DIVERSITY AND ECOLOGY OF ODONATES IN KOLE WETLANDS, CENTRAL KERALA, INDIA

Thesis submitted for the degree of

DOCTOR OF PHILOSOPHY IN ENVIRONMENTAL SCIENCE

Under the Faculty of Science

University of Calicut

By

VIVEK CHANDRAN A

Under the supervision of

DR. SUBIN K. JOSE

Assistant Professor

Department of Geology and Environmental Science

CHRIST COLLEGE (AUTONOMOUS), IRINJALAKUDA- 680125

KERALA

JULY 2025

July 2025

DECLARATION

I, **Vivek Chandran A**, hereby declare that the work embodied in this thesis, "**DIVERSITY AND ECOLOGY OF ODONATES IN KOLE WETLANDS, CENTRAL KERALA, INDIA**" submitted to the University of Calicut in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Environmental Science is a bona fide record of the research work carried out by me under the supervision of Dr. Subin K. Jose, Assistant Professor, Department of Geology and Environmental Science, Christ College (Autonomous), Irinjalakuda, affiliated to the University of Calicut. No part of the thesis has formed the basis for the award of any degree, diploma or similar titles of any university. The contents of the thesis have undergone a plagiarism check using iThenticate software at C.H.M.K. Library, University of Calicut, and the similarity index was found to be within the permissible limit. I also declare that this thesis is free from AI-generated content.

Signature:

Name of the scholar: Vivek Chandran A

Signature of the Research Supervisor:

Name:

Dr. SUBIN K JOSE
RESEARCH SUPERVISOR
DEPARTMENT OF GEOLOGY AND
ENVIRONMENTAL SCIENCE
CHRIST COLLEGE (AUTONOMOUS)
IRINJALAKUDA

Place: Irinjalakuda

Date: 01-07-2025

CHRIST
COLLEGE (AUTONOMOUS)
IRINJALAKUDA, KERALA
IRINJALAKUDA - 680125, KERALA, INDIA Office (0480) 2825258
office@christcollegeijk.edu.in www.christcollegeijk.edu.in
(Reg.No. 137/75; No.F.22-1/2015/AC.U.G.C.)
Affiliated to University of Calicut and Re-accredited by NAACA++&SAACA+ Grade

Date: 01-07-2025

CERTIFICATE

This is to certify that the thesis titled "**DIVERSITY AND ECOLOGY OF ODONATES IN KOLE WETLANDS, CENTRAL KERALA, INDIA**" submitted to the University of Calicut in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Environmental Science is an authentic record of the research work carried out by **Mr. Vivek Chandran A** under my supervision in the Department of Geology and Environmental Science, Christ College (Autonomous), Irinjalakuda, affiliated to the University of Calicut. No part of the thesis has formed the basis for the award of any degree, diploma or similar titles of any university. It is further certified that no corrections/suggestions were recommended by the adjudicators and that the contents of the thesis and the soft copy are one and the same.

Signature of Research Supervisor:

Dr. SUBIN K JOSE
RESEARCH SUPERVISOR
DEPARTMENT OF GEOLOGY AND ENVIRONMENTAL SCIENCE
CHRIST COLLEGE (AUTONOMOUS)
IRINJALAKUDA

Date: 01-07-2025

CERTIFICATE

This is to certify that **Mr. Vivek Chandran A** has completed the research work for the entire period prescribed under the PhD ordinance of the University of Calicut. This thesis, "**DIVERSITY AND ECOLOGY OF ODONATES IN KOLE WETLANDS, CENTRAL KERALA, INDIA**", embodies the results of his investigations conducted during the period in which he worked as a research scholar. I recommend that the thesis be submitted for evaluation for the Doctor of Philosophy in Environmental Science degree award from the University of Calicut.

CHRIST COLLEGE (AUTONOMOUS) IRINJALAKUDA

Head of the Institution

Fr. Dr. Jolly Andrews
Associate Professor -
In-Charge of Principal
Christ College (Autonomous)
Irinjalakuda

UNIVERSITY OF CALICUT

CERTIFICATE ON PLAGIARISM CHECK

1.	Name of the Research Scholar	VIVEK CHANDRAN A	
2.	Title of thesis / dissertation	DIVERSITY AND ECOLOGY OF ODONATES IN KOLE WETLANDS, CENTRAL KERALA, INDIA	
3.	Name of the Supervisor	DR. SUBIN K. JOSE	
4.	Department/Institution	DEPARTMENT OF GEOLOGY AND ENVIRONMENTAL SCIENCE, CHRIST COLLEGE (AUTONOMOUS), IRINJALAKUDA, THRISSUR, PIN: 680125	
5.	Similar content (%) identified	Non-Core	Core
		Introduction/ Theoretical overview/Review of literature/ Materials & Methods/ Methodology	**Analysis/Result/ Discussion/ Summary/ Conclusion/ Recommendations**
		4	0
	Acceptable maximum limit (%)	10	10
6.	Software used	**iThenticate**	
7.	Date of verification	22-01-2025	

**Report on plagiarism check, specifying included/excluded items with % of similarity to be attached.*

Checked by (with name, designation & signature)

JAMSHEER N. P.
Assistant Librarian
University of Calicut
Malappuram - 673 635

Name and signature of the Researcher Vivek Chandran. A

Name and signature of the Supervisor.

Dr. SUBIN K JOSE
RESEARCH SUPERVISOR
DEPARTMENT OF GEOLOGY AND ENVIRONMENTAL SCIENCE
CHRIST COLLEGE (AUTONOMOUS), IRINJALAKUDA

The Doctoral Committee* has verified the report on plagiarism check with the contents of the thesis, as summarized above and appropriate measures have been taken to ensure originality of the Research accomplished herein.

Name & Signature of the HoD/HoI (Chairperson of the Doctoral Committee)

**In case of languages like Malayalam, Tamil etc..on which no software is available for plagiarism check, a manual check shall be made by the Doctoral Committee, for which an additional certificate has to be attached.*

Fr. Dr. Jolly Andrews
Associate Professor -
In-Charge of Principal
Christ College (Autonomous)
Irinjalakuda

Acknowledgements

My heart is filled with gratitude towards the following people and institutions who helped and supported me in this journey in various ways. I would like to thank-

Dr. Subin K. Jose, my research supervisor, for his unwavering support, patience, and guidance throughout this endeavour.

My life partner, Abbi (Aparnadevi P.A), for finding hope when I could not find it myself. All those tea sessions helped in keeping this thesis alive.

My parents, for always giving me the first preference at every turn of their lives to see me succeed in life.

Friends Niranjana K.S., Subin K.S., Siji P.K., and Cicy Ann Theophin for making the fieldwork fun.

Fr. Dr. Jolly Andrews, the Principal, Christ College (Autonomous), Irinjalakuda, for standing firmly by my side when his support mattered the most.

Members of my Research Advisory Committee, especially Dr. Sylas V.P., for timely course corrections that led this research on the right path.

The Directorate of Environment and Climate Change (DoE&CC), Government of Kerala, for the financial support in the form of Paristhithi Poshini Fellowship.

My fellow scholars, Haritha D.S., Archana M., Shehnaz Usman, Leela Varma, Aleena K.A., Shaima M.M., and Ayyappadas C.S. for their helping hands in the lab and the lighter moments spent together.

Researchers of the Shadpada Entomology Lab (Zoology) led by Dr. Bijoy C., including, Suryanarayanan T.B., Aswathy P.G., Anju Sara Prakash, and Thasnim E.S., for sharing their knowledge and equipment.

Nandana K.P. (Independent researcher), Dr. Joby Paul (Assistant Professor, St. Thomas College, Thrissur), and Parvathy M.R. (Student, St. Thomas College, Thrissur) for helping me identify the plant species.

Prof. Prosenjit Dawn (Department of Zoology, Shyampur Siddheswari Mahavidyalay, Howrah, West Bengal), for throwing open the world of Odonata larvae for me. The collaboration we built truly turned the tide in my favour.

The NGO, Society for Odonate Studies (SOS), especially the members of SOS General Council, from whom I learned the basics of odonatology and the importance of voluntary work.

Dr. Nameer P.O., Dean, College of Climate Change and Environmental Science, Kerala Agricultural University, for making available the weather data that was crucial for this research.

Dr. Subramanian K.A., Scientist, Zoological Survey of India, for inspiring me to work on odonates and sharing his vast knowledge on them.

Dr. Dattaprasad Sawant and Reji Chandran, the duo that kept energizing me with thought-provoking discussions on odonates.

Dr. Sindhu Kaimal and Dr. Bindu Kaimal for their valuable advice on data analysis.

Dr. Krushnamegh Kunte, Associate Professor, National Centre for Biological Sciences, Bengaluru, for throwing open the doors of the Biodiversity Lab led by him for carrying out my work.

Laure Montchamp, Senior Grants Officer, IUCN SOS (International Union for Conservation of Nature- Save Our Species), for her constant encouragement for my studies.

Dr. Erik I. Svensson, Professor, Department of Biology, Lund University, Sweden, for the walks in the jungle and discussions on odonate evolution.

Rison K.J. of the ‘odonate village’ Thumboor, for sharing his field knowledge and photographs of odonate life cycle.

My cats, Sangi, Barenu, Kutyankaran, Nezhalootta, and Kunji, for their purrs and companionship.

In the end, I would like to thank myself for not giving up on my thesis when the going got tough.

Vivek Chandran A

Dedication

This thesis is dedicated to dragonflies and damselflies— true marvels of evolution with whom we share this remarkable planet.

CONTENTS

LIST OF TABLES

Page No

LIST OF FIGURES

LIST OF PLATES

Abstract

Insects in the Order Odonata, comprising dragonflies and damselflies, are key indicators of freshwater ecosystem health due to their amphibiotic life history, high trophic position, and diversity. The Kole wetlands in central Kerala, India, renowned for biodiversity and rice production, were studied for the first time to explore odonate diversity and ecology by sampling adults, larvae, and exuviae. Long-term sampling and supplementary random surveys for adults over two years recorded 63 species (39 dragonflies, 24 damselflies). Adult diversity peaked during early monsoon and dipped in winter, influenced by rainfall, humidity, and wind speed. Exuviae sampling proved inefficient in this open wetland ecosystem. Statistical analyses revealed significant effects of site-specific and broader vegetation factors, with seasonal changes being dominant. Wetlands showed higher species richness (44 species) compared to ponds (30 species), with 14 species exclusive to wetlands. Eight species were identified as potential indicators of water quality, and three emerged as specific wetland indicators. Larval sampling recorded 33 species, all previously detected as adults, with diversity peaking during late monsoon and winter, suggesting a temporal lag with adult emergence. Principal Component Analysis highlighted substrate composition, soil organic content, water and soil pH, turbidity, biochemical oxygen demand, nutrients, and vegetation cover as key determinants of larval distribution. This study also provided the first descriptions of adult male *Macrogomphus wynaadicus* Fraser, 1924 and final instar larvae of *Platylestes platystylus* (Rambur, 1842) and *Aethriamanta brevipennis* Rambur, 1842. Such descriptions are critical for taxonomic clarity and effective biomonitoring. Conservation recommendations were proposed to preserve Kole wetland biodiversity, emphasizing the role of odonates as key bioindicators.

Keywords: Odonata, wetland, biodiversity, conservation, bioindicator

സംഗ്രഹം

കല്ലൻത്തുമ്പികളും സൂചിത്തുമ്പികളും അടങ്ങുന്ന ഒഡോണാറ്റ എന്ന 'ഓർഡറി'ലെ പ്രാണികൾ അവയുടെ ജീവിതചരിത്രം, ഭക്ഷ്യശൃംഖലയിലെ സ്ഥാനം, വൈവിധ്യം എന്നീ പ്രത്യേകതകൾ കൊണ്ട് ശുദ്ധജല ആവാസവ്യവസ്ഥയുടെ ആരോഗ്യത്തിന്റെ പ്രധാന സൂചകങ്ങളാണ്. ജൈവവൈവിധ്യത്തിനും നെല്ലുൽപ്പാദനത്തിനും പേരുകേട്ട മധ്യകേരളത്തിലെ കോൾനിലങ്ങളിലെ തുമ്പികളെ കുറിച്ചുള്ള ആദ്യ പഠനമാണിത്. ഇതിനായി തുമ്പികളുടെ മുതിർന്നവ, ലാർവകൾ, എക്സുവിയകൾ (അവസാനഘട്ട ലാർവയുടെ പുറംതൊലി) എന്നിവ നിരീക്ഷിച്ച് തുമ്പികളുടെ വൈവിധ്യവും പരിസ്ഥിതിശാസ്ത്രവും പഠനവിധേയമാക്കി. 63 ഇനം തുമ്പികളെയാണ് (39 കല്ലൻത്തുമ്പികൾ, 24 സൂചിത്തുമ്പികൾ) രണ്ട് വർഷംകൊണ്ട് നടത്തിയ സർവേയിൽ മുതിർന്ന രൂപത്തിൽ കണ്ടെത്താനായത്. മഴ, ആപേക്ഷിക ആർദ്രത, കാറ്റിന്റെ വേഗത എന്നിവയുടെ സ്വാധീനത്തിൽ ഇവയുടെ വൈവിധ്യം മൺസൂണിന്റെ തുടക്കത്തിൽ ഉയർന്നുവരികയും ശൈത്യകാലത്ത് കുറയുകയും ചെയ്തു. കോൾനിലങ്ങൾ പോലുള്ള തുറന്ന തണ്ണീർത്തടങ്ങളിൽ എക്സുവിയകൾ നിരീക്ഷിച്ചു തുമ്പികളുടെ വൈവിധ്യം അളക്കാൻ ശ്രമിക്കുന്നത് കാര്യക്ഷമമല്ലെന്ന് തെളിഞ്ഞു. പഠനം നടത്തുന്ന സീസണും സ്ഥലത്തെ പ്രധാന ജലസസ്യങ്ങളും തുമ്പിവൈവിധ്യത്തെ ഗണ്യമായി ബാധിക്കുന്നുണ്ടെന്ന് വ്യക്തമായി. കുളങ്ങളെ അപേക്ഷിച്ചു തണ്ണീർത്തടങ്ങൾ കൂടുതൽ തുമ്പിവൈവിധ്യം നിലനിർത്തുന്നതായി കണ്ടെത്തി. എട്ടിനം തുമ്പികളെ ജലഗുണത്തിന്റെ സൂചകങ്ങളായും, മൂന്നിനത്തെ പ്രത്യേക തണ്ണീർത്തട സൂചകങ്ങളായും തിരിച്ചറിഞ്ഞു. 33 ഇനം തുമ്പികളുടെ ലാർവകളെയാണ് ഒരുവർഷം കൊണ്ട് കോൾനിലങ്ങളിൽ നിന്നും കണ്ടെത്തിയത്. ഇവയുടെ വൈവിധ്യം മുതിർന്നവയുടേതിന് വിപരീതമായി മൺസൂൺ അവസാനത്തിലും ശൈത്യകാലത്തും കൂടുതലായി കാണപ്പെട്ടു. മണ്ണിന്റെ ഘടന, ജലത്തിന്റെ ചില ഗുണനിലവാര ഘടകങ്ങൾ, ജലത്തിലെ പോഷകങ്ങളുടെ അളവ്, ചെടികളുടെ വിന്യാസം എന്നിവ ലാർവകളുടെ വിതരണത്തെ ബാധിക്കുന്നതായി തെളിഞ്ഞു. മാക്രോഗോംഫസ് വയനാടിക്കസ് എന്ന തുമ്പിയുടെ മുതിർന്ന ആൺരൂപത്തെയും പ്ലേറ്റിലെസ്റ്റസ് പ്ലേറ്റിസ്റ്റൈലസ്, എത്രിയാമാന്റ ബ്രെവിപെന്നിസ് എന്നീ തുമ്പികളുടെ ലാർവകളെയും ആദ്യമായി ശാസ്ത്രത്തിന് പരിചയപ്പെടുത്താനും വർണിക്കാനും ഈ പഠനത്തിന് സാധിച്ചു. കോൾനിലങ്ങളിലെ ജൈവവൈവിധ്യം, പ്രധാനമായും ജൈവസൂചകങ്ങളായ തുമ്പികളുടെ വൈവിധ്യം സംരക്ഷിക്കുന്നതിനായി സംരക്ഷണ ശുപാർശകൾ നിർദ്ദേശിച്ചുകൊണ്ട് പഠനം ഉപസംഹരിച്ചു.

Chapter 1

GENERAL INTRODUCTION

1.1. Order Odonata

Insects are among the most successful organisms on Earth due to their incredible diversity, adaptability, high reproductive rates, and efficient physiology. Their small size, protective exoskeleton, and varied reproductive strategies allow them to thrive in nearly every environment. Social structures, symbiotic relationships, and survival mechanisms like defence and dispersal further enhance their success. Insects play crucial ecological roles as pollinators, decomposers, and key components of food webs. Odonates, comprising dragonflies and damselflies, belong to the Order Odonata within the Class Insecta. They are characterised by aquatic larvae (nymphs/naiads), segmented and elongated bodies, large compound eyes, biting and chewing mouth parts, and two pairs of strong, transparent wings. The whole body of an odonate is divided into head, thorax and abdomen. Head has three ocelli in addition to the two large, compound eyes. The thorax is muscular where the wings and three pairs of spiny legs are attached. The abdomen is long, with ten well-demarcated segments (Figure 1.1). Odonates are carnivorous as both aquatic larvae and aerial adults. They are hemimetabolous- the larvae develop directly into adults without an intermediate pupal stage. Odonates are considered primitive organisms, with fossil records dating back over 300 million years.

The Order Odonata consists of three suborders:

1. Anisoptera: includes dragonflies, characterized by unequal, stalkless wings (hindwings broader than forewings), larger, robust bodies, wings held horizontally at rest, and eyes that often touch each other.
2. Zygoptera: includes damselflies, characterized by equal, stalked wings (hindwings and forewings of almost equal size and shape), smaller, slender bodies, wings held together at rest, and well separated eyes.
   (Figure 1.2)
3. Anisozygoptera: includes ancient odonates, sometimes called damseldragons, which is a relict group with characteristics of both

dragonflies and damselflies, found mainly in Asia. In India, only a single species is recorded from Darjeeling (Easten Himalayas), *Epiophlebia laidlawi* Tillyard, 1921.

Figure 1.1: The main divisions of an odonate body shown on *Indothemis limbata* (Selys, 1891).

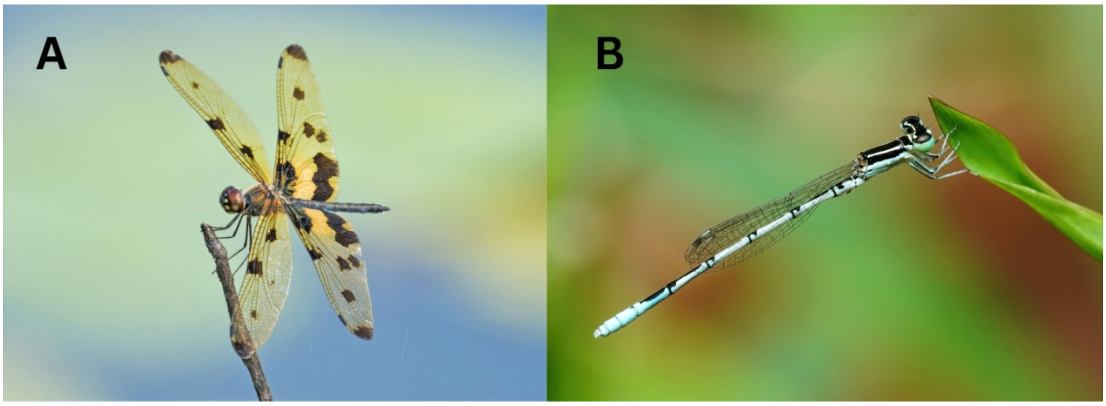


Figure 1.2: A- a dragonfly represented by *Rhyothemis variegata* (Linnaeus, 1763) and B- a damselfly represented by *Agriocnemis pieris* Laidlaw, 1919.

1.2. Odonate diversity

Currently, 6420 species of odonates are recognized worldwide (Paulson et al., 2024), with 504 species occurring in India in three suborders and 17 families (Subramanian and Babu, 2024). A total of 175 species are endemic to India. Most of the endemic species have a restricted distribution, confined to the two biodiversity hotspots of India, the Western Ghats and the Eastern Himalayas. The highest number of endemic species are recorded from Kerala, followed by Tamil Nadu and Karnataka. In Kerala, a total of 186 species of Odonata have been recorded till date (Society for Odonate Studies, 2024) and more new species are being described, mostly from the forested hills.

1.3. Odonate habitats

Odonates inhabit a wide range of freshwater habitats including temporary and permanent waterbodies. They are seen in the snow-clad mountains to tropical rainforests. Some families have an affinity to cool streams or rivers, others to ponds, lakes or still, clear waters, and some to marshy places. Larvae maybe sprawlers, crawlers, burrowers, climbers or hiders and rely on camouflage to hunt their prey. The labium of larvae is a special predatory tool that can be thrust forward at great speed to capture the prey (Figure 1.3).

Adults are very strong fliers and abundant in the vicinity of wetlands, especially along the shores and over the water of marshes, ponds, lakes, streams and rivers. They use their spiny legs to capture prey in mid-air and use their toothed mandibles to devour them. Odonate larvae feed on mostly invertebrates like chironomid larvae, mosquito wrigglers and crustaceans. Larvae of larger odonates like aeshnids may feed on small fishes and tadpoles. As adults, odonates feed mostly on flying insects. Cannibalism is not uncommon in odonates, both in the larval and adult stages. Some species like *Orthetrum sabina* (Drury, 1770) may also prefer to feed on smaller odonate species (Figure 1.4).

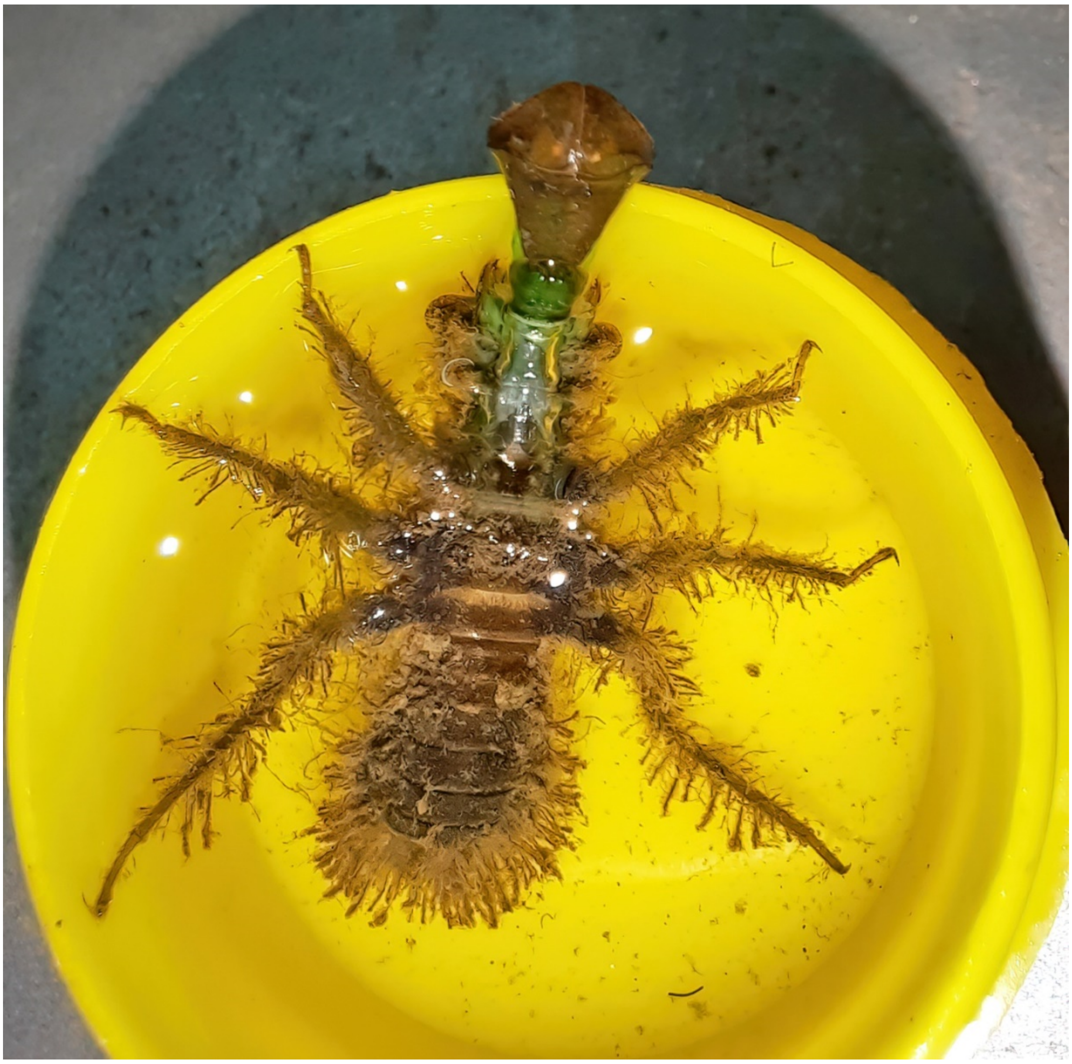


Figure 1.3: Ventral view of the larva of *Rhodothemis rufa* (Rambur, 1842) showing the extended labium used for prey capture and setae that has trapped soil and algae for camouflage.

Figure 1.4: *Orthetrum sabina* (Drury, 1770) feeding on *Neurothemis tullia* (Drury, 1773).

1.4. Odonate life cycle

The odonate life cycle begins with the female laying eggs near or in water. The egg laying (oviposition) may be exophytic where the eggs are released directly onto the water surface (e.g., most libellulids), or endophytic (e.g., most damselflies) where using specialized ovipositor at the tip of its abdomen, the female injects the eggs into aquatic plants or debris in or near water. In a few species like *Tetrathemis platyptera* Selys, 1878, it may also be epiphytic, where the female sticks the eggs on plants overhanging water. In tropical conditions, the eggs hatch within a few weeks and worm-like prolarvae emerge and find ideal microhabitats for larval life. The prolarvae moult within a few days to the first instar larvae. The larvae feed voraciously and grow by moulting 8-12 times. For their final moult, the larvae climb out of water and the fully grown, winged adults emerge out. They are soft and colourless for a few hours and are called tenerals. They are most vulnerable to predation at this stage and hence, eclosion usually occurs under the cover of night. The tenerals usually fly away from their natal waters and spend the next couple of weeks as pre-reproductive adults where their focus is on foraging. When they are sexually mature, the reproductive adults return to waterbodies. Some odonate species establish territories at this stage which are fiercely guarded. Male odonates are usually more colourful and active, while in most species, females are drab and found only during mating. Odonates have a unique system of copulation where the male bends its abdomen to transfer its sperms from the primary genitalia located between its last two segments to the accessory (secondary) genitalia located in the second segment. This is done before the female held in tandem using the caudal (anal) appendages mates with it. Since the deposited sperms can be scraped out by a rival male, the mated male stands guard during oviposition, either in tandem with the female, or hovering above it, or perched close by (Figure 1.5).

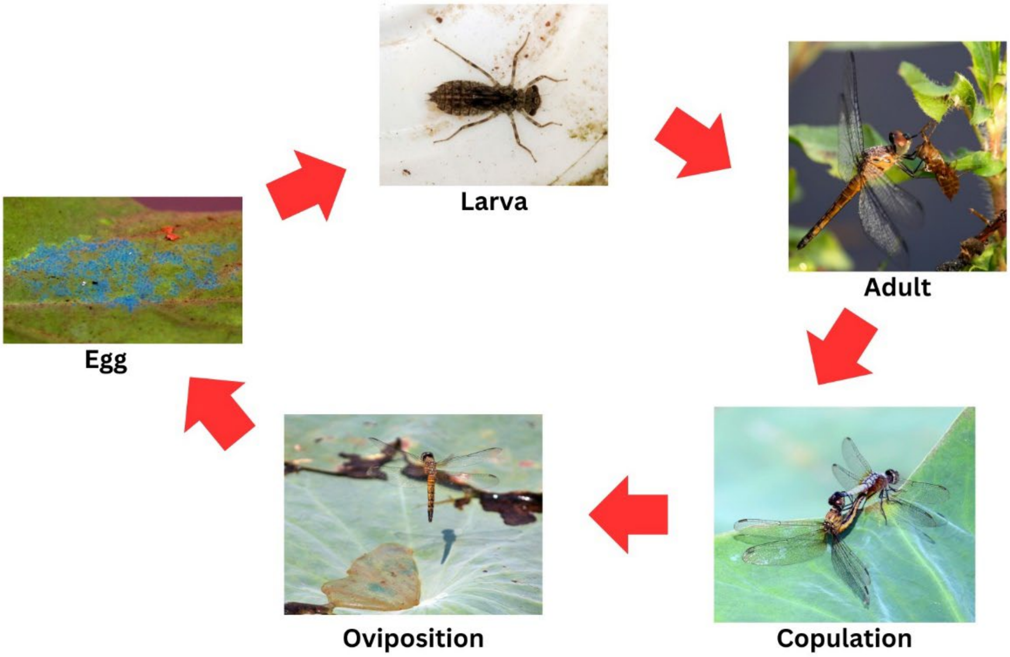


Figure 1.5: Life cycle of an odonate represented by *Brachydiplax chalybea* (Brauer, 1868).

