depicted the slightest similarity with Edge and plantation communities. This highlights that the forest communities are stable and less likely to occupy the edge or plantation site. Overall, the difference in the pattern of responsiveness to land use changes between dragonflies and Damselflies signifies the importance of considering odonates at a sub-order level to assess the quality or health of aquatic habitats.

8.0 CONSERVATION IMPLICATIONS

The study needs to emphasise the importance of landscape-level factors influencing the dispersal and distribution of the Odonates, as the study area was restricted to one protected area (Someshwara Wildlife Sanctuary). However, the study gives more insights into understanding the impact of land-use changes on Odonates at a local scale. The study's design can be replicated at a much larger scale to understand the simultaneous effects of landscape factors (patch metrics, altitude, catchment area, distance to source population, etc) and local factors (vegetation structure, habitat complexity, water quality parameters).

The study highlights the importance of protecting the Riparian vegetation, which drives the Odonate assemblages, providing ecosystem services as apex predators of terrestrial and aquatic habitats. Maintaining buffer riparian zones along threatened freshwater habitats such as streams and rivers in the western Ghats landscape should be necessary. More studies should be undertaken to understand the cascading effects of changes in Odonates assemblages on other invertebrate taxa and highlight the importance of Odonates as flagship taxa for conserving freshwater ecosystems in this landscape.

Studies can highlight the importance of secondary forests and plantations as refugees and important factors connecting a fragmented landscape. Understanding species habitat association is crucial for developing conservation strategies for indicator taxa like Odonates.

9.0 LIMITATIONS OF THE STUDY

- Accounting for seasonal variation in odonate assemblages

  Data collection should be done across the seasons and over a few years to make the data more reliable. Comparing seasons and checking their congruency would help us better understand the patterns.

- Consideration of Landscape variables

  Variables such as patch metrics, altitude, catchment area, and distance to the source population, which might influence the distribution and dispersal of odonates, should be considered. The results can be compared at the local and landscape levels to understand them better.

- Replicability of the study and avoiding pseudo-replication

  The replicability of the results obtained in other areas of the same or different landscapes should be carried out. The significant bias-influencing phenomena, such as Pseudo-replication, should be handled before replicating the study.

- Sampling efficiency

  The selection of multiple streams from different catchment areas with different combinations of riparian land use will increase the sampling efficiency and give better results for the research questions that need to be answered.

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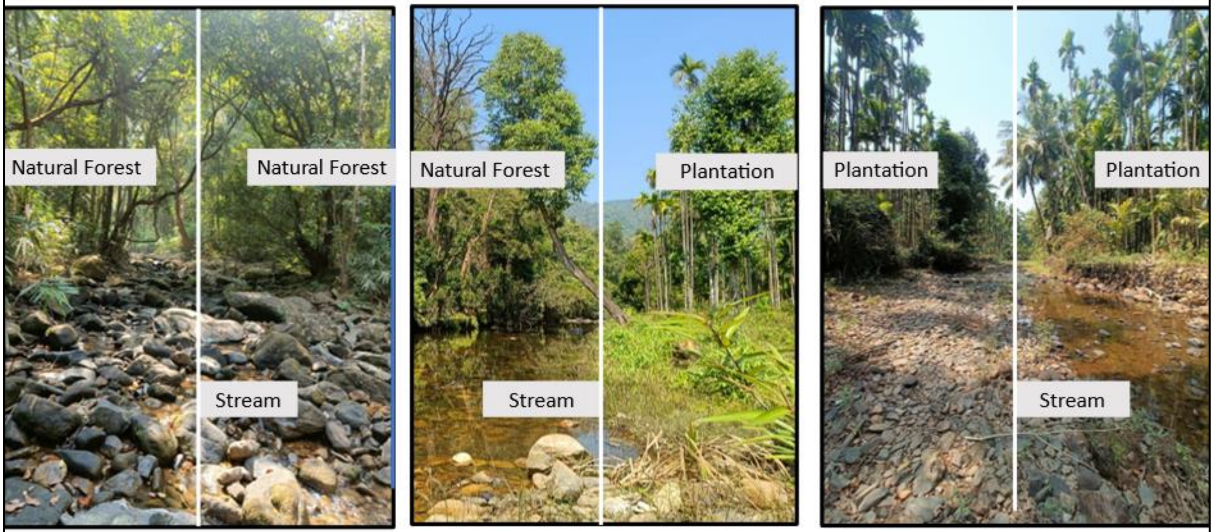
Appendix I