The eclosion, or the emergence of adults from larvae leave behind exuviae (exoskeletons) which may persist in the environment for a few days and are important markers of completion of odonate life cycle in an ecosystem (Figure 1.6).

Figure 1.6: Exuvia of *Pantala flavescens* (Fabricius, 1798) from Kole wetlands.

1.5. Ecological significance of odonates

Dragonflies and damselflies are among the dominant invertebrate predators in freshwater ecosystems and they feed on a wide range of invertebrates. They play a dual role of predator and prey in both stages of their life. In water, the larvae feed on a variety of invertebrates and small vertebrates and are, in turn, preyed upon by large fishes and frogs. As adults, odonates feed mostly on flying invertebrates and are hunted by spiders, lizards and birds. Ectoparasites like water mites (*Arrenurus* spp) and protozoan endoparasites are also known to afflict odonates. Thus, odonates play a crucial role in the food web. Odonates are very sensitive to environmental changes and they are commonly used as indicators of habitat disturbance. Relative ease in identification, moderate species diversity, short life cycles, and sensitivity to human disturbances like pollution, deforestation and climate change make them useful bioindicators. Odonates provide valuable ecosystem service by feeding on large numbers of harmful insects such as mosquitoes, termites, true flies, aphids, smaller moths, etc. and act as important biocontrol agents. They also control the pest populations in agro-ecosystems (Figure 1.7).

Figure 1.7: *Ceriagrion coromandelianum* (Fabricius, 1798) feeding on rice stem borer, *Scirpophaga innotata* (Walker, 1863).

1.6. Thermoregulation in odonates

Thermoregulation is essential for optimizing the physiological and behavioral functions of odonates, including flight, predation, and reproduction. Odonates can be broadly categorized into two ecological groups based on their thermoregulatory strategies: "fliers" and "perchers" (Corbet, 1999).

Fliers, such as many members of Family Aeshnidae (Figure 1.8), are highly active and spend much of their time in flight. These species often engage in physiological thermoregulation, where they modulate their body temperature internally. Fliers can generate heat through muscular activity, particularly during flight, and they have adaptations that help them retain or dissipate heat as needed. For example, they might vibrate their flight muscles to warm up before takeoff or alter their flight patterns to increase heat loss when overheated. The ability to regulate their temperature in this way allows them to remain active in a wide range of environmental conditions, enabling them to exploit various habitats and niches. All the crepuscular species of dragonflies fall in this category.

Figure 1.8: A flier, *Anax guttatus* (Burmeister, 1839) photographed over a paddy field.

Perchers, which include many species within Family Libellulidae and most damselflies, typically adopt a more sedentary lifestyle, spending much of their time resting on vegetation or other substrates. These species rely more heavily on behavioural thermoregulation. Perchers often bask in direct sunlight to increase their body temperature, adopting specific postures, such as tilting their bodies toward the sun, to maximize heat absorption. Conversely, they may seek shade or alter their body orientation to minimize heat gain (obelisk posture) when temperatures become too high (Figure 1.9). Some perchers also exhibit behaviours like abdominal dipping into water to cool down. This approach allows them to fine-tune their body temperature to stay within optimal ranges for activity, even in fluctuating environmental conditions.

Figure 1.9: *Diplacodes trivialis* (Rambur, 1842) perched in obelisk posture to reduce body temperature at noon when the sun is directly above it.

Together, these thermoregulatory strategies help odonates adapt to their environments. Both flier and percher strategies are critical for these insects' survival, influencing their distribution, behaviour, and ecological roles.

1.7. Wetlands

Wetlands are ecosystems in which water either covers the soil or is present at or close to the soil's surface throughout the year or for different lengths of time. Both aquatic and terrestrial species can be found in wetlands. Conditions that favour the establishment of particularly adapted plants (hydrophytes) and encourage the formation of distinctive wetland (hydric) soils are created by the extended presence of water. Wetland water is frequently groundwater that seeps up from a spring or aquifer. Another source of water for a wetland is a neighbouring lake or river. Wetlands may also be formed by seawater, particularly in coastal regions with high tides. Wetlands typically have shallow water depths, often less than 2 meters. This shallow water allows sunlight to penetrate, supporting the growth of aquatic plants. Marshes, swamps, mangroves and tidal mudflats are some of the kinds of wetlands.

Wetlands are highly significant ecosystems that provide a variety of functions critical to human survival and development. They prevent flooding by absorbing water after heavy rains or storms. This water is progressively released, limiting the likelihood of rapid flooding and erosion. Some of the water also percolates, replenishing the groundwater. Wetlands serve as natural filters for water, capturing pollutants, sediments, and nutrients. This helps to enhance the water quality. Mangroves and other wetlands are significant carbon sinks. They help to mitigate climate change by storing a significant amount of carbon in their soils. Wetlands can also serve to control local temperatures, cooling the surrounding areas. Wetlands provide habitat for a diverse range of plants and animals. They sustain the populations of birds, fish, amphibians, insects, and aquatic plants. Many species, notably birds and fish, require wetlands for nesting. They provide a safe habitat for reproduction and early life stages. Wetlands include resources such as fish, crabs, and plants, which may be utilized responsibly for food, medicine, and other purposes. Humans have changed many wetlands for agricultural and fishing purposes. These wetlands remain biodiversity hotspots. Wetlands are also popular places for hobbies like bird watching, fishing, and boating. This can produce revenue for local communities through eco-tourism. Wetlands also provide chances for recreational activities, which are critical to human well-being.

1.8. Threats to wetlands

The twin challenges of reclamation and pollution pose a danger to wetlands across the world. As human expansion and progress become more materialistic, wetlands are being taken over and transformed for housing and commercial purposes. They have also become dumping places for a wide range of trash, including hazardous and persistent waste such as biomedical and electronic waste. Agricultural operations, which use chemical fertilizers and pesticides, also contribute to the pollution burden. The other major concern to wetlands is the loss of natural biodiversity owing to the spread of alien species. Invasive hydrophytes like *Eichhornia crassipes*, native to South America has covered many wetland stretches in Asia and choke them of oxygen. They cause the local extinction of many native plants and animals. Invasive fish species cause disruption in the food webs of many wetlands.

1.9. Ramsar Convention

Considering the importance of wetlands for the prosperity of humankind and the anthropogenic pressures they face, world leaders met together at Ramsar, Iran, on 2nd February 1971 and framed the Ramsar Convention, formally called the Convention on Wetlands of International Importance especially as Waterfowl Habitat (Ramsar Convention Secretariat, 2024). It is one of the oldest international environmental treaties and focuses specifically on the protection of wetlands, recognizing their ecological, economic, cultural, and recreational value. The conservation and prudent use of wetlands via national, regional, and local initiatives as well as international collaboration is the main objective of the Ramsar Convention. The convention aims to ensure that the ecological character of wetlands is maintained while allowing for sustainable development that benefits human communities. Parties to this convention are obligated to implement measures to ensure the wise use of wetlands in their territory, which involves maintaining their ecological character through appropriate management practices. India is one of the 172 countries that are parties to the convention.

Ramsar Sites are wetlands of international importance declared by the Ramsar Convention. Each site is chosen based on factors such as biodiversity, ecological importance, and support for rare or endangered species. These sites seek to promote the protection and sustainable use of wetlands globally. As of 2024, there are 2,521 Ramsar Sites worldwide, encompassing more than 257 million hectares. Two major requirements for qualifying a wetland as a Ramsar Site are that it supports 20,000 or more waterbirds or that it sustains 1% of the global population of any one waterbird species. Other criteria include habitat for uncommon and endangered species, as well as ecological significance in the region. Thus, substantial attention is given to biodiversity protection when designating a wetland as a Ramsar site.

1.10. Wetlands in India

India has a broad range of wetlands in abundance. These include freshwater swamps, marshes, mangroves, coastal lagoons, and high-altitude lakes. This rich diversity has been shaped by the varied precipitation patterns, physiography, geomorphology, and climate. These wetlands are vital for biodiversity conservation, water storage, flood control, and supporting livelihoods. India has declared 85 of its wetlands as Ramsar Sites (Wetlands of India Portal, 2024). It shows the commitment of the country in conserving ecosystems even when it faces socio-economic and developmental issues. With 16 sites declared so far, Tamil Nadu leads the states in the number of Ramsar Sites. Some of the important wetland sites in India declared as Ramsar Sites include:

1. Sunderbans-Located in West Bengal of India and shared with Bangladesh, this is the largest stretch of mangrove forest in the world. Known for the Sundari tree (*Heritiera fomes*) that gives the place its name, Sunderbans also hosts mangrove species like *Avicennia*, *Rhizophora*, and *Sonneratia*. It offers sanctuary to the Estuarine Crocodile, Royal Bengal Tiger, many fish and bird species.

2. Chilika Lake- Located in Odisha, this is Asia’s largest brackish water lagoon. The lake and associated cultivated areas attract migratory birds in their thousands in the winter months. The local communities benefit from this abundance by playing the roles of bird guides, boat drivers and tour operators.

3. Keoladeo National Park- Located in Bharatpur, Rajasthan, this Ramsar Site is also a UNESCO World Heritage site. This is a world-renowned destination for many migratory bird species, including the rare Siberian Crane.

1.11. Wetlands in Kerala

Kerala, located in the southwestern part of India, is rich in various types of wetlands, including coastal, inland, and human-made wetlands. Kerala's distinctive wetland ecosystems encompass marshy and waterlogged regions, expansive polders (areas used for paddy cultivation) linked to backwaters, lakes, and the unique Myristica Swamps found within the forests of the Western Ghats. These wetlands play a vital role in supporting thousands of people, either directly or indirectly, by providing essential goods and services. However, their ecological integrity has been severely impacted by urbanization, developmental activities, and the rapid proliferation of residential complexes. Key challenges threatening Kerala's wetlands include pollution, eutrophication, encroachment, land reclamation, mining, and loss of biodiversity.

Vembanad-Kole, Ashtamudi and Sasthamkotta are the wetlands in Kerala currently designated as Ramsar Sites. Although the Vembanad-Kole wetlands are administratively grouped under the same Ramsar designation, they are often discussed separately due to their distinct geographical and ecological characteristics. Four other wetlands in Kerala are being considered to be declared as Ramsar Sites. These are Vellayani and the Akkulam-Veli in Thiruvananthapuram, Kottooli in Kozhikode and the Kattampally-Valapattanam-Kuppam wetland complex in Kannur.

1.12. Study area: Kole wetlands

The Kole wetlands, spanning 13,632 hectares, are located across the Thrissur and Malappuram districts of Kerala, southern India (Figure 1.10). It is part of a Ramsar site since 2002 (Islam and Rahmani, 2008), designated as an important bird area since 2004 (Islam and Rahmani, 2004), and a high value biodiversity area since 2009 (MoEF, 2009). Wetland agriculture, mainly paddy cultivation is the most important activity undertaken here and it is the third major rice producing area in Kerala (Figure 1.11). The term "Kole" in Malayalam, the regional language, signifies a bumper yield or high returns when conditions are favorable. (Srinivasan, 2012).

Kole wetlands are sandwiched between two rivers, Bharathapuzha in the north and Chalakkudy in the south. The rivers Kechery and Karuvannur drain into the Kole wetlands before entering the Arabian sea and give the wetlands their geographical divisions. The wetlands that lie north of the Kechery river are considered to constitute Ponnani Kole, between the two rivers they form Thrissur North Kole and the stretch that lies south of the Karuvannur river is considered as Thrissur South

Kole. The Kole wetlands are situated below sea level, with most of their area remaining submerged under floodwaters for approximately six months each year during the southwest monsoon. (Figure 1.12).

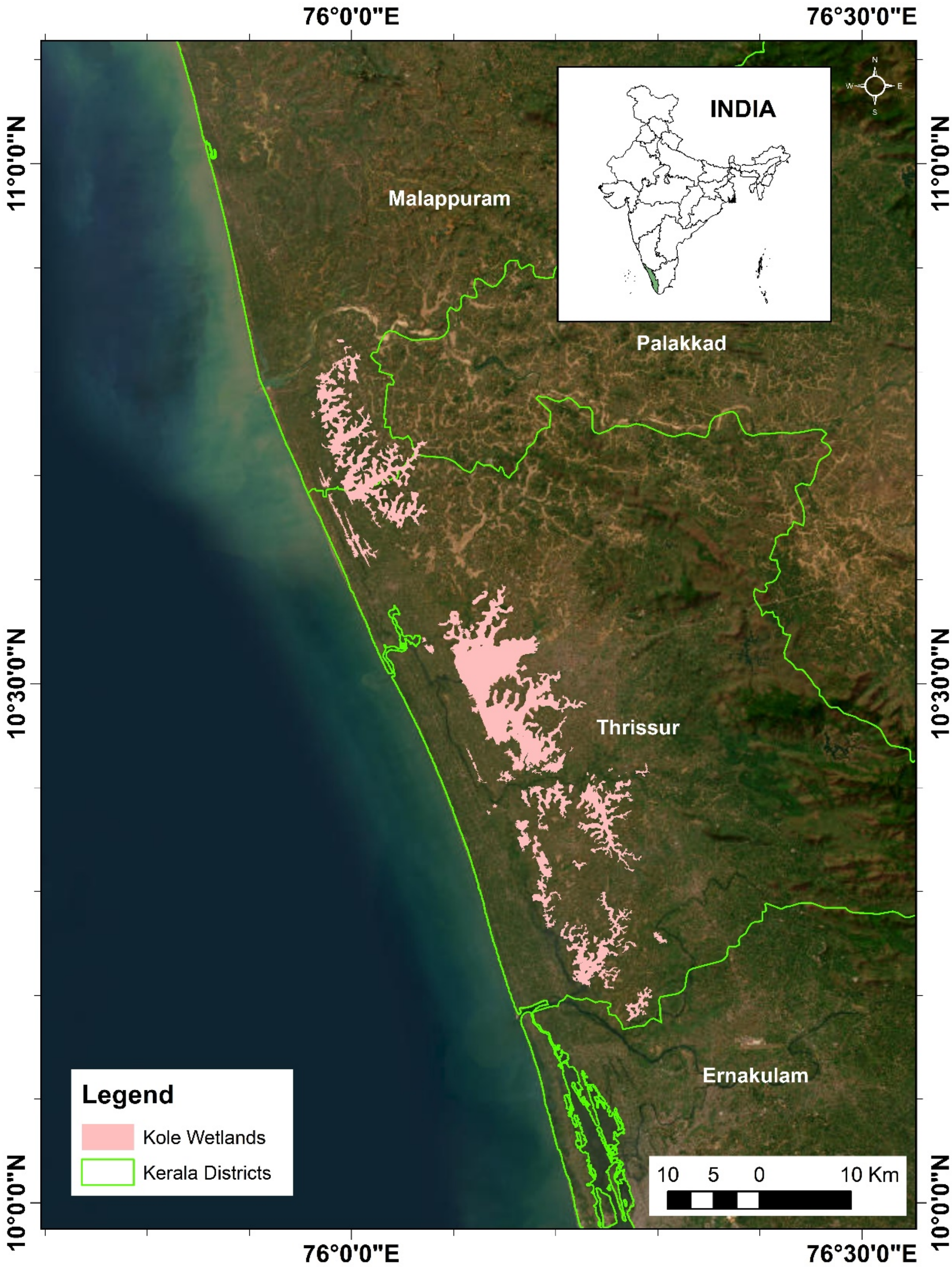


Figure 1.10: Map showing the location of Kole wetlands in Kerala.

Figure 1.11: Paddy cultivation in the Kole wetlands.

Figure 1.12: A stretch of Kole wetlands submerged under water during the southwest monsoon.

1.13. Odonates and wetlands

Odonates are closely associated with wetland ecosystems due to their life cycle, which requires both aquatic and terrestrial habitats. The combination of an aquatic larval stage and an aerial/a terrestrial adult stage makes odonates semiaquatic insects. Wetlands which are interfaces of terrestrial and aquatic ecosystems offer odonates conducive habitat for foraging, resting and reproduction. Odonates play important roles in wetland ecosystems as both predators and prey. As larvae, they control populations of aquatic insects, and as adults, they are important predators of small flying insects, including mosquitoes. They also act as prey for birds, amphibians, and insects. Numerous odonate species can be found in wetlands, and they are all suited to various environmental factors like water flow, pH, and vegetation. Since odonates are sensitive to changes in habitat type, water quality, and the presence of contaminants, they are frequently employed as bioindicators in wetland conservation. Odonates face a serious threat from the worldwide loss of wetland environments. Wetland loss as a result of agricultural drainage, urbanization, pollution, and climate change has an impact on odonate diversity worldwide. Odonates are frequently the focus of ecological restoration initiatives meant to preserve and rebuild these ecosystems as part of wetland conservation.

The Kole wetlands are celebrated as a biodiversity hotspot. It is best renowned for the avian life it supports during the winter months, when thousands of transcontinental migrants arrive. However, there has been no concerted effort to document the odonate diversity of this significant environment. The paucity of data on this group of animals, which can be easily examined to determine the health of the wetland ecosystem, is a critical gap that must be filled.

1.14. Studies on Odonata

The study of Odonata, formally known as odonatology, has a long history extending back to the 18th century. Carl Linnaeus's foundational work "Systema Naturae" (1758) documented several species of Odonata, which were then classified as Neuroptera, providing the groundwork for contemporary odonatology. Johann Christian Fabricius, Linnaeus' student, made additional contributions to odonate taxonomy in his writings "Systema Entomologiae" (1775) and established the Order

Odonata. In the nineteenth century, the Belgian aristocrat Baron Edmond de Selys Longchamps and the German entomologist Hermann August Hagen collaborated to describe several species from around the world, primarily utilizing specimens provided to them by collectors (Trueman and Rowe, 2009). During the early twentieth century, Philip Powell Calvert made significant contributions to the study of Neotropical Odonata, publishing multiple studies and a monograph (Garrison et al. 2006). Robin John Tillyard, another pioneering figure in early twentieth-century odonatology, wrote "The Biology of Dragonflies" (1917), which included aspects of odonate anatomy, physiology, behaviour, and ecology. He made significant advances to the understanding of Odonata wing venation and its evolutionary relevance. Tillyard also did pioneering studies on fossil Odonata, helping to understand their evolutionary history. Philip S. Corbet's "A Biology of Dragonflies" (1962) and its subsequent edition "Dragonflies: Behaviour and Ecology of Odonata" (1999) synthesized a great deal of information on the biology and ecology of Odonata and became seminal texts in the field of odonatology in the second half of the 20th century.

In odonatology, the 1990s were a pivotal decade that saw the emergence of molecular techniques, the blending of ecological and evolutionary viewpoints, and developments in conservation biology. McPeek (1990) advanced our knowledge of Odonata life cycle strategies by investigating habitat selection and its effects on damselfly reproductive success. The significance of taking into account the full life cycle in ecological research was highlighted by Fincke's (1992) investigation of the effects of larval ecology on adult fitness and population structure in damselflies. In their 1992 review of Odonata reproductive behavior, Conrad and Pritchard shed light on sexual selection and the development of mating systems. By using DNA fingerprinting techniques to investigate dragonfly paternity, Hadrys et al. (1992) created new opportunities to examine Odonata mating systems. By examining how temperature affects dragonfly larvae's growth and development, Rowe (1992) shed light on the possible effects of climate change on Odonata life cycles. Fincke (1997) summarized studies on sexual selection and mating behavior in order to assess female partner choice in Odonata. The impact of insecticides on non-target Odonata in South Africa was examined by Clark and Samways (1996), underscoring the significance of taking dragonflies into account when developing pest management plans. The groundwork for subsequent conservation initiatives was laid by Moore's (1997) publication of "Dragonflies: Status Survey and Conservation Action Plan," one of the first thorough evaluations of the conservation status of Odonata worldwide. As part of the Species Survival Commission's action plan series, the IUCN (International Union for Conservation of Nature) released this document. It was among the first worldwide evaluations with a conservation focus on Odonata. According to this study, a large number of Odonata species were seriously threatened, mostly as a result of habitat degradation and loss. There were many endangered species in some areas, like islands and tropical woods. Many species had insufficient data, highlighting the need for additional study.

Owing to their intricate life cycles that span both aquatic and terrestrial settings, as well as their particular habitat needs, odonates are regarded as good bioindicators (Corbet, 1999). They are useful markers of ecosystem health because of their sensitivity to changes in habitat structure, water quality, and landscape composition (Clausnitzer et al., 2009). Over the past 20 years, a number of indices that use odonate occurrence to evaluate ecosystem health have been proposed. Adult Odonata assemblages were used by Simaika and Samways (2009) to create the Dragonfly Biotic Index (DBI), which evaluates habitat quality and conservation importance. This index has been used in a number of locations and has shown promise in setting conservation priorities. Chovanec et al. (2015) assessed the effectiveness of river restoration initiatives in Austria using the Odonata Habitat Index, which was created by Chovanec and Waringer (2001). In order to determine the conservation value of sites based on Odonata diversity and rarity, Harabiš and Dolný (2012) created the Odonate Diversity Index (ODI) in the Czech Republic. Kutcher and Bried (2014) developed the Odonata Index of Wetland Integrity (OIWI) for freshwater wetlands in the northeastern United States. It uses adult Odonata occurrence data to calculate an index of wetland condition. These Odonata-specific indices offer several advantages- Odonata are sensitive to various environmental factors, making these indices effective for detecting subtle ecosystem changes. Many of these indices can assess both aquatic and terrestrial habitats due to the dual nature of odonate life cycle. Adult Odonata are relatively easy to identify compared to many other aquatic invertebrates, making these indices accessible for rapid bioassessment. However, these indices have the following limitations too- Odonata communities can vary seasonally, which may affect index scores if not accounted for in sampling design. Also, some habitats may naturally support fewer Odonata species, potentially leading to lower index scores that don't necessarily reflect poor ecological condition. While easier than many invertebrates, accurate species identification of Odonata still requires expertise, especially for larval stages. Despite these challenges, habitat quality indices using odonates can still be developed and used for rapid assessment of environmental quality.

Wetlands are crucial habitats for many Odonata species, serving as breeding grounds and supporting diverse communities. Samways and Simaika (2016) used the Dragonfly Biotic Index to assess wetland health across South Africa, emphasizing the conservation value of different wetland types. Raebel et al. (2012) investigated Odonata communities in UK farm ponds, highlighting the importance of these small water bodies for regional biodiversity. Bried and Mazzacano (2010) examined the conservation status of northeastern U.S. Odonata, emphasizing the importance of wetland protection for rare species. In their 2015 study, Bried et al. examined Odonata communities in coastal plain wetlands in the southeast United States, establishing a relationship between vegetation structure, hydroperiod, and species composition. The recovery of Odonata communities after wetland restoration in Japan was studied by Kadoya et al. (2011).

India has a rich Odonata biodiversity because of its varied terrain and climatic zones. India has a long history of studying odonata, and in recent years, there have been notable advancements. During the time of British colonization, the groundwork for Indian odonatology was established. With an emphasis on South Indian fauna, Frank Fortescue Laidlaw (1916–1922) made important contributions to the taxonomy of Indian odonata. The first thorough description of Indian Odonata was found in Frederic Charles Fraser's three-volume work "Fauna of British India: Odonata" (1933–1936), which included descriptions of 536 species from the Indian subcontinent. There was a hiatus in Indian odonatology following the British era. In a few decades, the Zoological Survey of India's scientists brought Odonata research back to life. Kumar (1973), who described multiple species and offered identification keys, made important contributions to the study of Odonata larvae. In "Studies on the Odonata fauna of Meghalaya," published in 1987, Lahiri gave a thorough description of the dragonflies and damselflies that inhabit this northeastern state. A thorough checklist of Indian Odonata was created by ZSI scientists Prasad and Varshney (1995), and it was used as a standard reference for many years. Subramanian (2010) oversaw the evaluation of various Indian Odonata species for the IUCN Red List, contributing vital information for their conservation. Mitra (2013) wrote the "Fauna of Karnataka" series' volume on Odonata, which includes thorough descriptions of the state's species. 176 endemic species of Odonata were reported by Subramanian and Babu (2013), accounting for roughly 40% of the country's then-known Odonata biodiversity. The 2018 publication of the "Odonata Atlas of the Western Ghats" is a seminal work in Indian odonatology. Written by K.A. Subramanian, K.G. Emiliyamma, R. Babu, C. Radhakrishnan, and S.S. Talmale, this thorough atlas offers in-depth details on the ecology, diversity, and distribution of Odonata in this ecologically vital area.

Over the last decade, there has been a substantial surge in Odonata study in India, with several studies concentrating on diversity, ecology, and conservation. Kulkarni and Subramanian (2013) investigated habitat usage by Odonata in Pune's urban landscape and discovered a positive correlation between species richness and aquatic vegetation cover. Koparde et al. (2014) investigated Odonata diversity across various forest types in the northern Western Ghats, discovering more diversity in moist deciduous forests. A revised checklist for Nagaland was presented by Joshi and Kunte (2014), who included a number of new state records. In recent years, a number of new species have been found in India, including several from the Western Ghats (Subramanian et al., 2013; Rangnekar et al., 2019; Joshi et al., 2020; Bhakare et al., 2021; Joshi et al., 2022; Payra et al., 2023; Chandran et al., 2024), Northeast India (Dawn, 2021; Joshi et al., 2024), and the west coastal region (Joshi and Sawant, 2019; Joshi and Sawant, 2020; Emiliyamma et al., 2020). Nonetheless, India lacks comprehensive, targeted research on the ecology of odonates in a given area.

Kerala has been a major focus of odonatological research in India because of its varied landscape, which includes the Western Ghats, coastal regions, and several wetlands. A thorough inventory of Odonata in Kerala was published by Emiliyamma et al. (2007), listing 151 species. The odonates observed on the campus of Kerala Agricultural University were recorded by Adarsh et al. (2014). Adarsh et al. (2015) documented 44 species and emphasized the significance of riparian habitats in their study of the variety and distribution of Odonata in Chinnar Wildlife Sanctuary. Odonates of Kerala's protected areas were documented in a number of studies conducted by the Zoological Survey of India's scientists (Emiliyamma and Radhakrishnan, 2000; Palot and Emilliyamma, 2015; Palot and Kiran, 2016). Gopalan et al. (2022) followed Kiran and Raju (2011) in revising the Kerala odonates checklist. In Kerala, efforts were also conducted to understand the seasonality and diversity of odonates at the Panchayat level (Arunima and Nameer, 2021; Chandran and Chandran, 2021).

Johnkutty and Venugopal (1993) conducted a thorough investigation that documented the Kole wetlands' physical characteristics and cropping patterns. An economic analysis of paddy cultivation in these wetlands was conducted by Sreenivasan (2012). Jayson (2002) conducted a study on the ecology and diversity of birds in the Kole wetlands. Sreehari (2011) studied the herpetofauna of these wetlands, while Sarath et al. (2017) documented butterflies. The odonate fauna of this internationally significant wetland has not been published ahead of this current study.

1.15. Relevance of the current study

Despite providing important services to humankind, wetlands around the globe are imperilled by multiple anthropogenic pressures. Odonates, which depend on these wetlands for completing their life cycle, have been found to be effective indicators of environmental change. They also occupy a significant position in the wetland food web. Although taxonomic studies on Indian Odonata were revived by researchers in the latter half of the twentieth century, their diversity remains undocumented in many habitats, including in wetlands. Even though they form the most affected life stage due to changes in water quality, the larvae of a majority of Indian species remain undescribed. The Kole wetlands in central Kerala is rich in biodiversity, but even a species inventory of odonates was unavailable for this habitat. Water in these wetlands is blended with a variety of chemicals that enter this ecosystem by means of runoff, fertilizer application, pesticide spray and waste dumping. Studying the response of odonate larvae to various water quality parameters could help in identifying indicator species for assessing the health of this freshwater ecosystem.

1.16. Objectives

1. To assess the diversity of odonates in Kole wetlands by sampling adults and exuviae.
2. To make a comparative assessment of Odonata diversity in Kole wetlands and adjacent ponds.
3. To study the ecology of odonate larvae in Kole wetlands.
4. To taxonomically describe hitherto unknown life stages of odonates from Kole wetlands.

1.17. General methodology

This was mostly an observation-based study and collections were made only when specimens had to be observed or dissected under a microscope for identification/description. Long-term study sites were fixed considering the spatial coverage of the wetlands and accessibility in all seasons. These were supplemented with random visits to multiple sites to maximise the detection of adult odonates. A pair of Pentax Papilio II 8.5 x 21 close focusing binoculars were used for observing adult odonates in the field and a Sony a7-III camera fitted with a Tamron 150-500 mm lens was used for photo documentation. Fixed-width belt transects were used for monitoring adult odonates in the wetlands across two years. Visual Encounter Surveys were used to compare the adult Odonata diversity between the wetlands and adjacent ponds. An aerial net was used for catching flying adults when identification was difficult. In most cases, they were released back shortly after closer examination. The adults were carried back to the laboratory only when they had to be described. Quadrat sampling was used for monitoring larvae, where they were collected using an aquatic D-net. The collected specimens were studied under a stereomicroscope (Labomed Luxeo 6Z).

Weather parameters used in the study were obtained from from the weather station closest to the Kole wetlands at Kerala Agricultural University, Vellanikkara, Thrissur. Most water quality parameters were measured in the field itself using a multiparameter water quality analyser (Deluxe Model 191 E). Water samples were carried back to the laboratory for remainder analysis. Pesticide residue analysis was done in the Pesticide Residue Analysis Laboratory of Kerala Agricultural University, Vellanikkara, Thrissur. For making maps, the free and open-source software, Quantum GIS (QGIS) v 3.22.14 was used and for data analysis, another free and open-source software, R v 4.3.3 was used.

1.18. Organisation of the thesis

This thesis is organised into six chapters. This first chapter is an introductory one, giving a succinct account of odonates, their life cycle and their significance in the ecosystem. It also discusses what are wetlands, how they support biodiversity including that of odonates, their role in sustaining human activities and the importance of conserving them. This is followed by a review of relevant studies, scope of this study and study objectives. Finally, a broad picture of the general methodology of the present study is also given.

The second chapter presents a comprehensive study of odonate diversity in the Kole wetlands by monitoring adults and exuviae. This study was done in four different seasons, across two years. Besides giving an exhaustive list of species seen in this wetland ecosystem, this chapter also gives insights into the seasonality shown by the odonates, how they are affected by the weather parameters and the dominant aquatic vegetation type. In the third chapter, a comparative assessment of odonate diversity is made between wetlands and adjacent ponds. This was a rapid assessment carried out in the four monsoon months when adult odonate diversity was at its peak. Water quality parameters between the two habitat types were compared to see if they were significantly different and how they influenced odonate diversity.

The fourth chapter deals with the ecology of Odonata larvae. Odonate larval diversity of the Kole wetlands was monitored across four seasons. The effects of macrophytes, water quality and soil parameters, including that of pesticide residue on odonate larval diversity were studied in detail. The fifth chapter is taxonomic in character, where the first descriptions of hitherto unknown life stages of odonates are given from the Kole wetlands. This includes one adult male description and two larval descriptions.

In the final sixth chapter, recommendations for the conservation of biodiversity of Kole wetlands are given along with suggestions for future research.

1.19. References

Adarsh, C. K., Aneesh, K. S., & Nameer, P. O. (2014). A preliminary checklist of odonates in Kerala Agricultural University (KAU) campus, Thrissur District, Kerala, southern India. *Journal of Threatened Taxa, 6*(8), 6127–6137. https://doi.org/10.11609/JoTT.o3491.6127-37

Adarsh, C. K., Arunraj, R., & Nameer, P. O. (2015). Odonata (Insecta) diversity of Chinnar Wildlife Sanctuary, the southern Western Ghats, India. *Journal of Threatened Taxa, 7*(2), 6910–6919. https://doi.org/10.11609/JoTT.o3771.6910-9

Arunima, J., & Nameer, P. O. (2021). A preliminary checklist of dragonflies and damselflies (Insecta: Odonata) of Vakkom Grama Panchayath, Thiruvananthapuram District, Kerala, India. *Journal of Threatened Taxa, 13*(8), 19125–19136. https://doi.org/10.11609/jott.7311.13.8.19125-19136

Bhakare, S. D., Nair, V. P., Pawar, P. A., Bhoite, S. H., & Sadasivan, K. (2021). Two new species of *Euphaea* Selys, 1840 (Odonata: Zygoptera: Euphaeidae) from northern Western Ghats, India. *Journal of Threatened Taxa, 13*(5), 18200–18214. https://doi.org/10.11609/jott.6579.13.5.18200-18214

Bried, J. T., & Mazzacano, C. A. (2010). National review of state wildlife action plans for Odonata species of greatest conservation need. *Insect Conservation and Diversity, 3*(2), 61–71. https://doi.org/10.1111/j.1752-4598.2009.00069.x

Bried, J. T., D'Amico, F. J., & Darner, R. A. (2015). Odonata (Dragonflies and Damselflies) communities in coastal plain wetlands of the southeastern United States: Species composition in relation to hydroperiod and vegetation structure. *Wetlands, 35*(4), 713–722. https://doi.org/10.1007/s13157-015-0667-2

Chandran, A. V., Chandran, R., Suraj, S. R., Jose, S. K., & Koparde, P. (2024). *Phylloneura rupestris* sp. n. (Odonata: Platycnemididae) from the Western Ghats, India, with notes on its reproductive behaviour. *International Journal of Odonatology, 27*(1), 26–36. https://doi.org/10.48156/1388.2024.1917259

Chandran, R., & Chandran, A. V. (2021). Dragonflies and damselflies (Insecta: Odonata) of Aryanad Grama Panchayat, Kerala, India. *Journal of Threatened Taxa, 13*(14), 20153–20166. https://doi.org/10.11609/jott.7342.13.14.20153-20166

Chovanec, A., & Waringer, J. (2001). Ecological integrity of river-floodplain systems—assessment by dragonfly surveys (Insecta: Odonata). *Regulated Rivers: Research & Management, 17*(4-5), 493–507. https://doi.org/10.1002/rrr.652

Chovanec, A., Waringer, J., Straif, M., Raab, R., & Wimmer, R. (2015). The dragonfly association index (DAI) for the ecological assessment of riverine landscapes. *Ecological Indicators, 57*, 1–11. https://doi.org/10.1016/j.ecolind.2015.04.029

Clark, T. E., & Samways, M. J. (1996). Dragonflies (Odonata) as indicators of biotope quality in the Kruger National Park, South Africa. *Journal of Applied Ecology, 33*(5), 1001–1012. https://doi.org/10.2307/2404688

Clausnitzer, V., Kalkman, V. J., Ram, M., Collen, B., Baillie, J. E. M., Bedjanič, M., Darwall, W. R. T., Dijkstra, K.-D. B., Dow, R., Hawking, J., Karube, H., Malikova, E., Paulson, D., Schütte, K., Suhling, F., Villanueva, R. J., von Ellenrieder, N., & Wilson, K. (2009). Odonata enter the biodiversity crisis debate: The first global assessment of an insect group. *Biological Conservation, 142*(8), 1864–1869. https://doi.org/10.1016/j.biocon.2009.03.028

Conrad, K. F., & Pritchard, G. (1992). An ecological classification of odonate mating systems: The relative influence of natural, intersexual, and intrasexual selection on males. *Biological Journal of the Linnean Society, 45*(4), 255–269. https://doi.org/10.1111/j.1095-8312.1992.tb00644.x

Corbet, P. S. (1962). *A biology of dragonflies*. Witherby.

Corbet, P. S. (1999). *Dragonflies: Behaviour and ecology of Odonata*. Comstock Pub. Associates.

Corbet, P. S. (1999). Odonata as indicators of ecosystem health. *Advances in Odonatology,* 5, 11–27.

Dawn, P. (2021). A new species of *Cephalaeschna* Selys, 1883 (Odonata: Anisoptera: Aeshnidae) from Neora Valley National Park, West Bengal, India, with notes on *C. acanthifrons* Joshi & Kunte, 2017 and *C. viridifrons* (Fraser, 1922). *Zootaxa, 4949*(2), 371–380. https://doi.org/10.11646/zootaxa.4949.2.10

Emiliyamma, K. G., & Radhakrishnan, C. (2000). Odonata (Insecta) of Parambikulam Wildlife Sanctuary, Kerala, India. *Records of the Zoological Survey of India, 98*(1), 19-25.

Emiliyamma, K.G., Radhakrishnan, C., & Palot, M.J. (2007). *Odonata (Insecta) of Kerala*, Zoological Survey of India.

Emiliyamma, K. G., Palot, M. J., & Charesh, C. (2020). *Platylestes kirani* sp. nov. (Odonata: Zygoptera: Lestidae) from the coastal area of Kannur District, Kerala, India. *Journal of Threatened Taxa, 12*(13), 16854–16860. https://doi.org/10.11609/jott.5209.12.13.16854-16860

Fabricius, J. C. (1775). *Systema entomologiae: Sistens insectorum classes, ordines, genera, species, adiectis synonymis, locis, descriptionibus, observationibus*. Kortii.

Fincke, O. M. (1992). Consequences of larval ecology for territoriality and reproductive success of a Neotropical damselfly. *Ecology, 73*(2), 449–462. https://doi.org/10.2307/1940755

Fincke, O. M. (1997). Conflict resolution in the Odonata: Implications for understanding female mating patterns and female choice. *Biological Journal of the Linnean Society, 60*(1), 201–220. https://doi.org/10.1006/bijl.1996.0097

Fraser, F. C. (1933). *The fauna of British India, including Ceylon and Burma: Odonata, Vol. I.* Taylor and Francis.

Fraser, F. C. (1934). *The fauna of British India, including Ceylon and Burma: Odonata, Vol. II.* Taylor and Francis.

Fraser, F. C. (1936). *The fauna of British India, including Ceylon and Burma: Odonata, Vol. III.* Taylor and Francis.

Garrison, R. W., von Ellenrieder, N., & Louton, J. A. (2006). *Dragonfly genera of the New World: An illustrated and annotated key to the Anisoptera*. The Johns Hopkins University Press.

Gopalan, S. V., Sherif, M., & Chandran, A. V. (2022). A checklist of dragonflies & damselflies (Insecta: Odonata) of Kerala, India. *Journal of Threatened Taxa, 14*(2), 20654–20665. https://doi.org/10.11609/jott.7504.14.2.20654-20665

Hadrys, H., Schroth, W., Schierwater, B., Streit, B., & Tiedemann, R. (1992). Applications of DNA fingerprinting in behavioural ecology and population genetics of insects. *Experientia, 48*(2), 193–199. https://doi.org/10.1007/BF01923558

Harabiš, F., & Dolný, A. (2012). Ecological factors determining the occurrence of dragonflies in different river habitats: Implications for conservation. *Biodiversity and Conservation, 21*(2), 397–411. https://doi.org/10.1007/s10531-011-0191-2

Islam, M. Z., & Rahmani, A. R. (2004). *Important bird areas in India: Priority sites for conservation*. Indian Bird Conservation Network: Bombay Natural History Society, BirdLife International.

Islam, M. Z., & Rahmani, A. R. (2008). *Potential and existing Ramsar sites in India*. Indian Bird Conservation Network: Bombay Natural History Society, BirdLife International, and Royal Society for the Protection of Birds. Oxford University Press.

Jayson, E.A. (2002). *Ecology of Wetland Birds in the Kole Lands of Kerala*. Kerala Forest Research Institute.

Johnkutty, I., & Venugopal, V.K. (1993). *Kole Lands of Kerala*. Kerala Agricultural University.

Joshi, S., & Kunte, K. (2014). Updated checklist of Odonata (dragonflies and damselflies) of Nagaland, with five new records from Dikhu River. *Journal of Threatened Taxa, 6*(11), 6441–6450. https://doi.org/10.11609/JoTT.o3927.6441-50

Joshi, S., & Sawant, D. (2019). *Ceriagrion chromothorax* sp. nov. (Odonata: Zygoptera: Coenagrionidae) from Sindhudurg, Maharashtra, India. *Journal of Threatened Taxa, 11*(7), 13875–13885. https://doi.org/10.11609/jott.4753.11.7.13875-13885

Joshi, S., & Sawant, D. (2020). *Bradinopyga konkanensis* sp. nov. (Odonata: Anisoptera: Libellulidae) from the coastal region of Maharashtra, India. *Zootaxa, 4779*(1), 65–78. https://doi.org/10.11646/zootaxa.4779.1.4

Joshi, S., Ogale, H., Sawant, D., & Kunte, K. (2022). *Burmagomphus chaukulensis* sp. nov. (Odonata: Gomphidae) from the Western Ghats, Maharashtra, India. *Zootaxa, 5133*(3), 413–430. https://doi.org/10.11646/zootaxa.5133.3.6

Kadoya, T., Suda, S.-I., & Washitani, I. (2011). The recovery of dragonfly communities following wetland restoration: A comparison of remnant and newly established wetlands. *Biodiversity and Conservation, 20*(13), 3363–3378. https://doi.org/10.1007/s10531-011-0116-0

Kiran, C.G., & Raju, D.V. (2011). Checklist of Odonata of Kerala with their Malayalam names. *Malabar Trogon*, 9(3), 31-35.

Koparde, P., Mhaske, P., & Patwardhan, A. (2014). New records of dragonflies and damselflies (Insecta: Odonata) from the Western Ghats of Maharashtra, India. *Journal of Threatened Taxa, 6*(3), 5534–5542. https://doi.org/10.11609/JoTT.o3588.5534-42

Kulkarni, A. S., & Subramanian, K. A. (2013). Habitat and seasonal distribution of Odonata (Insecta) of Mula and Mutha river basins, Pune, Maharashtra, India. *Journal of Threatened Taxa, 5*(7), 4084–4095. https://doi.org/10.11609/JoTT.o3247.4084-95

Kumar, A. (1973). *Odonata larvae of India: A review of studies on their biology, morphology, and taxonomy*. Oriental Insects, 7(1), 83–118. https://doi.org/10.1080/00305316.1973.10434051

Kutcher, T. E., & Bried, J. T. (2014). Adult Odonata conservatism as an indicator of freshwater wetland condition. *Ecological Indicators, 38*, 31–39. https://doi.org/10.1016/j.ecolind.2013.10.025

Lahiri, A. R. (1987). *Studies on the Odonata fauna of Meghalaya*. Records of the Zoological Survey of India, Occasional Paper No. 97.

Laidlaw, F. F. (1916). *Contributions to a knowledge of the dragonfly fauna of Borneo*. Transactions of the Entomological Society of London, 64(1), 47–60.

Laidlaw, F. F. (1920). *A list of the dragonflies recorded from the Indian Empire with special reference to the collection of the Indian Museum*. Records of the Indian Museum, 19, 169–195.

Laidlaw, F. F. (1922). The dragonflies (Odonata) of the Indo-Australian archipelago. *Treubia*, 3(3), 67–86.

Linnaeus, C. (1758). *Systema naturae per regna tria naturae: Secundum classes, ordines, genera, species, cum characteribus, differentiis, synonymis, locis* [System of nature through the three kingdoms of nature: According to classes, orders, genera and species, with characters, differences, synonyms, places] (10th ed.). Laurentius Salvius.

McPeek, M. A. (1990). Behavioral differences between Enallagma species (Odonata) influencing differential vulnerability to predators. *Ecology, 71*(5), 1714–1726. https://doi.org/10.2307/1937581

Ministry of Environment and Forests. (2009). *Integrated development of wildlife habitats*. Ministry of Environment & Forests.

Mitra, T. R. (2013). *Odonata*. In *Fauna of Karnataka* (State Fauna Series 21, Part 2, pp. 141–204). Zoological Survey of India.

Moore, N. W. (1997). *Dragonflies: Status survey and conservation action plan*. IUCN/SSC Odonata Specialist Group. IUCN.

Palot, M.J., & Emiliyamma, K.G. (2015). A Checklist of Odonates of Thusharagiri falls, Kozhikode district, Kerala. *Malabar Trogon,* 13(1), 24-28.

Palot, M.J., & Kiran, C.G. (2016). Dragonfly Survey of Aralam Wildlife Sanctuary, Kannur district, Kerala. *Malabar Trogon,* 14(1-3), 44-46.

Paulson, D. R., Schorr, M., & von Ellenrieder, N. (2024). *World Odonata List*. University of Puget Sound. https://www.pugetsound.edu/academics/academic-resources/slater-museum/biodiversity-resources/dragonflies/world-odonata-list

Payra, A., Chandran, R., Deshpande, A., & Koparde, P. (2023). *Protosticta armageddonia* sp. nov. (Odonata: Zygoptera: Platystictidae) from the Western Ghats of India. *International Journal of Odonatology, 26*(2), 93–102. https://doi.org/10.48156/1388.2023.1917043

Prasad, M., & Varshney, R. K. (1995). *A check-list of the Odonata of India including data on larval studies*. Oriental Insects, 29(1), 385–428.

Raebel, E. M., Merckx, T., Riordan, P., Macdonald, D. W., & Thompson, D. J. (2012). Identifying high-quality pond habitats for Odonata in lowland England: Implications for agri-environment schemes. *Insect Conservation and Diversity, 5*(6), 422–432. https://doi.org/10.1111/j.1752-4598.2012.00177.x

Ramsar Convention Secretariat. (2024). *Ramsar Convention*. https://www.ramsar.org/

Rangnekar, P., Dharwadkar, O., Sadasivan, K., & Subramanian, K. A. (2019). *Cyclogomphus flavoannulatus* sp. nov. (Insecta: Odonata: Gomphidae) from the Western Ghats, India, with comments on the status of *Cyclogomphus* *vesiculosus* Selys, 1873. *Zootaxa, 4656*(3), 515–524. https://doi.org/10.11646/zootaxa.4656.3.8

Rowe, R. J. (1992). The influence of temperature on growth rates and on the duration of larval instars in *Xanthocnemis zealandica* (McLachlan) (Zygoptera: Coenagrionidae). *Odonatologica, 21*(2), 179–185.

Samways, M. J., & Simaika, J. P. (2016). Manual of freshwater assessment for South Africa: Dragonfly Biotic Index. *Ecological Indicators, 60*, 176–191. https://doi.org/10.1016/j.ecolind.2015.06.019

Sarath, S., Sreekumar, E. R., & Nameer, P. O. (2017). Butterflies of the Kole Wetlands, a Ramsar site in Kerala, India. *Journal of Threatened Taxa, 9*(5), 10208–10215. https://doi.org/10.11609/jott.3513.9.5.10208-10215

Simaika, J. P., & Samways, M. J. (2009). An easy-to-use index of ecological integrity for prioritizing freshwater sites and for assessing habitat quality. *Biodiversity and Conservation, 18*(5), 1171–1185. https://doi.org/10.1007/s10531-008-9486-y

Society for Odonate Studies. (2024). *List of Odonates of Kerala*. Retrieved September 24, 2024, from https://odonatesociety.org/list-of-odonates-of-kerala/

Sreehari, V. S. (2012). *Diversity and abundance of herpetofauna in Kole Wetlands, Thrissur* (Master's thesis). Kerala Agricultural University.

Srinivasan, J. T. (2012). *An economic analysis of paddy cultivation in the Kole land of Kerala*. Indian Journal of Agricultural Economics, 67(2), 214–223.

Subramanian, K. A. (2010). *IUCN Red List assessment of Indian Odonata*. IUCN Red List of Threatened Species. https://www.iucnredlist.org

Subramanian, K. A., & Babu, R. (2013). *Endemic Odonates of India*. Zoological Survey of India.

Subramanian, K. A., Rangnekar, P., & Naik, R. (2013). *Idionyx gomantakensis* sp. nov. (Odonata: Corduliidae) of the Western Ghats with a description of a new species. *Zootaxa, 3652*(2), 277–288. https://doi.org/10.11646/zootaxa.3652.2.5

Subramanian, K. A., Emiliyamma, K. G., Babu, R., Radhakrishnan, C., & Talmale, S. S. (2018). *Atlas of Odonata (Insecta) of the Western Ghats, India*. Zoological Survey of India.

Subramanian, K. A., & Babu, R. (2024). *Fauna of India Checklist: Arthropoda: Insecta: Odonata* (Version 1.0). Zoological Survey of India.

Tillyard, R. J. (1917). *The biology of dragonflies (Odonata or Paraneuroptera)*. Cambridge University Press.

Trueman, J. W. H., & Rowe, R. J. (2009). *Odonata: Dragonflies and damselflies* (Version 16 October 2009). The Tree of Life Web Project. http://tolweb.org/Odonata/8266/2009.10.16

Wetlands of India Portal. (2024). *Indian Wetlands*. https://indianwetlands.in/

Chapter 2

ODONATA DIVERSITY ASSESSMENT IN KOLE WETLANDS

2.1. Introduction

Biodiversity of insects is threatened worldwide. About 40% of the world's insect species are feared to go extinct over the next few decades with drastic effects on earth's ecosystems (Sánchez-Bayo & Wyckhuys, 2019). The decline of insects could threaten essential insect-mediated ecosystem functions and services, including nutrient cycling, soil formation, decomposition, water purification, biological pest control, pollination, and food web support. These processes are vital for ecosystem health, human well-being, and survival (van der Sluijs, 2020). It has been emphasized that documenting and monitoring insect populations over time is crucial for understanding and reversing this trend (Didham et al., 2020). Odonates provide aesthetic/spiritual benefits to humans, and control populations of disease vectors and agricultural pests. In addition, their larvae are very important as intermediate or top predators in many aquatic ecosystems. Odonates are frequently employed with success as markers for conservation management and environmental health. According to May (2019), they are also used as model organisms in ecological and evolutionary studies. It is widely acknowledged that odonate diversity depends on wetland ecosystems. In a thorough analysis of wetlands throughout Africa, Simaika and Samways (2018) reported that aquatic vegetation diversity and habitat heterogeneity were important factors influencing the abundance of odonate species. Willigalla and Fartmann (2012) observed that species richness rises along a gradient from a city's centre to the rural area, with an average of 33 odonate species per city in Central Europe. Abbott et al. (2022) developed Species Distribution Models (SDMs) and evaluated Odonata diversity across the whole Nearctic Realm, encompassing Canada, the United States of America, and Mexico. The Palaearctic Realm also had similar SDMs constructed (Kalkman et al., 2022). This study revealed distinct patterns of diversity between lotic and lentic species, with lentic species predominating in arid and colder regions. A global assessment of odonate diversity by Kalkman et al. (2008) revealed that their highest diversity occurs in flowing waters within tropical rainforests, with the Oriental and Neotropical regions being the most species-rich.

In India, scientists from the Zoological Survey of India initiated the documentation of Odonata of Protected Areas (Lahiri, 1985; Kulkarni & Prasad, 2005; Emiliyamma & Radhakrishnan, 2003, 2006, 2007) and wetlands (Palot & Soniya, 2000, 2004). These works inspired other researchers and odonate enthusiasts who documented odonates of different habitats around them. Arulprakash and Gunathilagaraj (2010) documented 21 species of odonates from temporary water bodies in Salem and Coimbatore districts of Tamil Nadu. Koli et al. (2014) found 54 species from southern Rajasthan and Rathod et al. (2016) documented 55 species from southern Gujarat. Adarsh et al. (2014) recorded 52 odonate species from Kerala Agricultural University, Vellanikkara, Thrissur, Kerala, and found no significant seasonal difference in their diversity. A total of 82 species were recorded by Varghese et al. (2014) from Thattekkad Bird Sanctuary in Kerala, many of them endemic to the Western Ghats. Bose et al. (2021) recorded the diversity and abundance of riparian odonate fauna of the midstream Chalakkudy River in central Kerala. Rodrigues et al. (2022) found a total of 66 species of odonates from 42 genera, including four species endemic to the Western Ghats from the Kattampally wetland in Kannur. Muneer at al. (2023) recorded 85 species of odonates from the Wayanad Wildlife Sanctuary and noted that the ponds were the most species-rich, but the streams supported a greater number of endemic species. Recently, researchers have also taken up studying odonates at the local body-level, which has helped in updating the People's Biodiversity Registers. Arunima and Nameer (2021) reported 49 species from Vakkom Grama Panchayat, while Chandran and Chandran (2021) documented 93 species from Aryanad Grama Panchayat in Kerala. In the latter study, species richness showed a peak during the southwest monsoon season and a dip in winter. Studies with greater spatial resolution and over longer time periods are crucial to obtaining a thorough grasp of the diversity of odonates today and any potential changes in the future.

This chapter presents a comprehensive study on the diversity of odonates (dragonflies and damselflies) in the Kole wetlands of Kerala, India. By systematically sampling adults and exuviae (shed exoskeletons) from various locations and seasons, the study sought to evaluate odonate diversity. This chapter provides valuable insights into the odonate fauna of the Kole wetland ecosystem. The results advance our knowledge of seasonal trends in odonate populations, the impact of aquatic vegetation, regional biodiversity, and the possible effects of meteorological factors on these insects.

2.2. Materials and methods

Three locations each were set up in Ponnani Kole (Biyyam, Naranipuzha, and Uppungal), Thrissur North Kole (Mulloorkayal, Kanjani, and Palakkal), and Thrissur South Kole (Thottipal, Kattur, and Thommana) in order to systematically sample adult odonates and exuviae (Figure 2.1). To study the effect of seasons on odonate diversity, a year was considered to have four seasons (Monsoon 1- May, June, July; Monsoon 2- August, September, October; Winter- November, December, January; Summer- February, March, April). Each site was visited in all four seasons. Full-width belt transect (FWBT) was used to sample adults and exuviae (Darshetkar et al., 2023; Sutherland, 2006). In each site, a transect 500 metre in length was laid at the interface of land and water using a handheld GPS unit (Garmin GPS etrex 10). The major aquatic vegetation type of each transect was noted. Of the total nine transects, two had floating-leaved (FL), three had emergent (E), two had free-floating (FF), and two had submerged (S) plants as the dominant aquatic vegetation (Table 2.1).

Sampling was done only when the weather was fair, between 9 am and 12 pm. For sampling, the observer walked along the transect at a constant pace and recorded all individual odonates seen within a distance of 5 metres on either side. Individuals difficult to identify were caught using an aerial net, examined, and released. Adult odonates were identified by referring to field guides (Subramanian, 2005, 2009) and taxonomic monographs (Fraser, 1933, 1934, 1936). While walking back after sampling adults, along the same transect, a thorough search was made for exuviae. The exuviae were identified by referring to larval keys (Subramanian, 2005) and personal collections of Prof. Prosenjit Dawn (Department of Zoology, Shyampur Siddheswari Mahavidyalay, Howrah, West Bengal).

Weather parameters, namely, rainfall (in mm), temperature (in °C), relative humidity (in %), and wind speed (in m/s) were obtained for each season from the closest weather station at Kerala Agricultural University, Vellanikkara, Thrissur. Average values were used for temperature, relative humidity, and wind speed and total values for the periods were used for rainfall.

In addition to systematic sampling, sites were visited randomly to record both adults and exuviae, ensuring maximum geographic coverage of the study area. The data was collected for two years (May 2019 to April 2021).

2.3. Data analysis

Vegan package of R v. 4.3.3 was used for the data analysis. Shannon Index (Shannon Wiener diversity index) was calculated for each transect sampling as a measure of adult Odonata diversity. This measure was used as it is widely used in ecological studies, and takes into account both species richness and evenness.

$H' = - \Sigma (p_i * \ln(p_i))$

Where:

- H' = Shannon-Wiener diversity index
- p_i = proportion of individuals or abundance of the i^{th} species
- ln = natural logarithm
- Σ = summation over all species (i = 1 to S)

Scatterplots were drawn to understand the relationship between the measured weather parameters and adult Odonata diversity, and the effect of seasons. A species accumulation curve was drawn for transects grouped according to major aquatic vegetation types.

The effect of transects, seasons, years, and the predominant aquatic vegetation type on the diversity of adult Odonata was investigated using Permutational Multivariate Analysis of Variance (PERMANOVA). Multivariate datasets can be tested for differences using this non-parametric technique. To determine whether odonate diversity varied by transects, seasons, years, and the predominant aquatic vegetation type, Bray-Curtis dissimilarity was employed as the distance measure.

Conceptual equation of PERMANOVA: $SS_{total}=SS_{between\text{-}groups}+SS_{within\text{-}groups}$

Where:

- SS_{total}: Total sum of squared distances between all samples.
- $SS_{between\text{-}groups}$: Sum of squared distances attributable to differences among groups.
- $SS_{within\text{-}groups}$: Sum of squared distances within groups (residual variation).