Common name	*Scientific name*	Forest	Plantation-forest	Plantation
Anisoptera **Libellulidae**				
Brown-backed Marsh Hawk	*Orthetrum chrysis*	8	24	28
Fulvous Forest Skimmer	*Neurothemis fulvia*	32	47	13
Black Stream Glider	*Trithemis festiva*	1	35	46
Pied Paddy Skimmer	*Neurothemis tullia*	2	95	35
Crimson-tailed Marsh Hawk	*Orthetrum pruinosum*	-	7	1
Green Marsh Hawk	*Orthetrum sabina*	-	7	2
Tricoloured Marsh Hawk	*Orthetrum luzonicum*	-	-	2
Emerald Banded Skimmer	*Cratilla lineata*	1	2	-
Trumpet Tail	*Acisoma panorpoides*	-	3	2
Crimson Glider	*Trithemis aurora*	7	39	25
Blue Ground Skimmer	*Diplacodes trivialis*	-	5	8
Asiatic Bloodtail	*Lathrecista asiatica*	1	7	-
Pygmy Skimmer	*Tetrathemis platyptera*	2	1	-
Blue-Tailed Forest Hawk	*Orthetrum triangulare*	-	-	1
Little Blue Marsh Hawk	*Brachydiplax sobrina*	-	1	-
Emerald Cascader	*Zygonyx iris*	30	4	3
Yellow-Tailed Ashy Skimmer	*Potamarcha congener*	-	-	1
Common Picturewing	*Rhyothemis variegata*	-	3	-
Gomphidae				
River Hawker	*Onychothemis testacea*	1	-	1
Kodagu Tiger	*Gomphidia kodaguensis*	24	17	7
Lined Hooktail	*Paragomphus lineatus*	-	-	1
Microgomphus Souteri	*Microgomphus souteri*	-	-	1
Zygoptera **Calopterygidae**				
Stream Glory	*Neurobasis chinensis*	12	26	32

Clear-winged Forest Glory	*Vestalis gracilis*	8	-	-
Black-tipped Forest Glory	*Vestalis apicalis*	35	17	13
Chlorocyphidae				
Stream Ruby	*Heliocypha bisignata*	232	93	135
Southern Heliodor	*Libellago indica*	17	70	16
Euphaeidae				
Malabar Torrant Dart	*Euphaea fraseri*	4	-	7
Black Torrent Dart	*Dysphaea ethela*	-	5	3
Platycnemididae				
Yellow Bush Dart	*Copera marginipes*	18	61	40
Red-Striped Black Bambootail	*Prodasineura verticalis*	1	31	23
Blue Bush Dart	Copera vittata	-	10	7
Pygmy Dartlet	*Agriocnemis pygmaea*	-	1	2
Splendid Dartlet	*Agriocnemis splendidissima*	-	14	4
Yellow Striped Sprite	*Pseudagrion indicum*	-	26	11
Blue Sprite	*Pseudagrion microcephalum*	-	4	-
Elattoneura tetrica	Elattoneura tetrica	4	38	-
Coenagrionidae				
Orange marsh dart	*Ceriagrion rubiae*	-	18	2
Orange-tailed marsh Dart	*Ceriagrion cerinorubellum*	2	4	-
Western Goldent Dartlet	*Ischnura rubilio*	-	5	-
Saffron-faced Marsh Dart	*Pseudagrion rubriceps*	-	2	-
Coromandal marsh dart	*Ceriagrion coromandelianum*	-	2	-
Rusty Marsh Dart	*Ceriagrion olivaceum*	5	3	1
Pseudogrion spp	Pseudogrion spp	-	2	-
Platystictidae				
Pied Reedtail	*Protosticta gravelyi*	5	1	-
Anamalai Reedtail	*Protosticta davenporti*	-	-	-

Appendix II



Treatments

Forest | **Edge**: Areca nut Plantation - Forest | Areca nut **Plantation**

Seven transects in each treatment were **replicated three times**