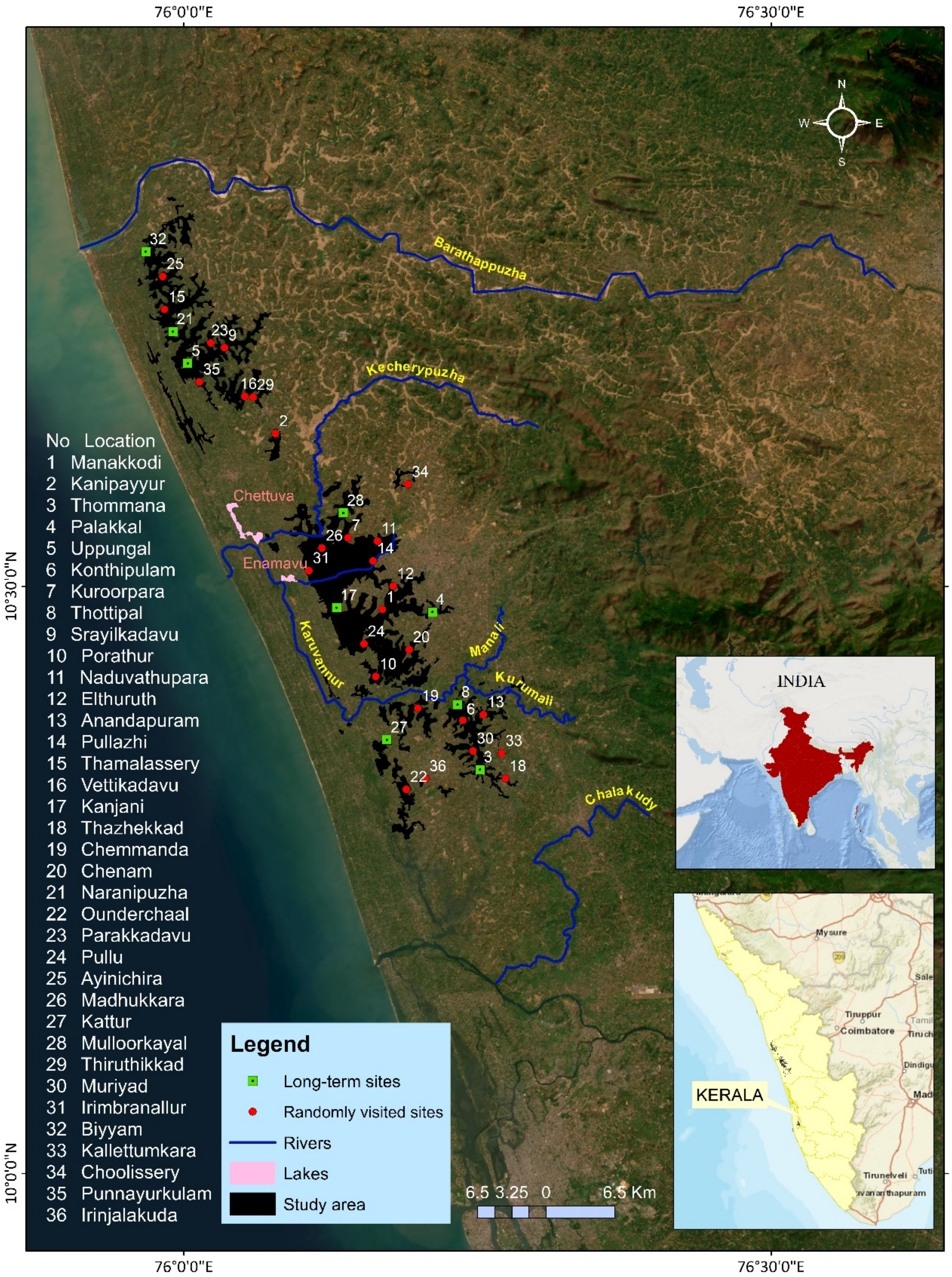


Figure 2.1: Location map of the Kole wetlands showing the sampling sites of the study.

Sl No	Site	Major aquatic vegetation	Species richness
1	Uppungal	FL	22
2	Marancherry	FL	25
3	Biyyam	E	16
4	Palakkal	FF	25
5	Kanjani	S	19
6	Mulloorkayal	S	15
7	Thommana	E	28
8	Thottipal	E	26
9	Kattur	FF	23

Table 2.1: Study sites showing major aquatic vegetation type and odonate species richness.

2.4. Results and discussion

The study identified 63 odonate species (39 species of dragonflies and 24 species of damselflies) from the Kole wetlands (Table 2.2, Figures 2.2 to 2.12). Of the recorded species, three are endemic to the Western Ghats, namely, *Platylestes kirani* Emiliyamma, Palot & Charesh, 2020, *Agriocnemis keralensis* Peters, 1981, and *Macrogomphus wynaadicus* Fraser, 1924. Two of the recorded species are endemic to India, namely, *Heliocypha bisignata* (Hagen in Selys, 1853), and *Libellago indica* (Fraser, 1928). In the IUCN Red List of Threatened Species, three of these species are Not Evaluated (NE), namely, *Platylestes kirani* Emiliyamma, Palot & Charesh, 2020, *Libellago indica* (Fraser, 1928), and *Ischnura rubilio* Selys, 1876, and two are Data Deficient (DD), *Gynacantha dravida* Lieftinck, 1960, and *Macrogomphus wynaadicus* Fraser, 1924 (IUCN, 2024).

Sl No/ Photo No	Scientific Name	English Name	Malayalam Name	IUCN	END
	Order: Odonata				
	I. Suborder: Zygoptera	**Damselflies**	**സൂചിത്തുമ്പികൾ**		
	1. Family: Lestidae	**Spreadwings**	**ചേരാച്ചിറകൻ തുമ്പികൾ**		
1	*Lestes elatus* Hagen in Selys, 1862	Emerald Spreadwing	പച്ച ചേരാച്ചിറകൻ	LC	
2	*Platylestes kirani* Emiliyamma, Palot & Charesh, 2020	Kiran's Spreadwing	കിരണി ചേരാച്ചിറകൻ	NE	EN WG
3	*Platylestes platystylus* (Rambur, 1842)	Green-eyed Spreadwing	പച്ചക്കണ്ണൻ ചേരാച്ചിറകൻ	LC	
	2. Family: Calopterygidae	**Broadwings**	**മരതകത്തുമ്പികൾ**		
4	*Vestalis apicalis* Selys, 1873	Black-tipped Forest Glory	ചുട്ടിച്ചിറകൻ തണൽത്തുമ്പി	LC	
5	*Vestalis gracilis* (Rambur, 1842)	Clear-winged Forest Glory	ചെറിയ തണൽതുമ്പി	LC	
	3. Family: Chlorocyphidae	**Stream Jewels**	**നീർരത്നങ്ങൾ**		
6	*Heliocypha bisignata* (Hagen in Selys, 1853)	Stream Ruby	നീർമാണിക്യൻ	LC	EN IND
7	*Libellago indica* (Fraser, 1928)	Southern Heliodor	തവളക്കണ്ണൻതുമ്പി	NE	EN IND
	4. Family: Platycnemididae	**Whitelegs**	**പാൽത്തുമ്പികൾ**		
8	*Copera marginipes* (Rambur, 1842)	Yellow Bush Dart	മഞ്ഞക്കാലി പാൽത്തുമ്പി	LC	
9	*Copera vittata* (Selys, 1863)	Blue Bush Dart	ചെങ്കാലി പാൽത്തുമ്പി	LC	
	5. Family: Coenagrionidae	**Narrowwings**	**നിലത്തന്മാർ**		
10	*Aciagrion occidentale* Laidlaw, 1919	Green-striped Slender Dartlet	നീലച്ചുട്ടി	LC	
11	*Agriocnemis keralensis* Peters, 1981	Kerala Dartlet	പത്തി പുൽച്ചിന്നൻ	LC	EN WG
12	*Agriocnemis pieris* Laidlaw, 1919	White Dartlet	വെള്ളപ്പുൽച്ചിന്നൻ	LC	
13	*Agriocnemis pygmaea* (Rambur, 1842)	Pygmy Dartlet	നാട്ടുപുൽച്ചിന്നൻ	LC	
14	*Archibasis oscillans* (Selys,	Blue-banded	അരുവിത്തുമ്പി	LC	

	1877)	Longtail			
15	*Ceriagrion cerinorubellum* (Brauer, 1865)	Orange-tailed Marsh Dart	കനൽവാലൻ ചതുപ്പൻ	LC	
16	*Ceriagrion coromandelianum* (Fabricius, 1798)	Coromandel Marsh Dart	നാട്ടുചതുപ്പൻ	LC	
17	*Ischnura rubilio* Selys, 1876	Western Golden Dartlet	മഞ്ഞപ്പുൽമാണിക്യൻ	NE	
18	*Ischnura senegalensis* (Rambur, 1842)	Senegal Golden Dartlet	നീല പുൽമാണിക്യൻ	LC	
19	*Paracercion calamorum* (Ris, 1916)	Dusky Lily-squatter	ചുട്ടിവാലൻ താമരത്തുമ്പി	LC	
20	*Pseudagrion australasiae* Selys, 1876	Short-tipped Grass Dart	കുറുവാലൻ പൂത്താലി	LC	
21	*Pseudagrion decorum* (Rambur, 1842)	Green-striped Grass Dart	ഇളനീലി പൂത്താലി	LC	
22	*Pseudagrion malabaricum* Fraser, 1924	Jungle Grass Dart	കാട്ടുപൂത്താലി	LC	
23	*Pseudagrion microcephalum* (Rambur, 1842)	Blue Grass Dart	നാട്ടുപൂത്താലി	LC	
24	*Pseudagrion rubriceps* Selys, 1876	Saffron-faced Grass Dart	ചെമ്മുഖപ്പൂത്താലി	LC	
	II. Suborder: Anisoptera	**Dragonflies**	**കല്ലൻത്തുമ്പികൾ**		
	6. Family: Aeshnidae	**Darners**	**സൂചിവാലൻ കല്ലൻത്തുമ്പികൾ**		
25	*Anax ephippiger* (Burmeister, 1839)	Vagrant Emperor	തുരുമ്പൻ ചാത്തൻ	LC	
26	*Anax guttatus* (Burmeister, 1839)	Pale-spotted Emperor	മരതകരാജൻ	LC	
27	*Anax indicus* Lieftinck, 1942	Lesser Green Emperor	പീതാംബരൻതുമ്പി	LC	
28	*Gynacantha dravida* Lieftinck, 1960	Brown Darner	സൂചിവാലൻ രാക്കൊതിച്ചി	DD	
	7. Family: Gomphidae	**Clubtails**	**കടുവാത്തുമ്പികൾ**		
29	*Ictinogomphus rapax* (Rambur, 1842)	Indian Common Clubtail	നാട്ടുകടുവ	LC	
30	*Macrogomphus wynaadicus* Fraser, 1924	Wayanad Bowtail	വയനാടൻ കടുവ	DD	EN WG
31	*Paragomphus lineatus* (Selys, 1850)	Common Hooktail	ചൂണ്ടവാലൻ കടുവ	LC	
	8. Family: Macromiidae	**Cruisers**	**നീർക്കാവലൻമാർ**		

32	*Epophthalmia vittata* Burmeister, 1839	Common Torrent hawk	നാട്ടു നീർക്കാവലൻ	LC	
	9. Family: Corduliidae	**Emeralds**	**മരതകക്കണ്ണന്മാർ**		
33	*Hemicordulia asiatica* Selys, 1878	Asian Emerald	കാട്ടു മരതകൻ	LC	
	10. Family: Libellulidae	**Skimmers**	**നീർമുത്തന്മാർ**		
34	*Acisoma panorpoides* Rambur, 1842	Trumpet Tail	മകുടിവാലൻ	LC	
35	*Aethriamanta brevipennis* (Rambur, 1842)	Scarlet Marsh Hawk	ചോപ്പൻ കുറുവാലൻ	LC	
36	*Brachydiplax chalybea* Brauer, 1868	Rufous-backed Marsh Hawk	തവിട്ടുവെണ്ണിറൻ	LC	
37	*Brachydiplax sobrina* (Rambur, 1842)	Little Blue Marsh Hawk	ചെറുവെണ്ണീറൻ	LC	
38	*Brachythemis contaminata* (Fabricius, 1793)	Ditch Jewel	ചങ്ങാതിത്തുമ്പി	LC	
39	*Bradinopyga geminata* (Rambur, 1842)	Grainte Ghost	മതിൽത്തുമ്പി	LC	
40	*Cratilla lineata* (Brauer, 1878)	Emerald-banded Skimmer	കാട്ടുപതുങ്ങൻ	LC	
41	*Crocothemis servilia* (Drury, 1773)	Ruddy Marsh Skimmer	വയൽത്തുമ്പി	LC	
42	*Diplacodes nebulosa* (Fabricius, 1793)	Black-tipped Ground Skimmer	ചുട്ടിനിലത്തൻ	LC	
43	*Diplacodes trivialis* (Rambur, 1842)	Blue Ground Skimmer	നാട്ടുനിലത്തൻ	LC	
44	*Hydrobasileus croceus* (Brauer, 1867)	Amber-winged Marsh Glider	പാണ്ടൻ പരുന്തൻ	LC	
45	*Lathrecista asiatica* (Fabricius, 1798)	Asiatic Bloodtail	ചോരവാലൻതുമ്പി	LC	
46	*Neurothemis fulvia* (Drury, 1773)	Fulvous Forest Skimmer	തുരുമ്പൻതുമ്പി	LC	
47	*Neurothemis tullia* (Drury, 1773)	Pied Paddy Skimmer	സ്വാമിത്തുമ്പി	LC	
48	*Orthetrum chrysis* (Selys, 1891)	Brown-backed Red Marsh Hawk	ചെന്തവിടൻ വ്യാളി	LC	
49	*Orthetrum pruinosum* (Burmeister, 1839)	Crimson-tailed Marsh Hawk	പവിഴവാലൻ വ്യാളി	LC	
50	*Orthetrum sabina* (Drury, 1770)	Green Marsh Hawk	പച്ചവ്യാളി	LC	

51	*Pantala flavescens* (Fabricius, 1798)	Wandering Glider	തുലാത്തുമ്പി	LC	
52	*Potamarcha congener* (Rambur, 1842)	Yellow-tailed Ashy Skimmer	പുള്ളിവാലൻതുമ്പി	LC	
53	*Rhodothemis rufa* (Rambur, 1842)	Rufous Marsh Glider	ചെമ്പൻതുമ്പി	LC	
54	*Rhyothemis variegata* (Linnaeus, 1763)	Common Picturewing	ഓണത്തുമ്പി	LC	
55	*Tetrathemis platyptera* Selys, 1878	Pygmy Skimmer	കുള്ളൻതുമ്പി	LC	
56	*Tholymis tillarga* (Fabricius, 1798)	Coral-tailed Cloudwing	പവിഴവാലൻ	LC	
57	*Tramea basilaris* (Palisot de Beauvois, 1817)	Red Marsh Trotter	ചെമ്പൻ പരുന്തൻ	LC	
58	*Tramea limbata* (Desjardins, 1832)	Black Marsh Trotter	കരിമ്പൻ പരുന്തൻ	LC	
59	*Trithemis aurora* (Burmeister, 1839)	Crimson Marsh Glider	സിന്ദൂരത്തുമ്പി	LC	
60	*Trithemis festiva* (Rambur, 1842)	Black Stream Glider	കാർത്തുമ്പി	LC	
61	*Trithemis pallidinervis* (Kirby, 1889)	Long-legged Marsh Glider	കാറ്റാടിത്തുമ്പി	LC	
62	*Urothemis signata* (Rambur, 1842)	Greater Crimson Glider	പാണ്ടൻ വയൽതെയ്യൻ	LC	
63	*Zyxomma petiolatum* Rambur, 1842	Brown Dusk Hawk	സൂചിവാലൻ സന്ധ്യാത്തുമ്പി	LC	

Table 2.2: Odonata species recorded in the study from Kole wetlands. IUCN Red List status: LC- Least Concern, DD- Data Deficient, NE- Not Evaluated; Endemicity: EN WG- Endemic to the Western Ghats, EN IND- Endemic to India.

Figure 2.2: Odonate species photographed from Kole wetlands (numbered as per table 2.2)

Figure 2.3: Odonate species photographed from Kole wetlands (continued)

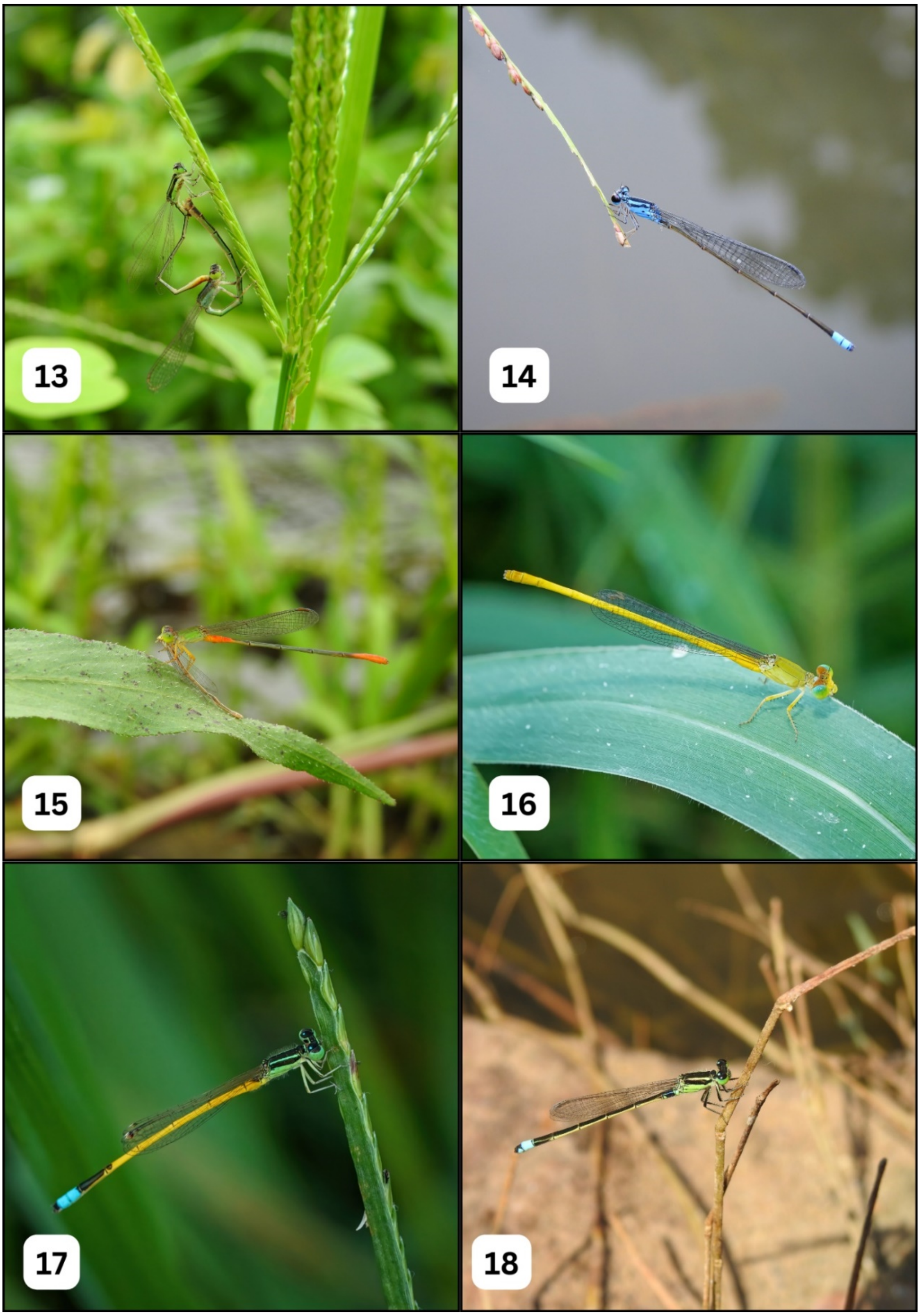


Figure 2.4: Odonate species photographed from Kole wetlands (continued)

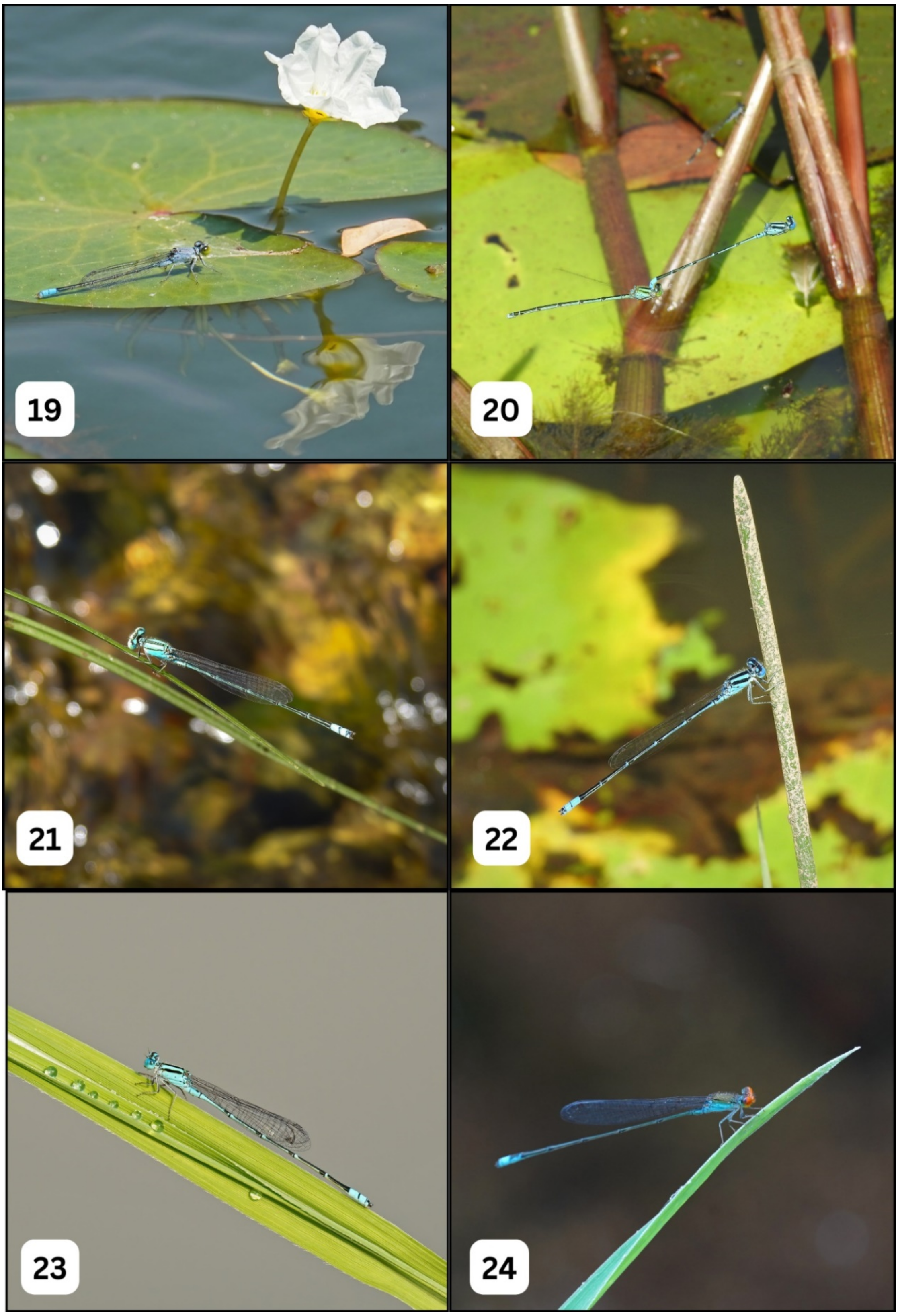


Figure 2.5: Odonate species photographed from Kole wetlands (continued)

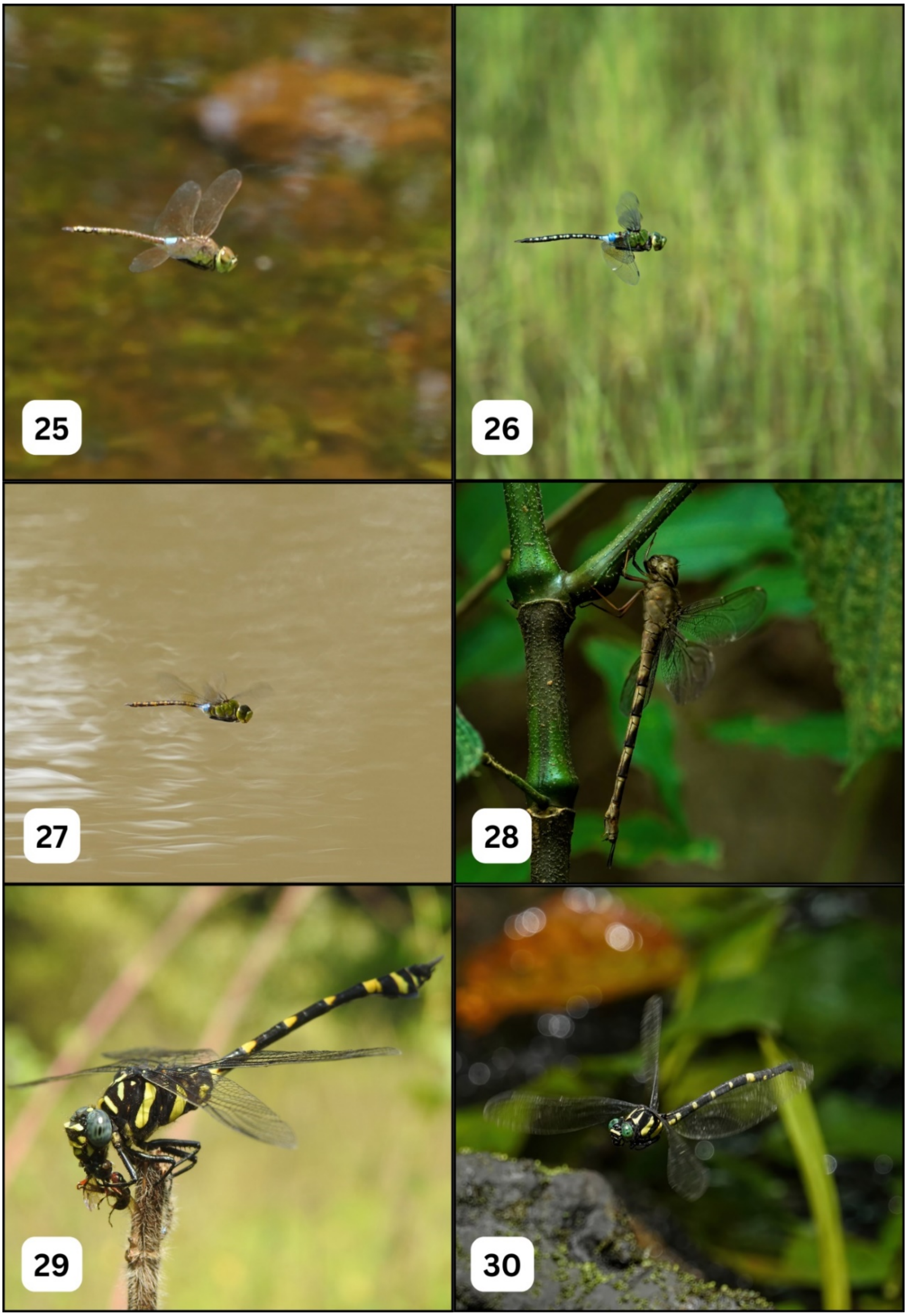


Figure 2.6: Odonate species photographed from Kole wetlands (continued)

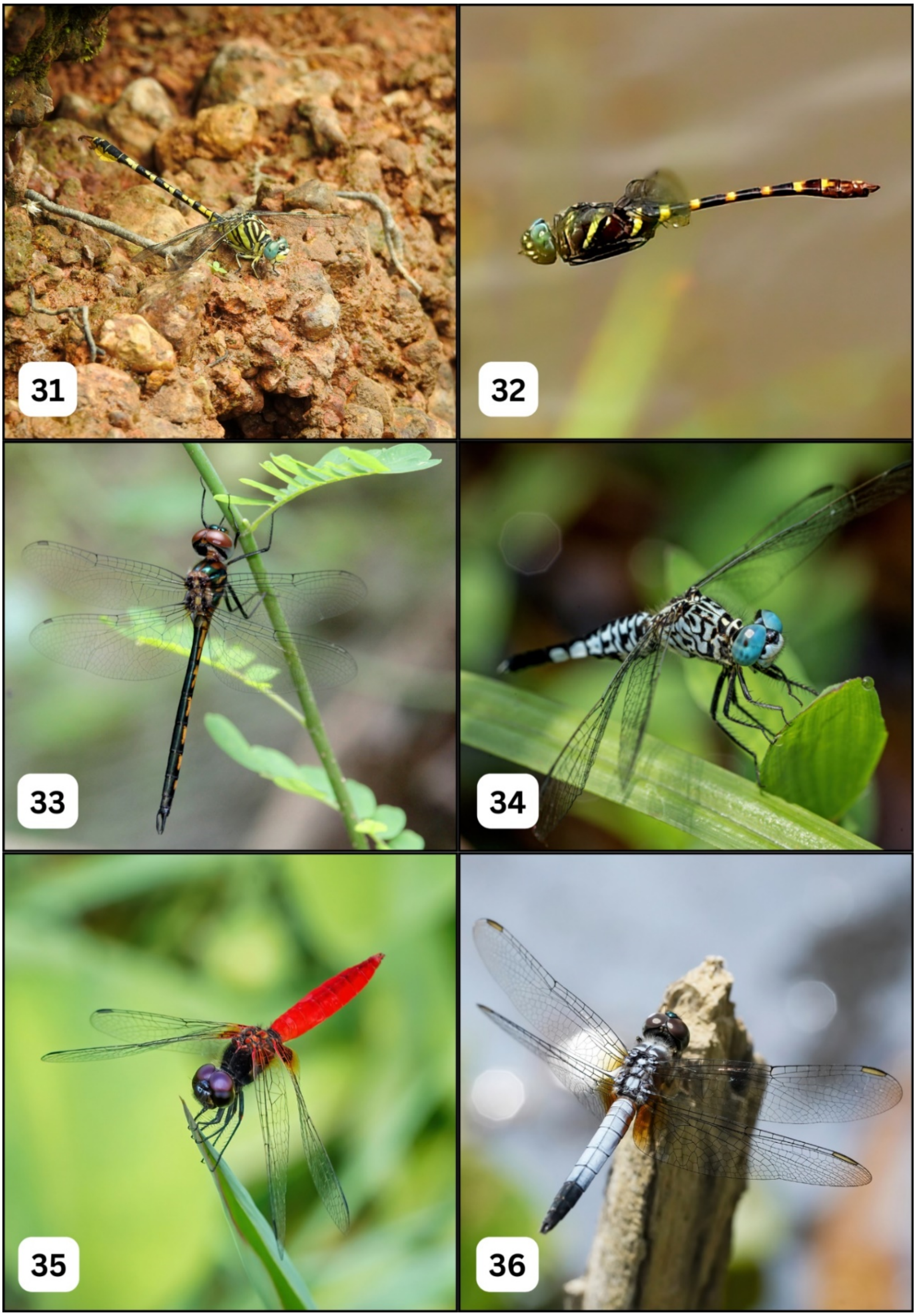


Figure 2.7: Odonate species photographed from Kole wetlands (continued)

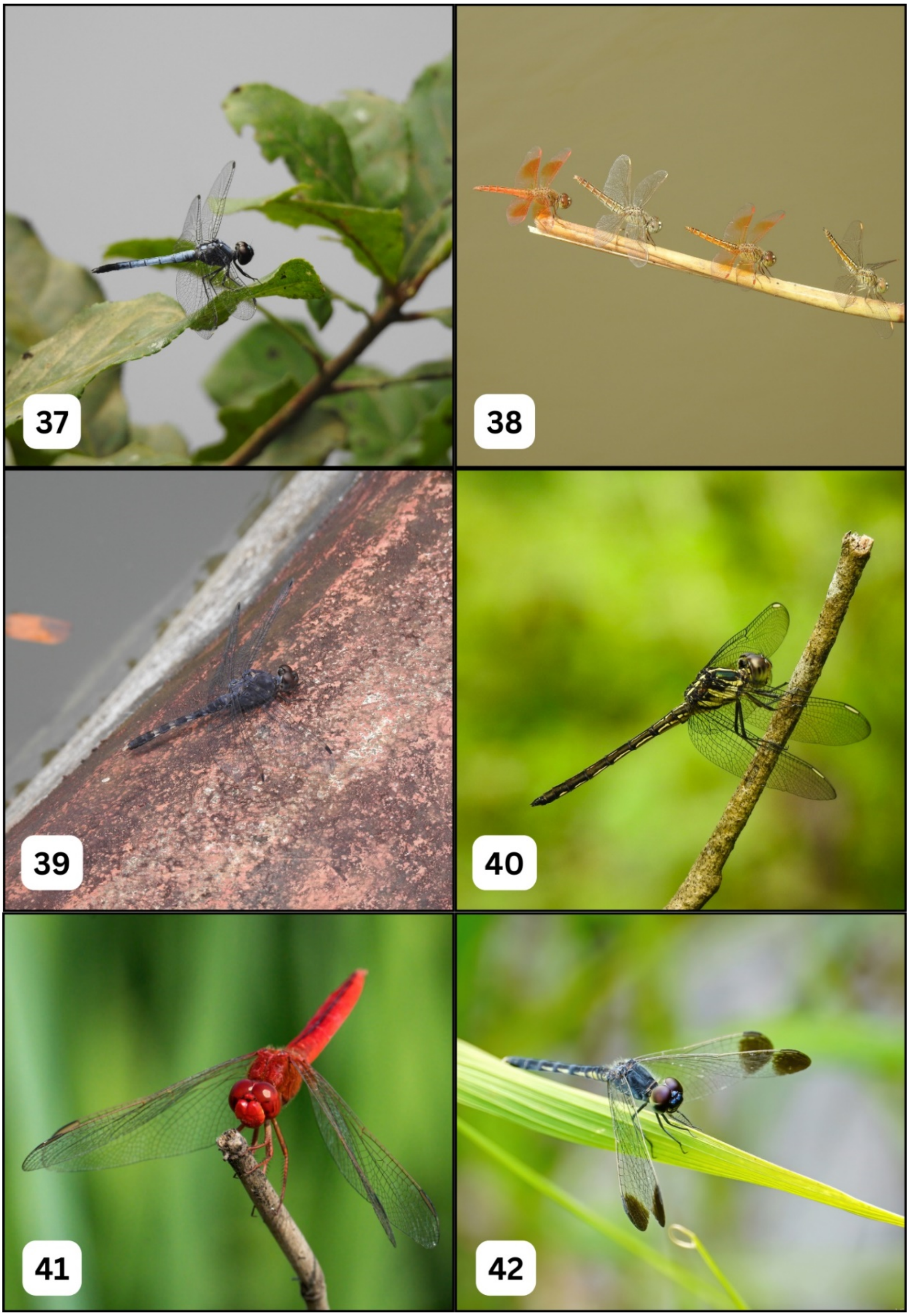


Figure 2.8: Odonate species photographed from Kole wetlands (continued)

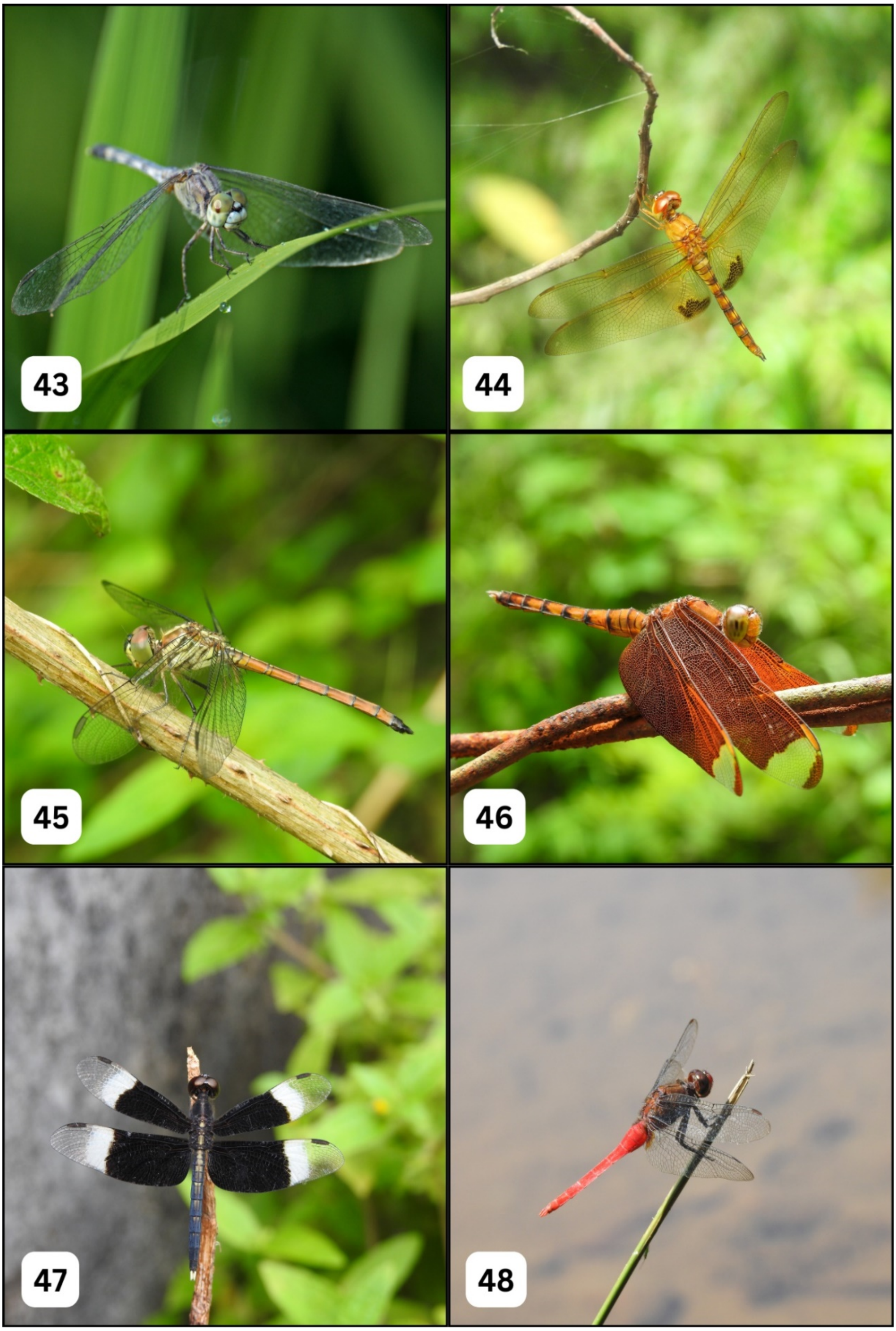


Figure 2.9: Odonate species photographed from Kole wetlands (continued)

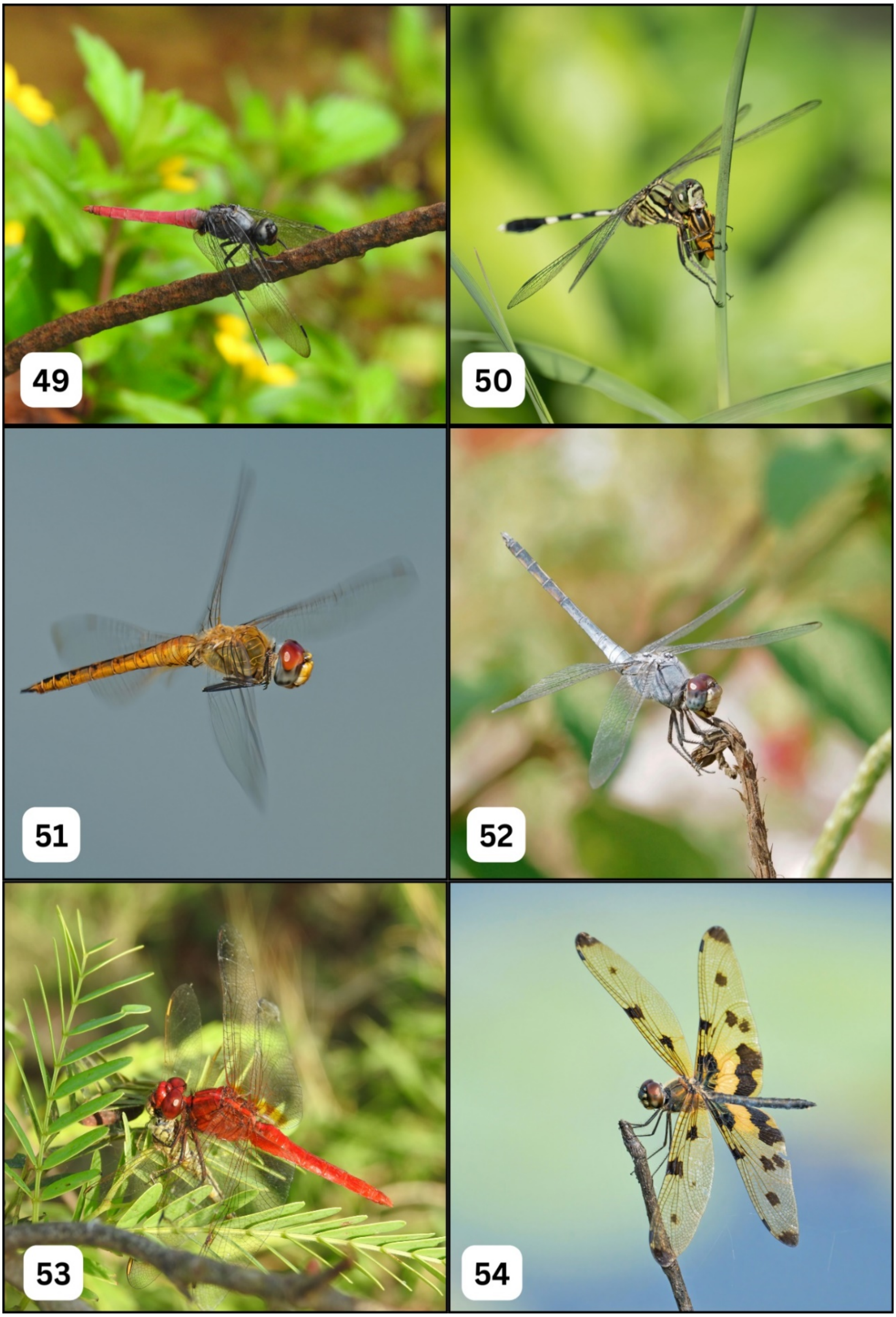


Figure 2.10: Odonate species photographed from Kole wetlands (continued)

Figure 2.11: Odonate species photographed from Kole wetlands (continued)

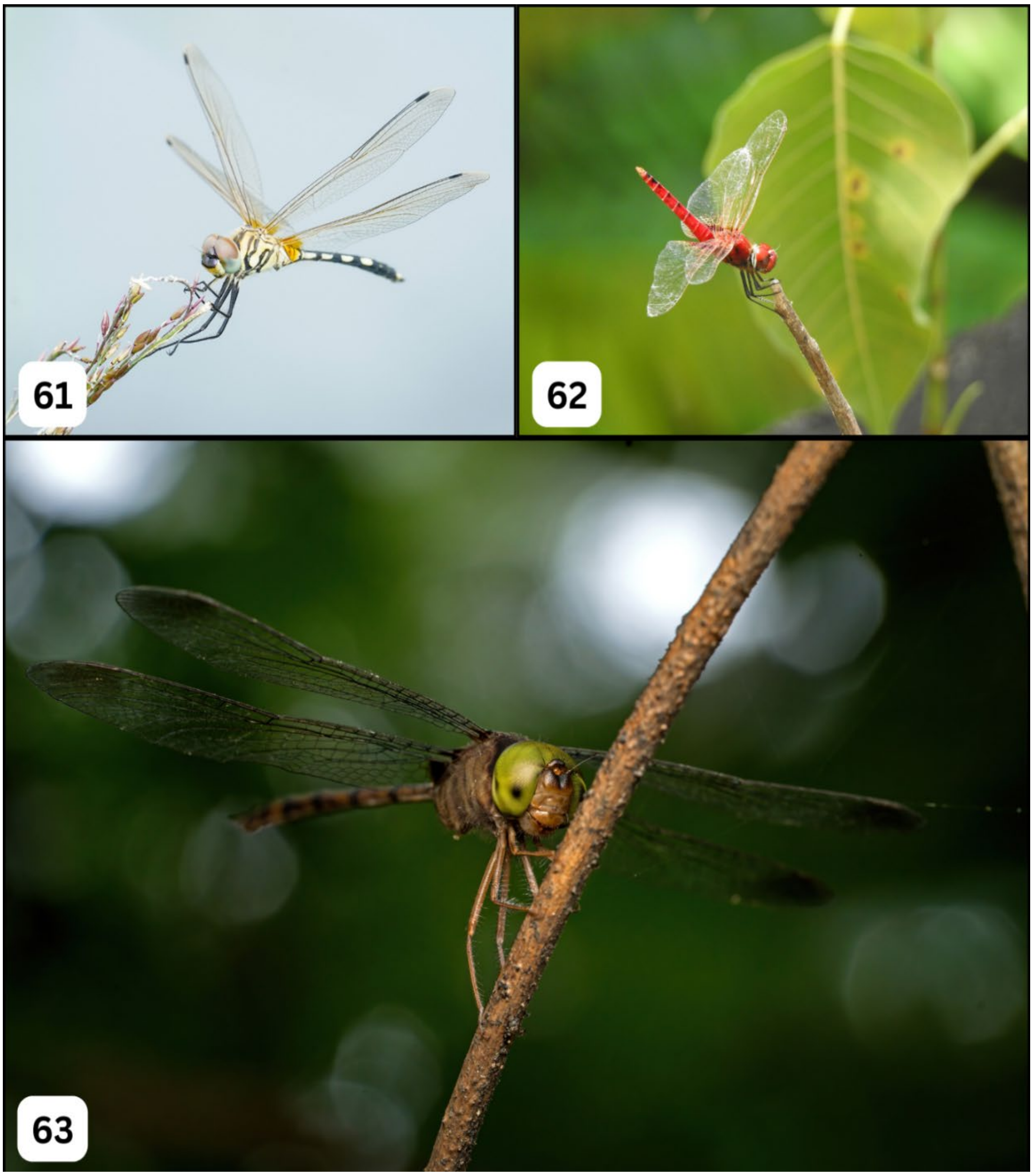


Figure 2.12: Odonate species photographed from Kole wetlands (continued)

The findings reveal a rich odonate fauna, with 63 species recorded, representing about 34% of the known odonate species in Kerala (Society for Odonate Studies, 2024). This high diversity underscores the ecological importance of the Kole wetlands as a habitat for these insects. The presence of three species endemic to the Western Ghats and two species endemic to India highlights the conservation value of the Kole wetlands. These endemic species and those listed as Data Deficient or Not Evaluated by the IUCN warrant particular attention in future conservation efforts.

The study provides crucial baseline data for monitoring these species and their habitats.

With a total count of over 11,000 individuals during the study period, *Pantala flavescens* has emerged as the most abundant species, with its count peaking during late monsoon (Figures 2.13 & 2.14). This migratory species holds the record for the longest insect migration (Fraser 1936; Anderson 2009). Their presence in large numbers just after the growing of paddy commences in most parts of the Kole wetlands probably has a favourable effect on the initial growth of the crop as they are known to control insect pests by predating on them.

Figure 2.13: *Pantala flavescens*, A- Male individual seen up close, B- Huge feeding swarm seen in October 2019.

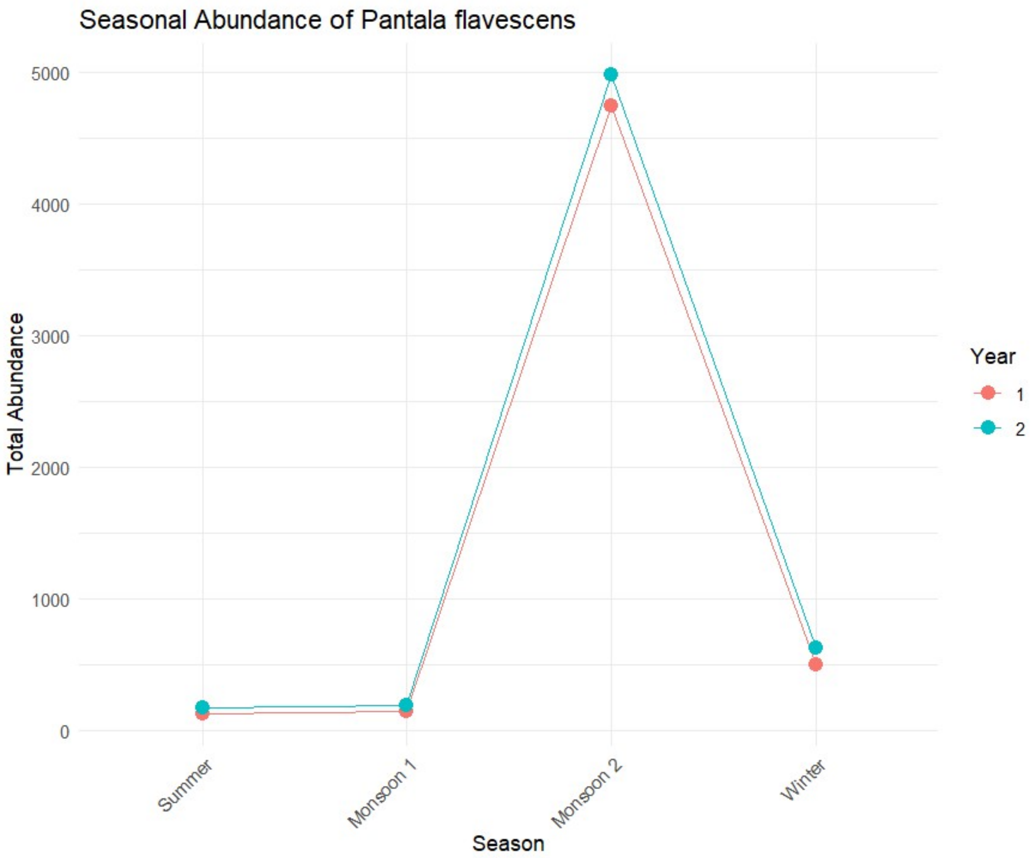


Figure 2.14: Seasonal abundance of the most numerous species, *Pantala flavescens* across the two years of study.

Eight species, viz. *Agriocnemis pygmaea, Pseudagrion microcephalum, Brachythemis contaminata, Crocothemis servilia, Neurothemis tullia, Orthetrum sabina,* and *Pantala flavescens* occurred in all 72 samples.

In both the years of sampling, adult Odonata diversity peaked during the early monsoon (Monsoon 1- May, June, July) and dipped during the cold months (Winter- November, December, January). A total of 58 exuviae were identified in the study period (Figure 2.15), which were also more in number during the early monsoon (Figure 2.16). A disproportionately large number of exuviae (51) were of Suborder Anisoptera (dragonflies) in comparison to Suborder Zygoptera (damselflies) (Table 2.3). The observed peak in adult odonate diversity during the early monsoon (May- July) and subsequent decline in winter months (November-January) reveal clear seasonal patterns. This trend was consistent across both years of the study, suggesting a strong influence of seasonal factors on odonate populations. The correlation between adult diversity and exuviae numbers further supports this seasonal pattern in odonate life cycles.

Figure 2.15: Exuvia of *Brachydipax chalybea* recorded in the study.

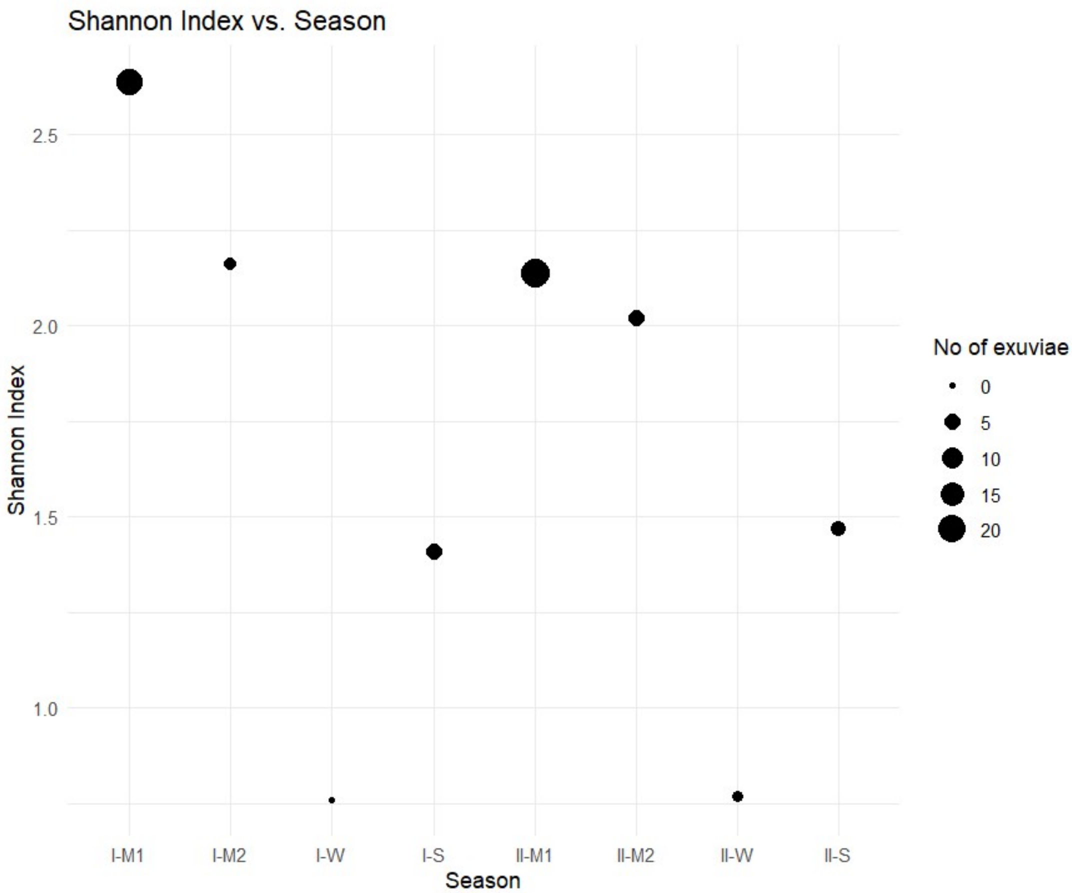


Figure 2.16: A combined plot showing the variation in adult odonate diversity as measured by Shannon Index and the number of exuviae recorded in different seasons across the two years of study.

The use of full-width belt transects (FWBT) and systematic sampling across seasons and sites provides a robust methodology for assessing odonate diversity. The inclusion of exuvial sampling offers valuable insights into breeding patterns and habitat use of odonates. The presence of exuviae is the only reliable proof of life cycle completion by odonate species in the habitat. However, the low number of exuviae recorded in the two-year study (58) points to the inefficacy of exuvial sampling in an open wetland ecosystem. Further, these exuviae belonged to 19 species, a very low proportion (30%) of the total number of species recorded as adults. The disproportionate number of dragonfly exuviae (15 spp, 51 no.s) compared to damselfly exuviae (4 spp, 7 no.s) raises questions about potential sampling biases. A wetland ecosystem is more exposed to the elements of weather like rain and wind, and the chances of exuviae getting washed off or blown away are very high. This is especially so in the case of damselfly exuviae which are much smaller and lighter in comparison. Hence, sampling of exuviae is not an effective method to document odonate diversity in a vast open wetland ecosystem like the Kole wetlands.

Species	I-M1	I-M2	I-W	I-S	II-M1	II-M2	II-W	II-S
Suborder Anisoptera								
Gynacantha dravida	2	0	0	1	2	0	0	1
Macrogomphus wynaadicus	1	0	0	0	2	0	0	0
Hemicordulia asiatica	2	0	0	0	2	0	0	0
Aethriamanta brevipennis	1	0	0	0	1	0	0	0
Brachydiplax chalybea	1	0	0	1	1	1	0	0
Brachythemis contaminata	1	0	0	0	2	0	0	1
Bradinopyga geminata	1	0	0	0	1	0	0	0
Crocothemis servilia	1	1	0	0	2	1	0	0
Diplacodes trivialis	1	0	0	1	2	1	0	0
Lathrecista asiatica	1	0	0	0	1	0	0	0
Neurothemis fulvia	1	0	0	0	1	0	0	0
Orthetrum sabina	1	1	0	0	1	1	1	0
Pantala flavescens	1	0	0	1	1	0	0	1
Rhyothemis variegata	1	0	0	0	0	0	0	0
Urothemis signata	1	0	0	0	0	0	0	1
Suborder Zygoptera								
Agriocnemis pygmaea	1	0	0	0	1	0	0	0
Ischnura senegalensis	1	0	0	1	0	1	0	0
Ceriagrion coromandelianum	0	0	0	0	1	0	0	0
Pseudagrion microcephalum	0	0	0	0	1	0	0	0

Table 2.3: Number of exuviae (shed exoskeletons of odonates) identified in the study in different seasons.

Plots of adult Odonata diversity and weather parameters suggest that Odonata diversity is influenced by multiple weather parameters, with rainfall, humidity, and wind speed showing more apparent positive correlations. The effect of temperature is less clear from this data (Figure 2.17).

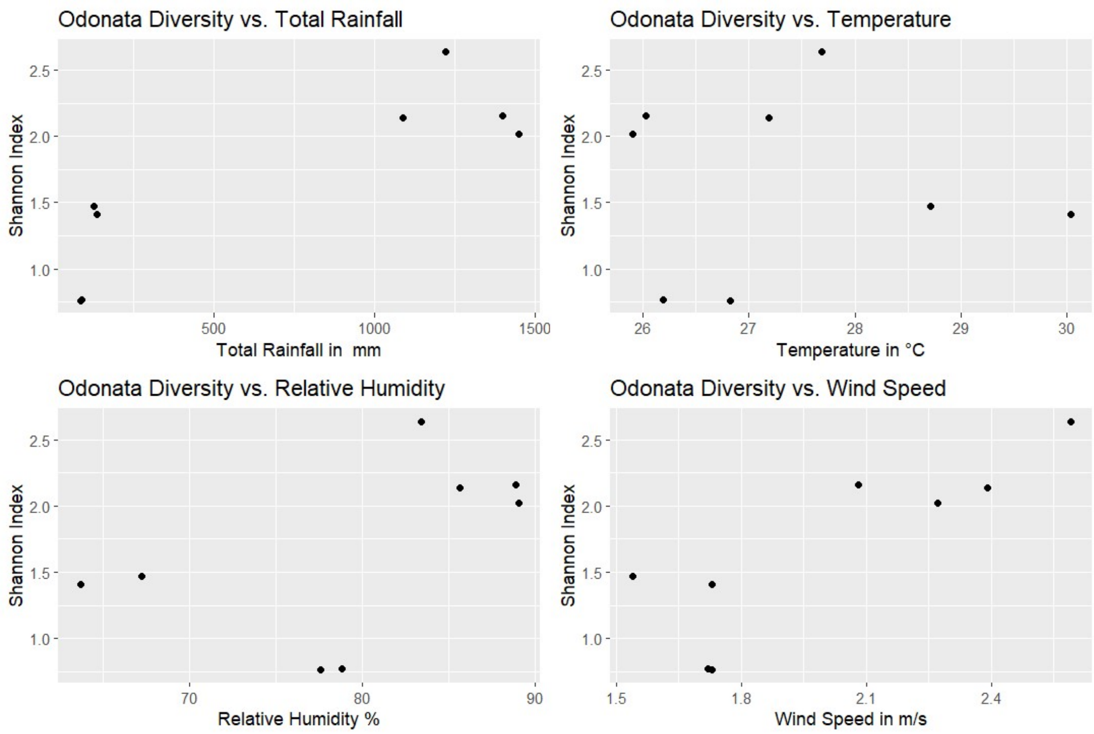


Figure 2.17: Plots of adult Odonata diversity as measured by Shannon Index and the measured weather parameters.

The apparent positive correlations with rainfall, humidity, and wind speed suggest these factors may play important roles in shaping odonate communities. The less clear relationship with temperature warrants further investigation, possibly considering interactions between temperature and other factors.

It is clear from the graph for species accumulation (Figure 2.18) that the highest species richness is seen in transects where the dominant aquatic vegetation type is free-floating (FF), followed by floating-leaved (FL). Submerged type (S) has the lowest richness (Figure 2.19).

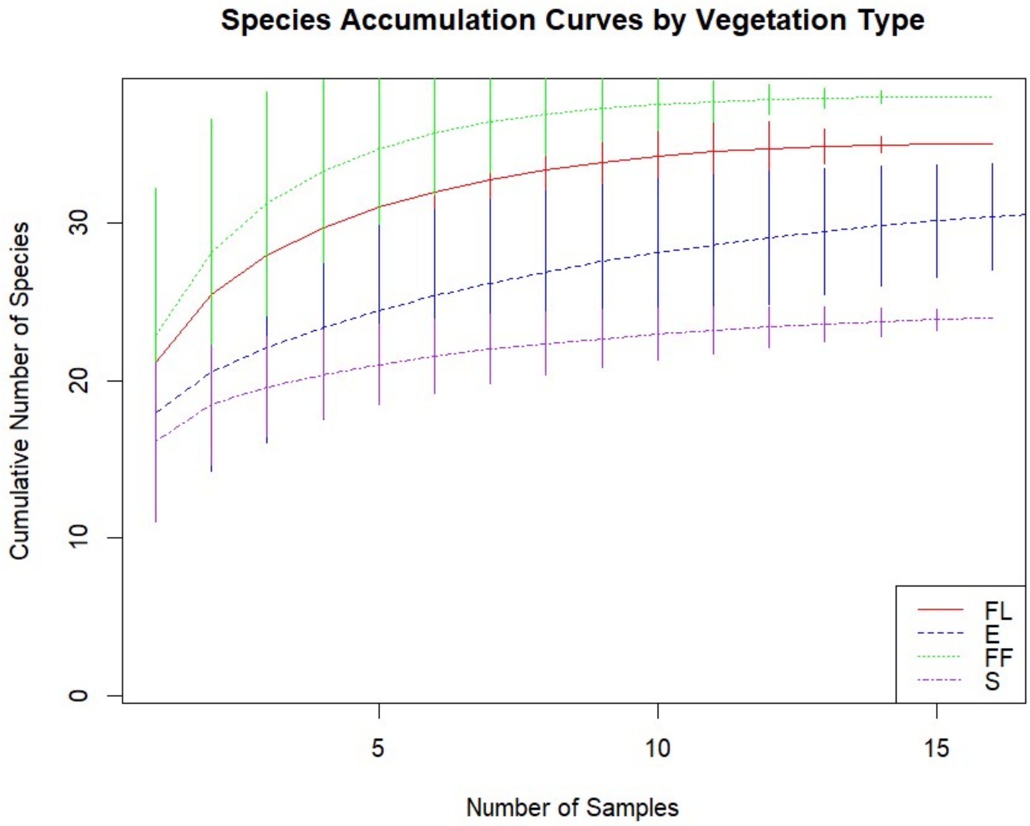


Figure 2.18: Species accumulation curves for the major aquatic vegetation types.

The species accumulation curve shows that the sampling was adequate for free-floating (FF) and floating-leaved (FL) vegetation types, as the curves reached asymptotes. The curves for emergent (E) and submerged (S) vegetation types are still rising, indicating potential for more species with additional sampling. This was considered while visiting sites randomly, and hence the study recorded a total of 63 species, against the 38 observed in the transects. The free-floating (FF) vegetation in Kole wetlands is dominated by exotic species such as *Salvinnia*, *Pistia*, and *Eichhornia*, despite which it supports the highest species richness of odonates. However, the submerged vegetation type (S), which in these wetlands is now dominated by exotic *Cabomba* spp has the lowest species richness. This could be because of the lack of perches for adult odonates in such habitats. It must also be noted that free-floating and floating-leaved vegetation types occur in deeper waters which are seldom drained for cultivation. This stability offered to the larval habitats could also be the cause for the higher abundance of adults seen there. On the other hand, sites with emergent and submerged vegetation types face seasonal draining in the Kole wetlands for the cultivation of paddy. This could be detrimental for odonate larvae, and in turn, could affect the adult abundance adversely.

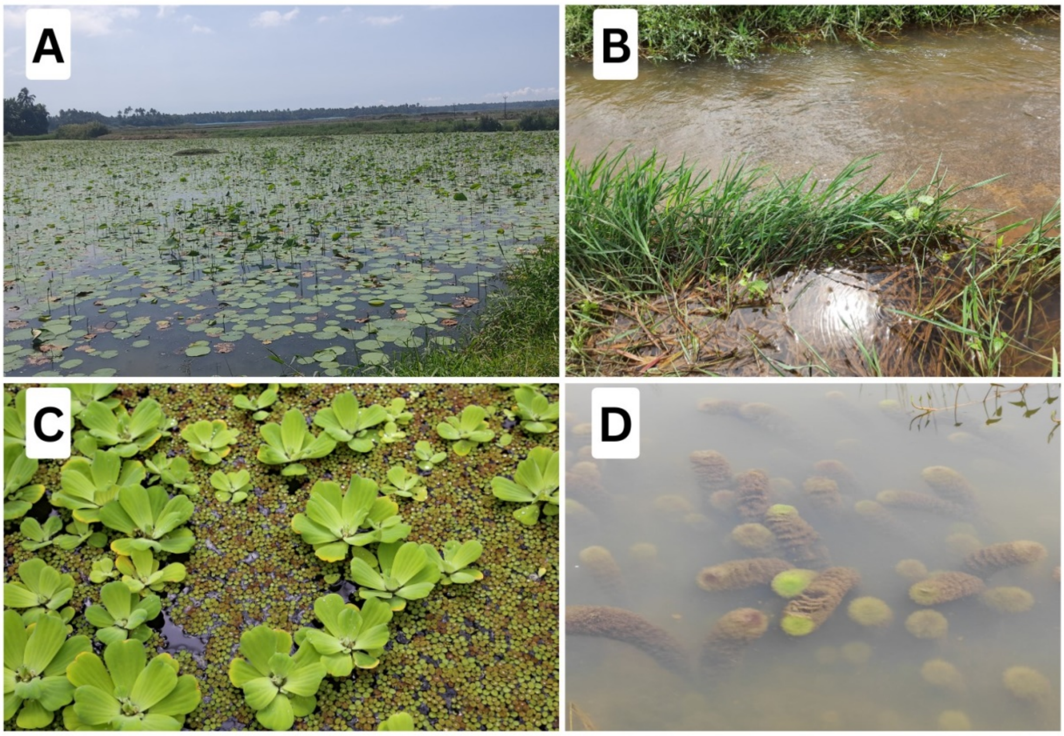


Figure 2.19: Major aquatic vegetation types in Kole wetlands- A: Floating-leaved (FL), B: Emergent (E), C: Free-floating (FF), D: Submerged (S).

The Permutational Multivariate Analysis of Variance (PERMANOVA) model explains about 75.62% of the total variation in community composition. Both Transect (R^2 = 0.10478) and Season (R^2 = 0.64960) have significant effects on odonate diversity (p = 0.001). The effect of year (R^2 = 0.00183) was not significant (p = 0.764) (Table 2.4).

However, this analysis does not include aquatic vegetation type as a factor due to collinearity with Transect. Hence, a separate PERMANOVA was performed by replacing the factor Transect with Vegetation type. The result of this second analysis shows that the effect of Vegetation type (R^2 = 0.05017) is also significant (p = 0.003) (Table 2.5).

Permutation test for adonis under reduced model					
Terms added sequentially (first to last)					
Permutation: free					
Number of permutations: 999					
	Df	**Sum of Sqs**	**R^2**	**F**	**Pr(>F)**
Transect	8	1.0552	0.10478	3.1699	0.001
Season	3	6.5418	0.6496	52.4052	0.001
Year	1	0.0184	0.00183	0.4427	0.764
Residual	59	2.455	0.24378		
Total	71	10.0704	1		

Table 2.4: PERMANOVA results for factors affecting odonate diversity in Kole wetlands.

Permutation test for adonis under reduced model					
Terms added sequentially (first to last)					
Permutation: free					
Number of permutations: 999					
	Df	**Sum of Sqs**	**R^2**	**F**	**Pr(>F)**
Vegetation type	3	0.5052	0.05017	3.5869	0.003
Season	3	6.5418	0.6496	46.4426	0.001
Year	1	0.0184	0.00183	0.3923	0.814
Residual	64	3.005	0.2984		
Total	71	10.0704	1		

Table 2.5: PERMANOVA results for effects of vegetation type, season, and year on odonate diversity in Kole wetlands.

The PERMANOVA results prove that the dominant aquatic vegetation type of a locality (FL, E, FF, S) does have a significant effect on odonate community composition, but it explains less variation than the site-specific effects (Transect). There are likely local factors within each vegetation type that influence odonate communities. Seasonal changes remain the dominant factor influencing odonate community composition, regardless of whether we consider site-specific effects or broader vegetation types. The consistency of the Year effect across both models reinforces the idea that odonate communities were relatively stable between the two years of the study.

2.5. Conclusion

This comprehensive study of odonate diversity in the Kole wetlands of Kerala, India has yielded valuable insights into the rich dragonfly and damselfly fauna of this important ecosystem. Through systematic sampling of both adults and exuviae across multiple sites and seasons over a two-year period, the research documented a total of 63 odonate species, representing about one-third of Kerala's known odonate diversity.

Several key findings emerged:

1. The presence of three species endemic to the Western Ghats and two endemic to India highlights the conservation value of the Kole wetlands.
2. Clear seasonal patterns were observed, with peak diversity during the early monsoon and lowest diversity in winter months. This trend was consistent across both study years.
3. While exuvial sampling provided some insights into breeding patterns, it proved less effective in this open wetland system compared to adult sampling.
4. Weather parameters, particularly rainfall, humidity, and wind speed, showed positive correlations with odonate diversity.

5. Aquatic vegetation type significantly influenced odonate communities, with free-floating and floating-leaved vegetation supporting the highest species richness.
6. Statistical analysis revealed that both site-specific factors (transects) and broader habitat characteristics (vegetation types) significantly affect odonate diversity, with seasonal changes being the dominant influence.

This study provides crucial baseline data for future monitoring and conservation efforts in the Kole wetlands. It underscores the ecological importance of this habitat for odonates, including several endemic and data-deficient species. The research also highlights the complex interplay of weather parameters, habitat characteristics, and seasonal changes in shaping odonate communities.

Future research directions could include more detailed investigations into the specific habitat requirements of endemic species, long-term monitoring to detect potential impacts of climate change or habitat alterations, and focused studies on the less understood aspects of odonate ecology in this wetland system. Additionally, the observed differences in species richness among vegetation types, particularly the low diversity in areas dominated by exotic submerged vegetation, warrant further investigation for potential conservation implications.

Overall, the present study contributes significantly to our understanding of odonate diversity in the Kole wetlands and provides a strong foundation for future research and conservation initiatives in this ecologically important region.

2.6. References

Abbott, J. C., Bota-Sierra, C. A., Guralnick, R., Kalkman, V., González-Soriano, E., Novelo-Gutiérrez, R., Bybee, S., Ware, J., & Belitz, M. W. (2022). Diversity of Nearctic dragonflies and damselflies (Odonata). *Diversity*, 14(7), 575. https://doi.org/10.3390/d14070575

Adarsh, C. K., Aneesh, K. S., & Nameer, P. O. (2014). A preliminary checklist of odonates in Kerala Agricultural University (KAU) campus, Thrissur District, Kerala, southern India. *Journal of Threatened Taxa*, *6*(8), 6127-6137. https://doi.org/10.11609/JoTT.o3491.6127-37

Anderson, R. C. (2009). Do dragonflies migrate across the western Indian Ocean? *Journal of Tropical Ecology*, *25*(4), 347-358. https://doi.org/10.1017/S0266467409006087

Arulprakash, R., & Gunathilagaraj, K. (2010). Abundance and diversity of Odonata in temporary water bodies of Coimbatore and Salem districts in Tamil Nadu. *Journal of Threatened Taxa*, *2*(8), 1099-1102. https://doi.org/10.11609/JoTT.o2035.1099-102

Arunima, J., & Nameer, P. O. (2021). A preliminary checklist of dragonflies and damselflies (Insecta: Odonata) of Vakkom Grama Panchayath, Thiruvanthapuram District, Kerala, India. *Journal of Threatened Taxa*, *13*(8), 19125-19136. https://doi.org/10.11609/jott.7311.13.8.19125-19136

Bose, C. N., Binoy, C. F., & Kakkassery, F. K. (2021). On the diversity and abundance of riparian odonate fauna (Insecta) of the midstream Chalakkudy River, Kerala, India. *Journal of Threatened Taxa*, 13(8), 19053-19059. https://doi.org/10.11609/jott.7328.13.8.19053-19059

Chandran, R., & Chandran, A. V. (2021). Dragonflies and Damselflies (Insecta: Odonata) of Aryanad Grama Panchayat, Kerala, India. *Journal of Threatened Taxa*, *13*(14), 20153-20166. https://doi.org/10.11609/jott.7342.13.14.20153-20166

Darshetkar, A., Patwardhan, A., & Koparde, P. (2023). A comparison of four sampling techniques for assessing species richness of adult odonates at riverbanks. *Journal of Threatened Taxa, 15*(1), 22471–22478. https://doi.org/10.11609/jott.7259.15.1.22471-22478

Didham, R. K., Basset, Y., Collins, C. M., Leather, S. R., Littlewood, N. A., Menz, M. H. M., Müller, J., Packer, L., Saunders, M. E., Schönrogge, K., Stewart, A. J. A., Yanoviak, S. P., & Hassall, C. (2020). Interpreting insect declines: Seven challenges and a way forward. *Insect Conservation and Diversity*, 13(2), 103-114. https://doi.org/10.1111/icad.12408

Emiliyamma, K. G., & Radhakrishnan, C. (2003). Odonata (Insecta) of Indira Gandhi Wildlife Sanctuary and National Park, Tamil Nadu. *Zoo's Print Journal*, *18*(11), 1264-1266.

Emiliyamma, K. G., & Radhakrishnan, C. (2006). Insecta: Odonata. In Director (Ed.), *Fauna of Biligiri Rangaswamy Wildlife Sanctuary, Conservation Area Series No. 27* (pp. 21-25). Zoological Survey of India.

Emiliyamma, K. G., & Radhakrishnan, C. (2007). Insecta: Odonata. In Director (Ed.), *Fauna of Kudremukh National Park, Conservation Area Series No. 32* (pp. 27-48). Zoological Survey of India.

Fraser, F. C. (1933). *The fauna of British India, including Ceylon and Burma: Odonata, Vol. I*. Taylor and Francis.

Fraser, F. C. (1934). *The fauna of British India, including Ceylon and Burma: Odonata, Vol. II*. Taylor and Francis.

Fraser, F. C. (1936). *The fauna of British India, including Ceylon and Burma: Odonata, Vol. III*. Taylor and Francis.

IUCN. (2024). The IUCN Red List of Threatened Species. Version 2024-1. https://www.iucnredlist.org/

Kalkman, V. J., Clausnitzer, V., Dijkstra, K.-D. B., Orr, A. G., Paulson, D. R., & van Tol, J. (2008). Global diversity of dragonflies (Odonata) in freshwater. *Hydrobiologia*, *595*, 351-363. https://doi.org/10.1007/s10750-007-9029-x

Kalkman, V. J., Boudot, J.-P., Futahashi, R., Abbott, J. C., Bota-Sierra, C. A., Guralnick, R., Bybee, S. M., Ware, J., & Belitz, M. W. (2022). Diversity of

Palaearctic dragonflies and damselflies (Odonata). *Diversity*, 14(11), 966. https://doi.org/10.3390/d14110966

Koli, V. K., Bhatnagar, C., & Shekhawat, D. S. (2014). Diversity and species composition of Odonates in Southern Rajasthan, India. *Proceedings of the Zoological Society*, 1-10. https://doi.org/10.1007/s12595-014-0103-x

Kulkarni, P. P., & Prasad, M. (2005). Insecta: Odonata. In Director (Ed.), *Fauna of Melghat Tiger Reserve, Conservation Area Series No. 24* (pp. 297-316). Zoological Survey of India.

Lahiri, A. R. (1985). Odonata fauna of Namdhapa, Arunachal Pradesh. *Records of the Zoological Survey of India*, *82*, 61-67.

May, M. L. (2019). Odonata: Who they are and what they have done for us lately: Classification and ecosystem services of dragonflies. *Insects*, *10*(3), 62. https://doi.org/10.3390/insects10030062

Muneer, P. K., Babu S., N., Chandran, A. V., & Jose, S. K. (2023). Odonata checklist of Wayanad Wildlife Sanctuary, Kerala State, Southern India. *International Journal of Tropical Insect Science*. https://doi.org/10.1007/s42690-023-01135-y

Palot, M. J., & Soniya, V. P. (2000). Odonata from Courtallam, Tamil Nadu, Southern India. *Zoo's Print Journal*, *15*(7), 301-303.

Palot, M. J., & Soniya, V. P. (2004). Studies on the Odonata (Insecta) from a backwater swamp on Northern Kerala. *Journal of the Bombay Natural History Society*, *101*(1), 177-179.

Rathod, D. M., Parasharya, B. M., & Talmale, S. S. (2016). Odonata (Insecta) diversity of southern Gujarat, India. *Journal of Threatened Taxa*, *8*(11), 9339-9349. https://doi.org/10.11609/jott.2609.8.11.9339-9349

Rodrigues, M., Nayakkan, A., Nair, V. P., Rowther B, E., & Roshnath, R. (2022). Odonata of Kattampally wetland, Kerala state, India. *Notulae odonatologicae*, 9(9), 441-450. https://doi.org/10.60024/nodo.v9i9.a7

Sánchez-Bayo, F., & Wyckhuys, K. A. G. (2019). Worldwide decline of the entomofauna: A review of its drivers. *Biological Conservation*, 232, 8-27. https://doi.org/10.1016/j.biocon.2019.01.020

Simaika, J. P., & Samways, M. J. (2008). Valuing dragonflies as service providers. In A. Córdoba-Aguilar (Ed.), *Dragonflies: Model organisms for ecological and evolutionary research* (pp. 109-123). Oxford University Press.

Society for Odonate Studies. (2024). List of odonates of Kerala. https://odonatesociety.org/list-of-odonates-of-kerala/

Subramanian, K. A. (2005). *Dragonflies and damselflies of Peninsular India - A field guide*. Indian Academy of Sciences.

Subramanian, K. A. (2009). *Damselflies and dragonflies of India - A field guide*. Indian Academy of Sciences.

Sutherland, W. J. (Ed.). (2006). *Ecological census techniques: A handbook* (2nd ed.). Cambridge University Press.

van der Sluijs, J. P. (2020). Insect decline, an emerging global environmental risk. *Current Opinion in Environmental Sustainability*, *46*, 39-42. https://doi.org/10.1016/j.cosust.2020.08.012

Varghese, A. P., Nikesh, P. R., & Mathew, J. (2014). Odonata (Insecta) diversity of Salim Ali Bird Sanctuary and its adjacent areas in Thattekkad, Kerala, India. *Journal of Threatened Taxa*, *6*(6), 5887-5893. https://doi.org/10.11609/JoTT.o3395.5887-93

Willigalla, C., & Fartmann, T. (2012). Patterns in the diversity of dragonflies (Odonata) in cities across Central Europe. *European Journal of Entomology*, 109(2), 235-245. https://doi.org/10.14411/eje.2012.031

Chapter 3

COMPARATIVE ASSESSMENT OF ODONATA DIVERSITY IN PONDS AND WETLANDS

3.1. Introduction

Due to their sensitivity to environmental changes, especially in freshwater habitats, odonates are commonly acknowledged as bioindicators. Odonates are ideal subjects for studies comparing habitats such as ponds and wetlands because of their dual-phase lifecycle and sensitivity to both aquatic and terrestrial conditions (Corbet, 1999). Because Odonata are bioindicators, there has been a lot of interest in studying their diversity in aquatic environments (Clausnitzer et al., 2017). Dragonflies and damselflies are excellent indicators of wetland health and ecological integrity, according to research conducted in a variety of geographical regions (Kutcher & Bried, 2014). The diversity of environmental reactions across various ecological environments is better captured by regional research. Odonate communities differ by region and are impacted by climate, habitat type, and other ecological factors. According to Samways and Steytler (1996), regional studies enable the creation of ecological indices that are locally relevant and tailored for particular species assemblages.

Given their habitat heterogeneity, wetlands are important for biodiversity, according to existing research (Perron & Pick, 2020). Based on a recent study by Vilenica et al. (2024), semi-natural urban wetlands have a lot of potential to be good Odonata habitats. Ponds also play an essential role in supporting local odonate populations, particularly in anthropogenic landscapes (Oertli et al., 2005). Perron et al. (2021) found that in Canadian ponds, plant communities explained the largest amount of variation in both dragonfly and damselfly community structure followed by water quality. Water quality parameters, including dissolved oxygen, salinity, and nutrient levels, significantly affect odonate diversity and community structure (Hassall, 2014). Adult odonates retain an ecological connection to aquatic habitats where they developed as larvae. Water bodies with poor quality may fail to support larval development, indirectly reducing the abundance and diversity of adults (Suhling et al., 2004). Bried and Hinchliffe (2019) found that for better taxonomic resolution of odonates in a habitat, surveys of adults give better results. Conservation strategies should integrate ponds and wetlands within landscape management plans to ensure the protection of odonate diversity and the ecosystem services they support (Chovanec & Waringer, 2001).

In India, Mitra (1999) gave an account of ecology of odonates and their adaptations to various habitats. This paper discusses the general details of Indian Odonata such as their reproduction, development, foraging, territoriality, thermoregulation, roosting, and migration. Research by Kulkarni and Subramanian (2013) showed that waterbodies with natural shoreline vegetation and absence of solid waste dumping had higher odonate diversity. Tiple & Koparde (2015) recorded 47 species from urban water bodies of Maharashtra, emphasizing the role of artificial ponds in Odonata conservation. Koparde et al. (2015) showed that canopy cover and area of water on the transect are the major drivers of Odonata species assemblages in the Sahyadri Tiger Reserve of the northern Western Ghats. Almost all the Western Ghats endemics recorded in their study were associated with high canopy forests and streams, suggesting the critical habitat requirements of these species. Koparde (2016) also found that in the urban wetlands of Pune, damselflies are more sensitive to seasonal changes as well as water pollution. Jere et al. (2020) identified urban sensitive, urban tolerant and generalist species of odonates in Pune city, Maharashtra. According to their findings, the intermediate disturbance hypothesis explains why odonate diversity was highest at a site that was partly urbanized. According to Chandran et al. (2024), vegetation cover, air temperature, and water quality metrics like pH, total dissolved solids, conductivity, and salinity were significant predictors of odonate diversity on the Kuruva Island in Wayanad, Kerala. The ecological requirements of the extremely range-restricted and vulnerable *Disparoneura apicalis* (Fraser, 1924) were also emphasized in the study. Beyond the purview of these investigations, there is still a dearth of ecological research on Indian Odonata, particularly in the areas of comprehending the variables influencing odonate assemblages in diverse environments and methodically comparing these assemblages.

This chapter compares and contrasts the diversity of adult Odonata in ponds and wetland sites within the Kole Wetlands in Thrissur, Kerala. The goal of this study was to identify important water quality parameters influencing Odonata diversity, identify possible indicator species, and clarify differences in species richness and composition among these habitat types. This study advances our knowledge of Odonata ecology in Kole wetlands and investigates their potential as bioindicators of aquatic ecosystem health by combining field surveys with water quality studies.

3.2. Materials and methods

To conduct this study, 20 wetland sites and 20 ponds were selected in the wetscape of Thrissur South Kole, considering both geographical coverage and ease of access (Figure 3.1). The study was conducted in the early monsoon months (May 2021-August 2021) when adult odonate diversity was observed to be at its peak (Chapter 1). Each site was visited once in fair weather, between 9 am and 12 pm. Timed Visual Encounter Surveys (VES) were used to record species richness and abundance of adult odonates (Crump and Scott, 1994). The researcher surveyed odonates along the edge of the water body for 20 minutes, walking a distance of 20 metres (Figure 3.2). The time was fixed considering it took 20 minutes to finish surveying the smallest pond. A pair of close-focusing binoculars (Pentax Papilio II 8.5 x 21) were used to observe the odonates. Every species encountered was photographed using a mirrorless camera (Sony a7 III) attached to a telephoto lens (Tamron 150-500 mm). The odonates were identified by referring to field guides (Subramanian, 2005, 2009) and taxonomic monographs (Fraser, 1933, 1934, 1936).

Water quality parameters were measured in each site at a fixed time of 11 am. Temperature (°C), pH, dissolved oxygen (mg/L), conductivity (µS/cm), turbidity (NTU), TDS (ppm), and salinity (ppt) were measured in the field itself using a multiparameter water quality analyser (Deluxe Model 191 E). Biochemical oxygen demand (BOD) was calculated after incubating the water samples at 20°C for 5 days in the laboratory. Nitrate (mg/L) and phosphate (mg/L) levels were measured using a UV-VIS Spectrophotometer (Model LT 2900) in the water samples carried to the laboratory.

3.3. Data analysis

The packages 'vegan' and 'ggplot2' of R v. 4.3.3 were used for the basic analysis and plotting respectively. A simple bar diagram was drawn to represent the number of Odonata species recorded per pond and wetland site. A correlation matrix was drawn with the measured water quality parameters, species richness of Odonata, and Odonata diversity as measured using the Shannon Index to understand the relationships between them, using the package 'corrplot'. This was followed by separate multiple linear regression analyses with species richness and Shannon Index as response variables to see how adult Odonata are influenced by water quality.

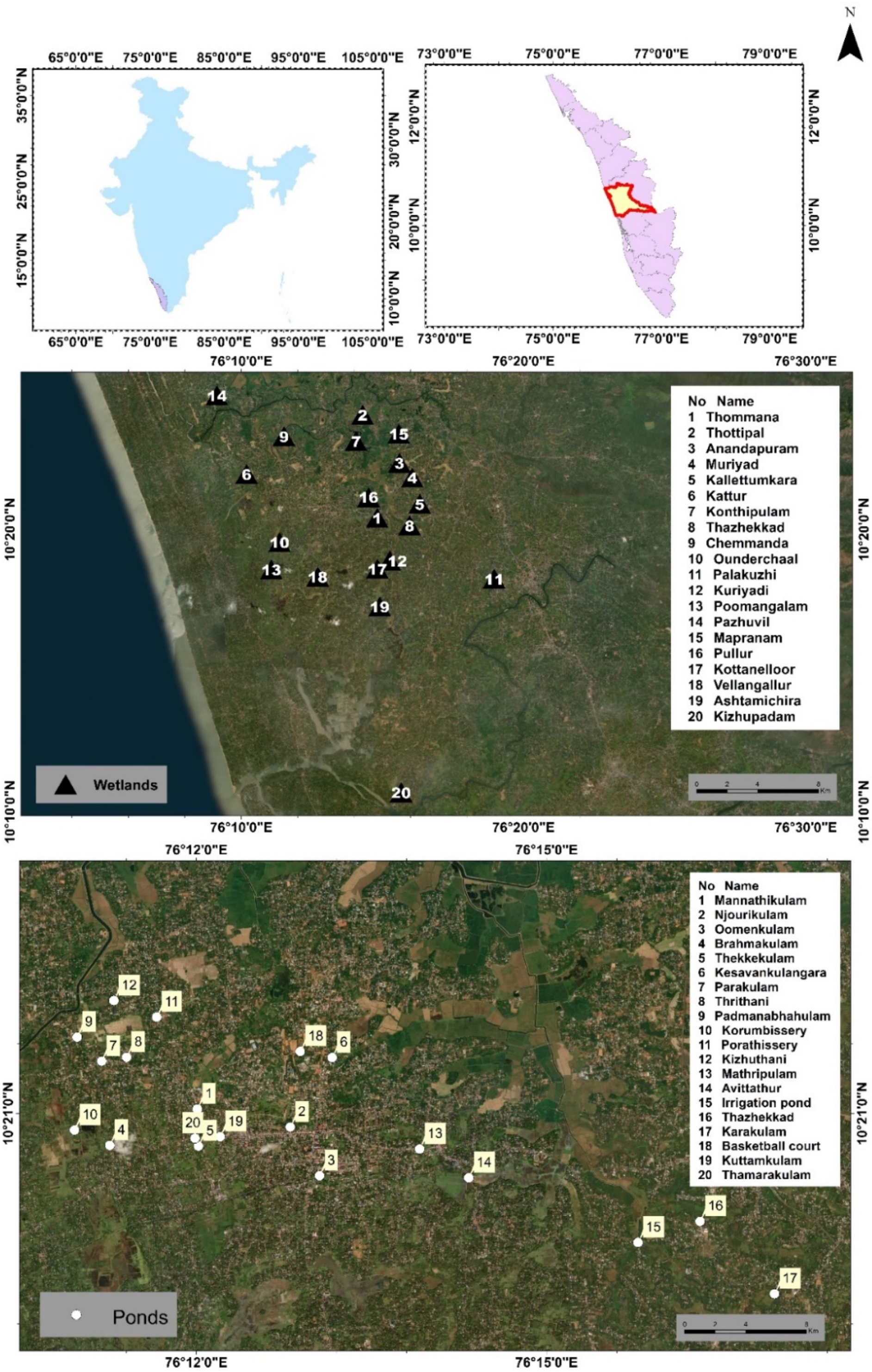


Figure 3.1: Locations of the sampled wetland sites and ponds.

Figure 3.2: Thekkekulam, one of the ponds sampled.

A PERMANOVA (Permutational Multivariate Analysis of Variance) was performed using Euclidean distances to test whether water quality parameters differed significantly between ponds and wetlands, followed by Non-metric Multidimensional Scaling (NMDS) plots to visualize the differences.

Another PERMANOVA was performed using Bray-Curtis dissimilarity indices to compare the Odonata species assemblages between ponds and wetlands. To understand which species contribute most to the differences between the habitat types, a SIMPER (Similarity Percentage) analysis based on Bray-Curtis dissimilarity indices was run. This analysis gives the cumulative contributions of the most influential species to the dissimilarity between ponds and wetlands. Separate Indicator Species Analyses were run for water quality and habitat type as grouping variables to identify odonate species that could be used as indicator species, using the package ‘indicspecies’. In this analysis, each species is assigned an indicator value (IV) based on its specificity (A- proportion of the species' occurrences that are confined to a specific group) and fidelity (B- proportion of sites in the group where the species is present.)

IV = A x B

A permutation test is then run to test the significance of the IV.

3.4. Results and discussion

A total of 44 species of odonates (30 species of dragonflies and 14 species of damselflies) were recorded in this study (Table 3.1). Ponds had a total count of 30 species, while the wetland sites had all the 44 species. Wetlands had 14 species exclusively occurring in them, while ponds did not have any such exclusive species. Wetland sites also tended to have higher numbers of odonate species in comparison (Figure 3.3).

Wetlands support more odonate species than ponds primarily due to their greater habitat diversity, which provides various ecological niches that can cater to a wider range of species. Wetlands typically have a mix of open water, emergent vegetation, and areas with different levels of water permanence, which create various microhabitats essential for the life cycles of different odonate species.

The correlation matrix shows a strong positive correlation between species richness and Shannon index. Also, conductivity and TDS are strongly correlated, as are BOD and nitrate levels. Many parameters show weak correlations, indicating complex relationships in water quality that are not easily reduced to simple linear relationships (Figure 3.4).

The strong positive correlation between species richness and species diversity (as measured by Shannon Index) indicates healthy, diverse ecosystems. The positive correlation between BOD and Nitrate might indicate organic pollution sources, as both can increase with sewage or agricultural runoff.

Sl No	Scientific Name	Wetlands	Ponds
	Order: Odonata		
	I. Suborder: Zygoptera		
	1. Family: Lestidae		
1	*Platylestes platystylus* (Rambur, 1842)	✓	×
	2. Family: Chlorocyphidae		
2	*Libellago indica* (Fraser, 1928)	✓	×
	3. Family: Platycnemididae		
3	*Copera marginipes* (Rambur, 1842)	✓	✓
	4. Family: Coenagrionidae		✓
4	*Aciagrion occidentale* Laidlaw, 1919	✓	✓
5	*Agriocnemis keralensis* Peters, 1981	✓	✓
6	*Agriocnemis pygmaea* (Rambur, 1842)	✓	✓
7	*Ceriagrion cerinorubellum* (Brauer, 1865)	✓	✓
8	*Ceriagrion coromandelianum* (Fabricius, 1798)	✓	✓
9	*Ischnura rubilio* Selys, 1876	✓	✓
10	*Ischnura senegalensis* (Rambur, 1842)	✓	✓
11	*Paracercion calamorum* (Ris, 1916)	✓	✓
12	*Pseudagrion australasiae* Selys, 1876	✓	✓
13	*Pseudagrion decorum* (Rambur, 1842)	✓	×
14	*Pseudagrion microcephalum* (Rambur, 1842)	✓	✓
	II. Suborder: Anisoptera		
	5. Family: Aeshnidae		
15	*Anax guttatus* (Burmeister, 1839)	✓	×
16	*Anax indicus* Lieftinck, 1942	✓	×
	6. Family: Gomphidae		
17	*Ictinogomphus rapax* (Rambur, 1842)	✓	✓
18	*Paragomphus lineatus* (Selys, 1850)	✓	×
	7. Family: Macromiidae		
19	*Epophthalmia vittata* Burmeister, 1839	✓	✓
	8. Family: Libellulidae		
20	*Acisoma panorpoides* Rambur, 1842	✓	✓
21	*Aethriamanta brevipennis* (Rambur, 1842)	✓	✓
22	*Brachydiplax chalybea* Brauer, 1868	✓	✓
23	*Brachydiplax sobrina* (Rambur, 1842)	✓	×
24	*Brachythemis contaminata* (Fabricius, 1793)	✓	✓
25	*Bradinopyga geminata* (Rambur, 1842)	✓	✓
26	*Crocothemis servilia* (Drury, 1773)	✓	✓
27	*Diplacodes nebulosa* (Fabricius, 1793)	✓	×
28	*Diplacodes trivialis* (Rambur, 1842)	✓	✓
29	*Hydrobasileus croceus* (Brauer, 1867)	✓	✓
30	*Lathrecista asiatica* (Fabricius, 1798)	✓	×
31	*Neurothemis tullia* (Drury, 1773)	✓	✓

32	*Orthetrum chrysis* (Selys, 1891)	✓	✓
33	*Orthetrum pruinosum* (Burmeister, 1839)	✓	×
34	*Orthetrum sabina* (Drury, 1770)	✓	✓
35	*Pantala flavescens* (Fabricius, 1798)	✓	✓
36	*Potamarcha congener* (Rambur, 1842)	✓	×
37	*Rhodothemis rufa* (Rambur, 1842)	✓	✓
38	*Rhyothemis variegata* (Linnaeus, 1763)	✓	✓
39	*Tholymis tillarga* (Fabricius, 1798)	✓	×
40	*Tramea limbata* (Desjardins, 1832)	✓	✓
41	*Trithemis aurora* (Burmeister, 1839)	✓	×
42	*Trithemis pallidinervis* (Kirby, 1889)	✓	✓
43	*Urothemis signata* (Rambur, 1842)	✓	✓
44	*Zyxomma petiolatum* Rambur, 1842	✓	×

Table 3.1: Odonata species recorded in the study from both ponds and wetland sites.

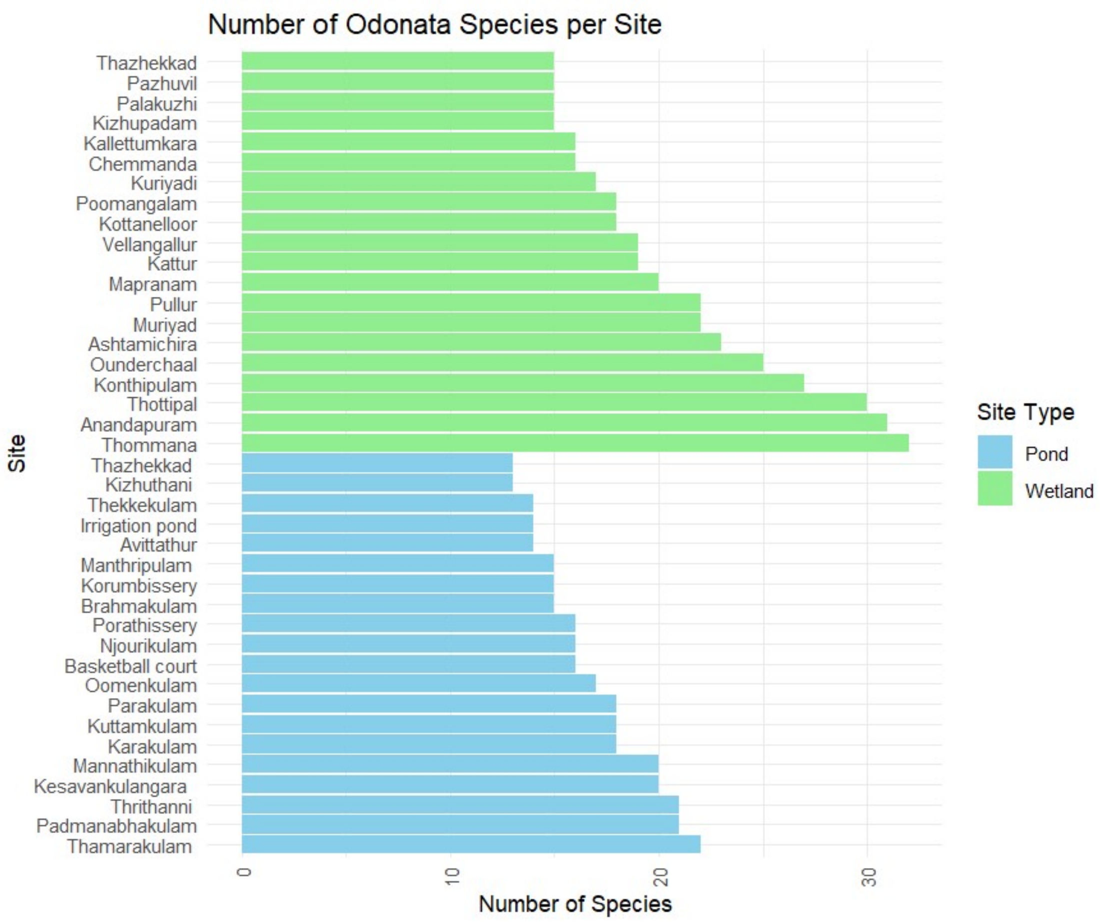


Figure 3.3: Number of Odonata species recorded per pond and wetland site.

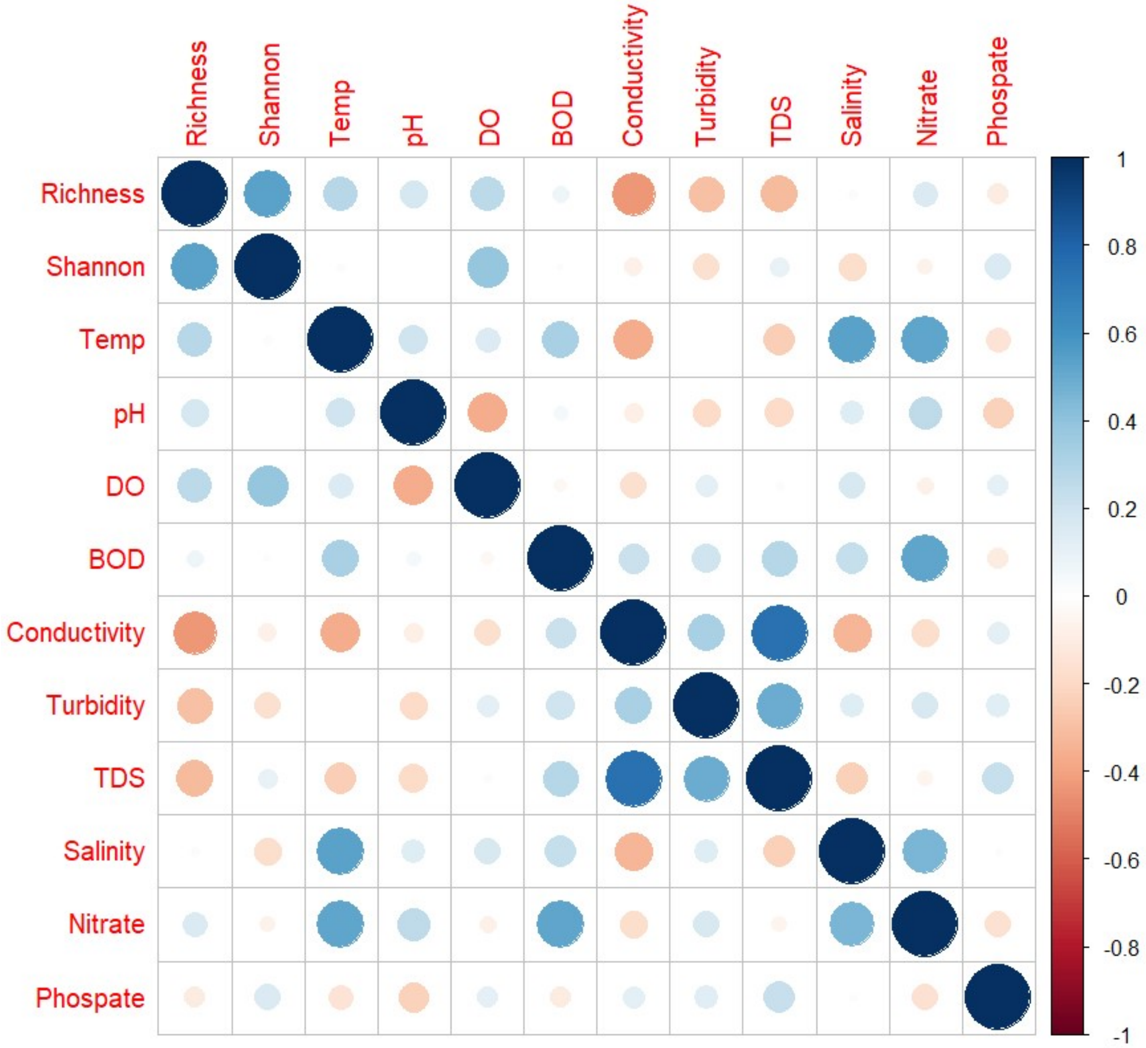


Figure 3.4: Correlation plot of species richness of Odonata, Shannon Index, and water quality parameters.

The multiple linear regression model was statistically significant when species richness was treated as the response variable (F-statistic = 2.244, p-value = 0.0438 < 0.05), but not when Shannon Index was (F-statistic = 1.585, p-value = 0.161 > 0.05). This suggests that the water quality parameters, as a group, have a significant relationship with species richness, but their relationship with Shannon Index is unclear. The Adjusted R-squared value of the species richness model is 0.2418, indicating that it explains about 24.18% of the variability in species richness. Dissolved oxygen (positive) and salinity (negative) are significant predictors of odonate species richness according to the model (Table 3.2). The model has no severe multicollinearity as evidenced by the Variance Inflation Factor (VIF) results. None of the VIF values exceed 5 (Table 3.3). The residuals show an approximately normal distribution, which is generally acceptable for linear regression (Figure 3.5).

Residuals:				
Minimum	1Q	Median	3Q	Maximum
-6.381	-2.4428	-0.8149	1.7874	7.8366
Coefficients:				
	Estimate	Std.Error	t value	Pr(>|t|)
(Intercept)	2.5374562	11.110529	0.228	0.821
Temp	0.1977846	0.2917474	0.678	0.5032
pH	1.4113784	0.9176468	1.538	0.1349
DO	0.8290796	0.3682502	2.251	0.0321*
BOD	0.5307781	0.4726961	1.123	0.2707
Conductivity	-0.0364704	0.0202477	-1.801	0.0821
Turbidity	-0.1773785	0.202942	-0.874	0.3893
TDS	-0.0008488	0.028153	-0.03	0.9762
Salinity	-0.9737073	0.4685922	-2.078	0.0467*
Nitrate	0.1140437	0.3486539	0.327	0.7459
Phosphate	0.077931	0.4432586	0.176	0.8617
Residual standard error: 4.19 on 29 degrees of freedom				
Multiple R-squared: 0.4362, Adjusted R-squared: 0.2418				
F-statistic: 2.244 on 10 and 29 DF, p-value: 0.0438				

Table 3.2: Summary of the regression model for species richness and water quality parameters.

Temp	**pH**	**DO**	**BOD**	**Cond**	**Turb**	**TDS**	**Salinity**	**Nitrate**	**Phosphate**
1.84	1.36	1.33	1.80	2.74	1.54	3.04	1.70	2.06	1.15

Table 3.3: Variance Inflation Factor (VIF) values of the water quality parameters

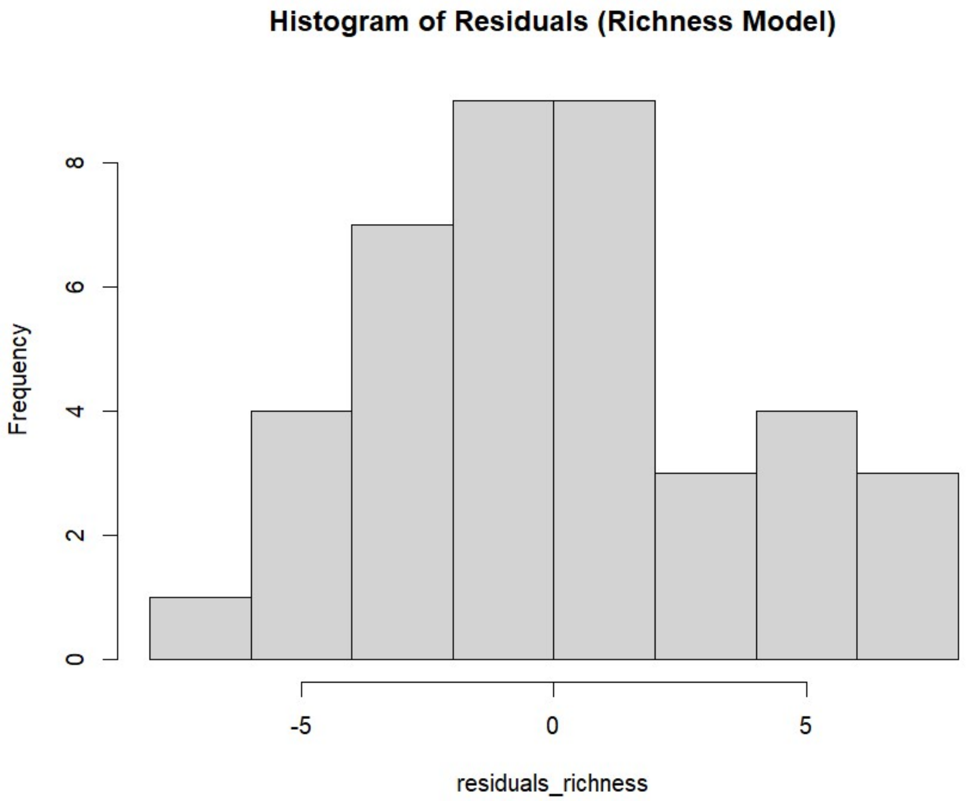


Figure 3.5: Histogram of residuals for the species richness model of multiple linear regression.

Based on this model, dissolved oxygen is the most important positive factor for Odonata species richness, while salinity is the most important negative factor. The positive relationship with DO makes ecological sense, as many aquatic organisms, including

Odonata larvae, require well-oxygenated water. The negative relationship with salinity suggests that Odonata in this study prefer freshwater.

According to the PERMANOVA run, there is a statistically significant difference in overall water quality between ponds and wetlands (F-statistic = 6.2397, p-value = 0.021 < 0.05). The R^2 value is 0.14104, meaning that about 14.1% of the total variance in water quality parameters can be explained by the habitat type (Table 3.4).

Permutation test for adonis under reduced model					
Terms added sequentially (first to last)					
Permutation: free					
Number of permutations: 999					
	Df	**Sum Of Sqs**	**R^2**	**F**	**Pr(>F)**
Habitat type	1	26373	0.14104	6.2397	0.021
Residual	38	160614	0.85896		
Total	39	186987	1		

Table 3.4: PERMANOVA table for water quality parameters (ponds vs. wetlands).

The NMDS plot shows a visible separation between ponds and wetland sites, although there is some overlap. This suggests that there are differences in overall water quality characteristics between the two habitat types. The NMDS plot supports the PERMANOVA results, showing that there are indeed differences in overall water quality between ponds and wetlands. (Figure 3.6).

The stress value obtained for the NMDS ordination is 0.1500576 (< 0.2) indicating that the NMDS provides a usable representation of the multivariate relationships in the water quality data. The observed separation between ponds and wetlands is meaningful, supporting the PERMANOVA results.

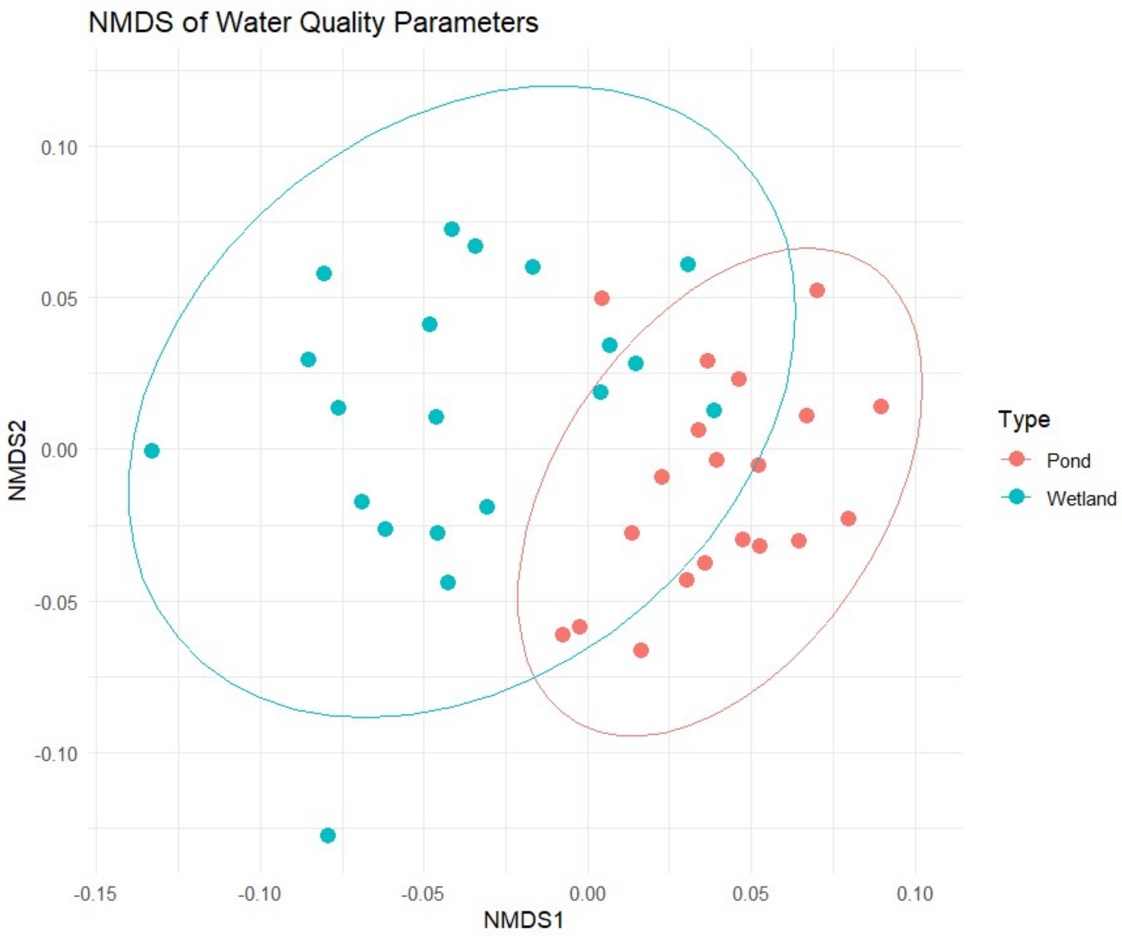


Figure 3.6: NMDS plot of water quality parameters (ponds and wetland sites).

The NMDS plot with environmental vectors (Figure 3.7) shows the effect of key influencing parameters. The longer vectors indicate stronger influences on the ordination. Vector direction shows the gradient of increase for that parameter.

- BOD: Strong influence, primarily differentiating along the vertical axis.
- TDS and Conductivity: Strong influences, associated more with pond sites.
- Nitrate: Moderate influence, more associated with wetland sites.
- Temperature and Salinity: Moderate influence, more associated with wetland sites.

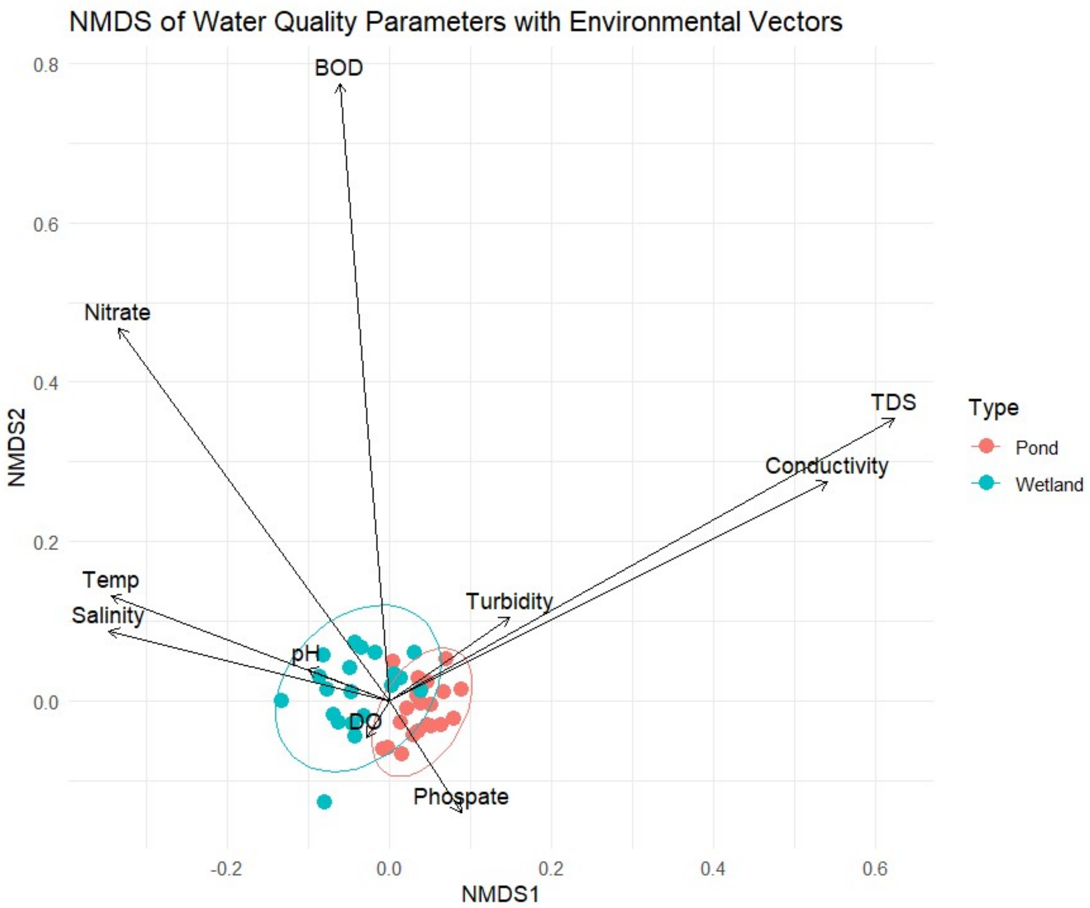


Figure 3.7: NMDS plot of water quality parameters with environmental vectors for ponds and wetland sites.

The following relationships between parameters are also revealed:

- TDS and Conductivity are closely aligned, which is expected as they are often correlated.
- Temperature and Salinity are closely associated, both more characteristic of wetlands.
- BOD and Nitrate are somewhat opposed, suggesting different nutrient dynamics.

The following site characteristics are notable:

- Ponds: Generally higher in TDS, Conductivity, and slightly higher in Turbidity.

- Wetlands: Tend to have higher Temperature, Salinity, and often higher Nitrate levels.
- BOD shows high variability, particularly in wetlands.

Many of the ponds sampled had evidence of waste dumping. Some of these ponds were also used for bathing, washing clothes, vehicles, etc. These could be the reasons for higher levels of TDS, Conductivity, and Turbidity. The Kole wetlands lie below sea level and parts of it are subjected to seasonal ingress of brackish water. This probably results in higher values of Salinity recorded. The higher levels of Nitrate recorded for wetlands are probably the result of fertilizer application in agriculture.

The environmental fit (Table 3.5) of these vectors shows that the effects of Temperature, BOD, Conductivity, TDS, and Nitrate are highly significant ($p < 0.001$), the effect of Salinity is very significant ($p < 0.01$), and the effects of Turbidity and Phosphate are significant ($p < 0.05$).

	NMDS1	**NMDS2**	r^2	**Pr(>r)**
Temp	-0.93355	0.35843	0.3679	0.001
pH	-0.92984	0.36795	0.1088	0.136
DO	-0.50842	-0.86111	0.0544	0.361
BOD	-0.07862	0.9969	0.7777	0.001
Conductivity	0.89124	0.45354	0.6078	0.001
Turbidity	0.81552	0.57873	0.1823	0.025
TDS	0.86961	0.49374	0.7172	0.001
Salinity	-0.96911	0.24662	0.3571	0.002
Nitrate	-0.58021	0.81447	0.5749	0.001
Phosphate	0.53774	-0.84311	0.1658	0.038
Permutation	**No. of permutations**			
Free	999			

Table 3.5: The environmental fit of vectors in NMDS.

Strong associations (r^2 values) are seen for BOD (0.7777), TDS (0.7172), Conductivity (0.6078), and Nitrate (0.5749).

Thus, BOD, TDS, Conductivity, and Nitrate have the strongest associations with the ordination. These are likely the key factors differentiating ponds and wetlands.

The community composition of Odonata species shows a statistically significant difference between ponds and wetlands according to the PERMANOVA (F-statistic = 7.9204, p-value = 0.001). Approximately 17.2% of the variation in community composition is explained by the difference between ponds and wetlands (Table 3.6).

Permutation test for adonis under reduced model					
Terms added sequentially (first to last)					
Permutation: free					
Number of permutations: 999					
	Df	**Sum Of Sqs**	**R^2**	**F**	**Pr(>F)**
Habitat type	1	0.7827	0.17248	7.9204	0.001
Residual	38	3.7553	0.82752		
Total	39	4.5381	1		

Table 3.6: PERMANOVA table for Odonata community composition in ponds and wetland sites.

SIMPER analysis gives the cumulative contributions of the most influential species to the dissimilarity between ponds and wetlands. According to this analysis, *Pantala flavescens* and *Brachythemis contaminata* together account for about 35% of the total dissimilarity in Odonata species composition between ponds and wetlands (Table 3.7).

Pantala flavescens	0.2595775
Brachythemis contaminata	0.3546492
Crocothemis servilia	0.4370892
Rhyothemis variegata	0.5098455
Acisoma panorpoides	0.5785635
Neurothemis tullia	0.6468344
Pseudagrion microcephalum	0.7132438

Table 3.7: Cumulative contributions of most influential species according to SIMPER analysis.

Both these species, the migratory *Pantala flavescens* especially, were seen more abundantly in the wetland sites compared to the ponds.

The Indicator Species Analysis for water quality has identified eight odonate species as indicators of water quality measures (Table 3.8, Figure 3.8).

Species	**Statistic**	**p-value**	**Relationship**	**Water quality parameter**
Agriocnemis keralensis	0.67535	0.008	+	Conductivity
Trithemis pallidinervis	0.671775	0.004	+	Phosphate
Pseudagrion australasiae	0.657129	0.009	+	Conductivity
Diplacodes trivialis	0.642262	0.04	+	Nitrate
Copera marginipes	0.58554	0.03	+	BOD
Paracercion calamorum	0.520749	0.028	-	DO
Platylestes platystylus	0.5	0.042	+	Conductivity
Libellago indica	0.5	0.04	-	Nitrate

Table 3.8: Odonata species and the corresponding water quality parameter they indicate.

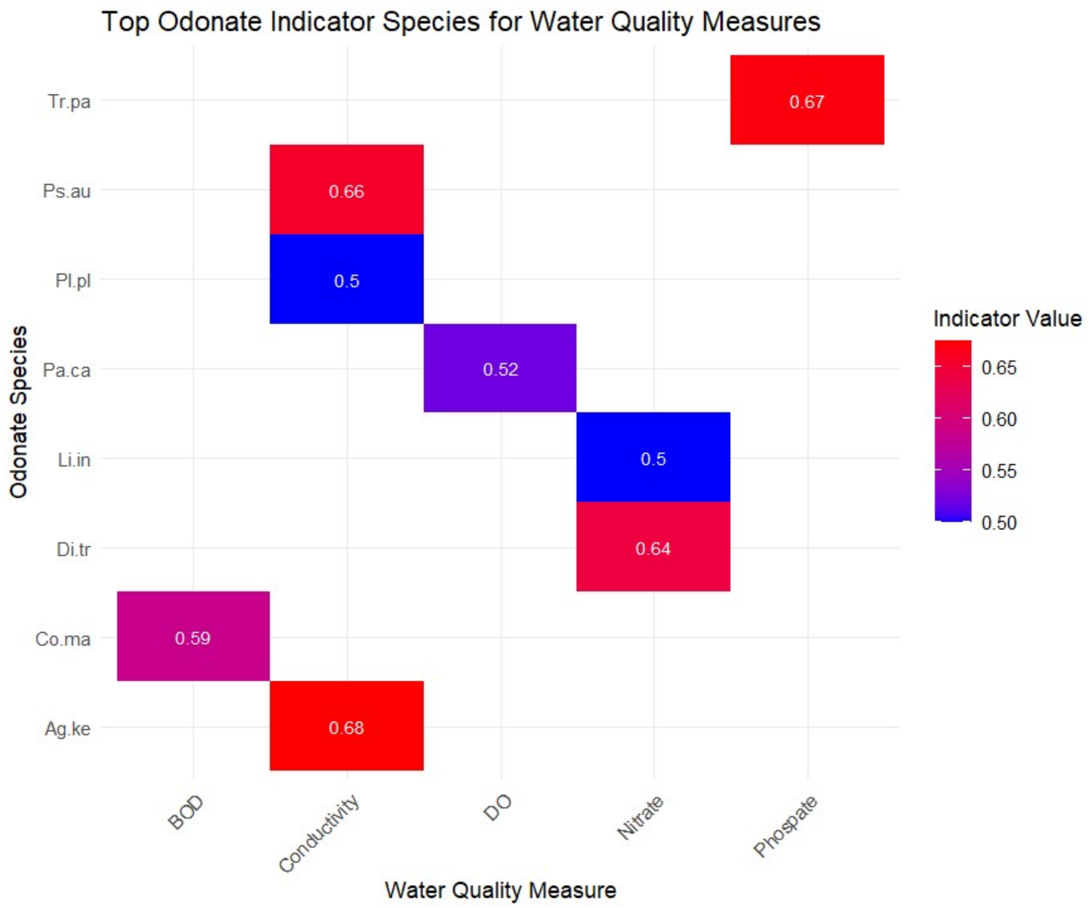


Figure 3.8: Odonata species and their indicator value for different water quality measures.

1. Conductivity: Three species (*Agriocnemis keralensis*, *Pseudagrion australasiae*, *Platylestes platystylus*) are indicators of high conductivity. This suggests these species prefer or are more tolerant of water with higher dissolved ion content.
2. BOD: *Copera marginipes* is an indicator of high BOD, suggesting it might tolerate or prefer waters with higher organic content.
3. DO: *Paracercion calamorum* is an indicator of low dissolved oxygen, which might mean it is adapted to less oxygenated waters.
4. Nutrients:
    - *Diplacodes trivialis* indicates high nitrate levels
    - *Libellago indica* indicates low nitrate levels
    - *Trithemis pallidinervis* indicates high phosphate levels

This analysis provides a good starting point for understanding the relationships between these odonate species and water quality parameters, which could be valuable for water quality assessment and monitoring programmes. It must be noted that these associations have been revealed for the adult stage of odonates when they are not expected to be affected by water quality as much as in the larval stage. This hints that with further studies, even adult Odonata, which are easier to record compared to their larval stages, could be used as biomonitoring tools in these wetlands.

The Indicator Species Analysis for habitat type resulted in three species, namely, *Trithemis pallidinervis*, *Brachydiplax sobrina*, and *Platylestes platystylus* showing strong and statistically significant preference for the wetland habitat type (Table 3.9, Figure 3.9). It is noteworthy that no odonate species had such a preference for ponds.

Species	**Statistic**	**p-value**	**Habitat**
Trithemis pallidinervis	0.669864	0.009	Wetland
Brachydiplax sobrina	0.591608	0.013	Wetland
Platylestes platystylus	0.5	0.044	Wetland

Table 3.9: Odonata species that are indicators of the wetland habitat type.

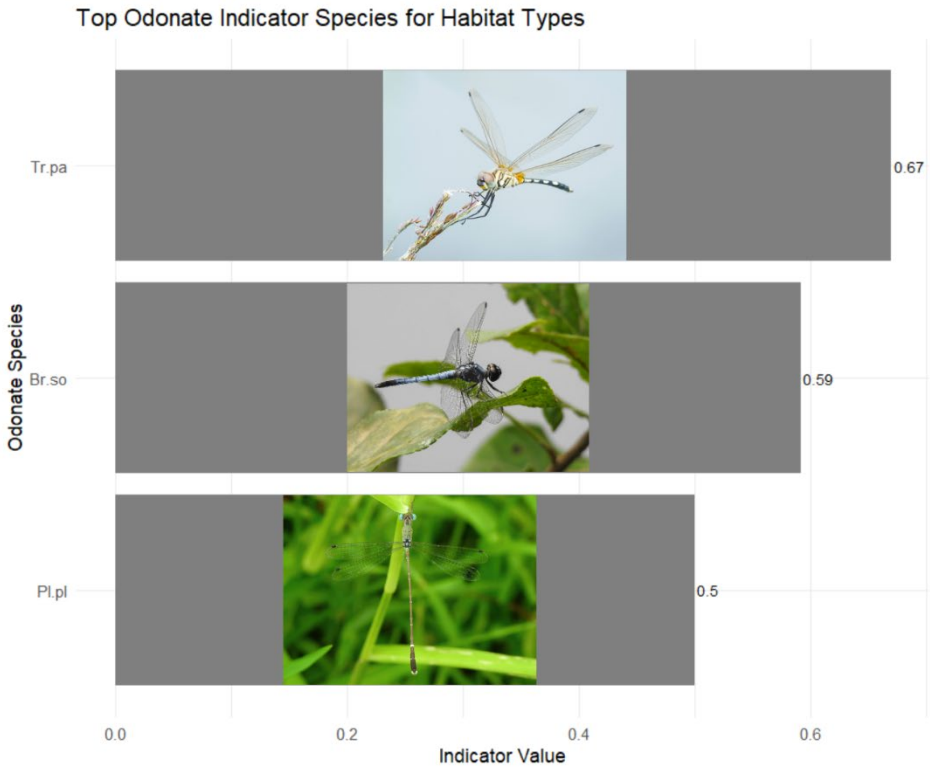


Figure 3.9: Odonata species that are indicators of wetland habitat type.

These results suggest that wetlands have a distinct odonate community compared to ponds. The three identified species, particularly *Trithemis pallidinervis*, could potentially be used as indicator species for wetland habitats in the region.

3.5. Conclusion

This study comparing Odonata diversity in Kole wetlands and adjacent ponds in Kerala, India revealed several key findings:

Wetlands supported higher Odonata species richness (44 species) compared to ponds (30 species), with 14 species found exclusively in wetlands. This higher diversity is likely due to the greater habitat heterogeneity in wetlands. Water quality parameters significantly influenced Odonata species richness, with dissolved oxygen showing a positive correlation and salinity a negative one. This underscores the importance of water quality in shaping Odonata communities.

Ponds and wetlands exhibited distinct water quality profiles, with ponds generally having higher TDS, conductivity, and turbidity, while wetlands showed higher temperature, salinity, and nitrate levels. These differences likely contribute to the observed variations in Odonata assemblages.

Community composition of Odonata differed significantly between ponds and wetlands, with *Pantala flavescens* and *Brachythemis contaminata* contributing most to this dissimilarity. Eight Odonata species were identified as potential indicators of specific water quality parameters, suggesting their utility in biomonitoring programmes. Notably, these associations were observed in adult Odonata, indicating that even this life stage could be valuable for water quality assessment. Three species - *Trithemis pallidinervis*, *Brachydiplax sobrina*, and *Platylestes platystylus* - showed strong preference for wetland habitats, potentially serving as wetland indicator species in the region.

These findings highlight the ecological importance of wetlands in supporting diverse Odonata communities and underscore the complex relationships between water quality, habitat type, and Odonata diversity. The study provides valuable insights for conservation strategies and suggests that adult Odonata could be effective bioindicators for both water quality and wetland habitats. Future research should focus on long-term monitoring to assess temporal changes in Odonata communities and their responses to environmental variations, as well as investigating the mechanistic links between specific water quality parameters and Odonata species preferences.

3.6. References

Bried, J. T., & Hinchliffe, R. P. (2018). Improving taxonomic resolution in large-scale freshwater biodiversity monitoring: an example using wetlands and Odonata. *Insect Conservation and Diversity*, *11*(6), 1-9. https://doi.org/10.1111/icad.12323

Chandran, A. V., Muneer, P. K., Madhavan, M., & Jose, S. K. (2025) Odonata diversity of the Kuruva Islands, southern India, with notes on the ecology of *Disparoneura apicalis* (Fraser, 1924) (Odonata: Platycnemididae). *Journal of Insect Biodiversity and Systematics*, *11*(in press).

Chovanec, A., & Waringer, J. (2001). Ecological integrity of river-floodplain systems—Assessment by dragonflies (Insecta: Odonata). *Regulated Rivers: Research & Management, 17*(4–5), 493–507. https://doi.org/10.1002/rrr.636

Clausnitzer, V., Simaika, J. P., Samways, M. J., & Daniel, B. A. (2017). Dragonflies as flagships for sustainable use of water resources in environmental education. *Applied Environmental Education & Communication, 16*(3), 196-209. https://doi.org/10.1080/1533015X.2017.1333050

Corbet, P. S. (1999). *Dragonflies: Behavior and ecology of Odonata*. Harley Books.

Crump, M. L., & Scott, N. J. (1994). Visual encounter surveys. In W. R. Heyer, M. A. Donnelly, R. W. McDiarmid, L. A. C. Hayek, & M. S. Foster (Eds.), *Measuring and monitoring biological diversity: Standard methods for amphibians* (pp. 84–92). Smithsonian Institution Press.

Fraser, F. C. (1933). *The fauna of British India, including Ceylon and Burma: Odonata, Vol. I*. Taylor and Francis.

Fraser, F. C. (1934). *The fauna of British India, including Ceylon and Burma: Odonata, Vol. II*. Taylor and Francis.

Fraser, F. C. (1936). *The fauna of British India, including Ceylon and Burma: Odonata, Vol. III*. Taylor and Francis.

Hassall, C. (2014). The ecology and biodiversity of urban ponds. *Wiley Interdisciplinary Reviews: Water, 1*(2), 187–206. https://doi.org/10.1002/wat2.1014

Jere, A., Darshetkar, A., Patwardhan, A., & Koparde, P. (2020). Assessing the response of odonates (dragonflies and damselflies) to a tropical urbanization gradient. *Journal of Urban Ecology, 6*(1), 1-7. https://doi.org/10.1093/jue/juaa029

Koparde, P., Mhaske, P., & Patwardhan, A. (2015). Habitat correlates of Odonata species diversity in the northern Western Ghats, India. *Odonatologica, 44*(1/2), 21-43.

Koparde, P. (2016). Damsels in distress – seasons, habitat structure and water pollution changes damselfly diversity and assemblage in urban wetlands. *Animal Biology*, *66*(3-4), 305-319. https://doi.org/10.1163/15707563-00002506

Kulkarni, A. S., & Subramanian, K. A. (2013). Habitat and seasonal distribution of Odonata (Insecta) of Mula and Mutha river basins, Maharashtra, India. *Journal of Threatened Taxa, 5*(7), 4084-4095. http://dx.doi.org/10.11609/JoTT.o3253.4084-95

Kutcher, T. E., & Bried, J. T. (2014). Adult Odonata conservatism as an indicator of freshwater wetland condition. *Ecological Indicators, 38*, 31-39. https://doi.org/10.1016/j.ecolind.2013.10.028

Mitra, T. R. (1999). Biology and ecology of dragonflies (Insecta: Odonata) with notes on their adaptations in different ecosystems of India. *Records of the Zoological Survey of India*, *97*(2), 173-188.

Oertli, B., Joye, D. A., Castella, E., Juge, R., Cambin, D., & Lachavanne, J.-B. (2005). Ponds and biodiversity: Functional roles of ponds and isolated water bodies in the landscape. *Biological Conservation, 104*(2), 171–179. https://doi.org/10.1016/j.biocon.2004.12.024

Perron, M., & Pick, F. R. (2020). A framework for assessing the biodiversity and ecological functions of wetlands. *Ecological Indicators, 113*, 106-113. https://doi.org/10.1016/j.ecolind.2020.106113

Perron, M. A. C., Richmond, I. C., & Pick, F. R. (2021). Plants, water quality and land cover as drivers of Odonata assemblages in urban ponds. *Science of the Total Environment*, 773, 145467. https://doi.org/10.1016/j.scitotenv.2021.145467

Samways, M. J., & Steytler, N. S. (1996). Dragonfly (Odonata) distribution patterns in urban and forest landscapes, and recommendations for riparian management.

Biological Conservation, 78(3), 279-288. https://doi.org/10.1016/S0006-3207(96)00032-8

Subramanian, K. A. (2005). *Dragonflies and damselflies of Peninsular India - A field guide*. Indian Academy of Sciences.

Subramanian, K. A. (2009). *Damselflies and dragonflies of India - A field guide*. Indian Academy of Sciences.

Suhling, F., Sahlén, G., Kasperski, J., & Gaedecke, D. (2004). Behavioral and ecological traits of Odonata—Comparing specialists and generalists. *Insect Science, 11*(2), 125–132. https://doi.org/10.1111/j.1744-7917.2004.tb00104.x

Tiple, A. D., & Koparde, P. (2015). Odonata of Maharashtra, India with notes on species distribution. *Journal of Insect Science, 15*(1), 47. https://doi.org/10.1093/jisesa/iev028

Vilenica, M., Brigić, A., Štih Koren, A., Koren, T., Sertić Perić, M., Schmidt, B., Bužan, T., & Gottstein, S. (2024). Odonata assemblages in urban semi-natural wetlands. *Insects*, *15*(3), 207. https://doi.org/10.3390/insects15030207

Chapter 4

ECOLOGY OF ODONATA LARVAE

4.1. Introduction

Effective conservation of odonates depends on thorough assessments of both their distribution and habitat needs. While odonates have aquatic (larval) and terrestrial (adult) life stages, most surveys focus solely on sampling the adult stage. This bears the risk of underestimation of Odonata diversity in the habitat. Odonates spend most of their life as aquatic larvae, compared to the relatively short adult stage. Studying larvae provides insights into their ecology and life history that cannot be inferred from adult studies alone. Also, some odonate species are cryptic or elusive as adults. Such species may be found through larval sampling, which would yield a more thorough inventory of the biodiversity in the area. As they reflect pollution levels, oxygen availability, and habitat structure in aquatic habitats, odonates are effective bioindicators of habitat conditions and water quality. Since the larval stage lives in water, it is crucial to sample them in order to investigate their function as water quality indicators. Larvae frequently exhibit habitat specificity, indicating preferences for specific substrates, flora, or types of water bodies, which helps with habitat conservation planning. Since environmental conditions have a direct impact on the distribution, abundance, and ecological significance of odonates in aquatic habitats, it is imperative to comprehend how these factors affect odonate larval diversity. Incorporating larval studies into odonate research provides a comprehensive understanding of their biology while enhancing their utility as bioindicators of environmental health.

Calvert (1893) and Williamson (1923) provided taxonomic descriptions of odonate larvae of numerous North American taxa, laying the groundwork for early odonate larval research. Needham's (1901) thorough study of the area's odonate larvae includes ecological linkages, sampling and rearing techniques, and in-depth life cycle observations. In-depth descriptions of larval biology were provided by Corbet (1962, 1999), who concentrated on voltinism, growth and development, feeding behavior, respiratory systems, emerging patterns, diapause mechanisms, and ecological linkages. Ecological energetics research on odonate larvae was first conducted by Lawton (1971). Pierce et al. (1985) investigated the ecological and behavioral interactions of Odonata larvae in Sullivan County, USA, ponds. Corbet (2002) gave a comprehensive review of odonate larval development and standardized the terminology. Important ecological studies on odonate larvae at the turn of the century included the works of Johansson and Brodin (2003) who studied effects of fish predators and abiotic factors on Odonata community structure, and McCauley (2008) who examined the relationship between the distribution of odonate larvae across a gradient of habitat permanence and an associated transition in the composition of top predators. Tüzün and Stoks (2018) studied the carry-over effects of late hatching of odonate larvae on lifetime mating success in odonates. Jinguji et al. (2020) did an experimental study to suppress *Aedes* mosquito larvae using libellulid larvae in Japan with remarkable success. Brito et al. (2020) found that aquatic macrophytes are important substrates for libellulid larvae in the Brazilian Amazon region. Silva et al. (2021) investigated the functional responses of odonate larvae to human disturbances in neotropical savanna headwater streams.

The first detailed descriptions of Indian odonate larvae were given by Fraser (1933, 1934, 1936). Scientists of Zoological Survey of India gave larval descriptions of several other species. Kumar (1979, 1980, 1984, 1989) studied the life history of some common Indian odonates by rearing their larvae. Kumar and Khanna (1983) published a review of taxonomy and ecology of Indian odonate larvae. Subramanian (2005) built a family-level key to the larvae of Indian odonates. For the first time in India, larvae of an odonate species, *Lyriothemis tricolor* Ris, 1919, were collected from phytotelmata in the Western Ghats and described by Das et al. (2013). More larvae were described by Dawn and Chandra (2016), Dawn (2019), and Payra et al. (2021) from different parts of India. The work by Koparde et al. (2019) is the sole ecological study on odonate larvae in India where the researchers studied species turnover along an urbanization gradient. Only about 15% of Indian species are thought to have known larval stages, and fewer than 10% of them have had their entire life histories determined (Subramanian & Babu, 2020).

The ecology of Odonata larvae in the Kole wetlands is examined in this chapter, with an emphasis on how environmental conditions influence the larvae's abundance and distribution in these aquatic environments. The study sought to uncover important factors impacting larval diversity and habitat preferences in these wetlands through systematic sampling and analysis of various environmental parameters, such as water quality, soil properties, vegetation patterns, and seasonal fluctuations. Key questions regarding the interactions and responses of odonate larvae to changing ecological conditions are addressed in this study, offering valuable information for both their conservation and the overall management of wetland ecosystems.

4.2. Materials and Methods

For sampling Odonata larvae, the same long-term sites fixed for sampling adults and exuviae in the Kole wetlands were chosen. This included Biyyam, Naranipuzha, and Uppungal in Ponnani Kole, Mulloorkayal, Kanjani, and Palakkal in Thrissur North Kole, and Thottipal, Kattur, and Thommana in Thrissur South Kole. Each site was visited once in each of the four seasons (M1, M2, W, S) as done for monitoring adults and exuviae. Quadrat method was used to sample odonate larvae (Sutherland, 2006; Callisto et al., 2021) A quadrat (1 m x 1 m) was made using PVC pipes and connectors. The size of the quadrat was fixed based on a species-area curve. During each field visit, this quadrat was put over water to collect samples of Odonata larvae, water, macrophytes, and soil (Figure 4.1). At first, a water sample was taken from the quadrat causing the least disturbance. A D-frame aquatic net (nylon mesh size 500 µ, dimensions 30 cm x 29 cm x 19 cm) was used to collect Odonata larvae from water. In each bout of larval collection, three sweeps with the net were made, one targeting macrophytes, one targeting the water column, and one targeting the soil underneath. After each sweep, the contents were transferred to a white tray which was thoroughly searched. The obtained Odonata larvae were transferred to plastic vials filled with water and taken back to the laboratory. Two 1 Kg soil samples were taken in zip-lock covers, one was used for determining pH, organic carbon content, and sieve analysis, while the other was used for pesticide residue analysis. The macrophytes were identified at the species level after discussion with experts. Vegetation cover was estimated as a percentage of the water column in the quadrat covered by the macrophytes. The larval collections were supplemented with random sampling for larvae in the wetlands, as was done for the adults.

4.3. Laboratory techniques

The collected Odonata larvae were identified after examining them under a stereomicroscope (Labomed CZM4) and referring to published keys (Subramanian, 2005; Subramanian and Babu, 2020) and reference collections of Prof. Prosenjit Dawn (Department of Zoology, Shyampur Siddheswari Mahavidyalay, Howrah, West Bengal). Larvae that were difficult to be identified were reared in the laboratory in an aquarium till they reached adulthood (Figure 4.2).

Temperature (°C), pH, dissolved oxygen (mg/L), conductivity (μS/cm), turbidity (NTU), TDS (ppm), and salinity (ppt) were measured in the field itself using a multiparameter water quality analyser (Deluxe Model 191 E). Depth of water was measured using a meter scale carried to the field. Biochemical oxygen demand (BOD) was calculated after incubating the water samples at 20°C for 5 days in the laboratory. Nitrate (mg/L) and phosphate (mg/L) levels were measured using a UV-VIS Spectrophotometer (Model LT 2900) in the water samples carried to the laboratory.

Soil pH was measured by preparing a slurry of soil and distilled water in a 1:1 ratio. Soil texture analysis for determining the percentages of sand, silt, and clay was done using the pipette method. Organic carbon content in soil samples was estimated using the Walkley-Black method. Pesticide residue analysis was carried out in the Pesticide Residue Analysis Laboratory of Kerala Agricultural University, Vellanikkara, Thrissur. In this, the air-dried soil samples were subjected to gas chromatography (GC) and high-performance liquid chromatography (HPLC) to detect traces of organochlorines, organophosphates, and synthetic pyrethroids (ppm).

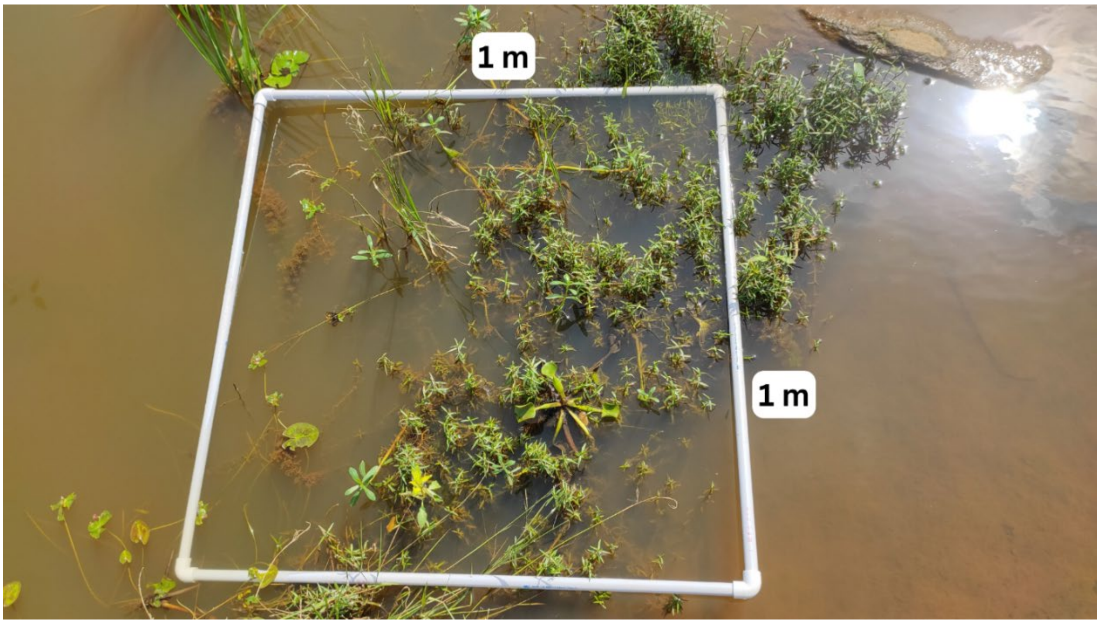


Figure 4.1: Quadrat put in Palakkal, one of the study sites, for collecting samples.

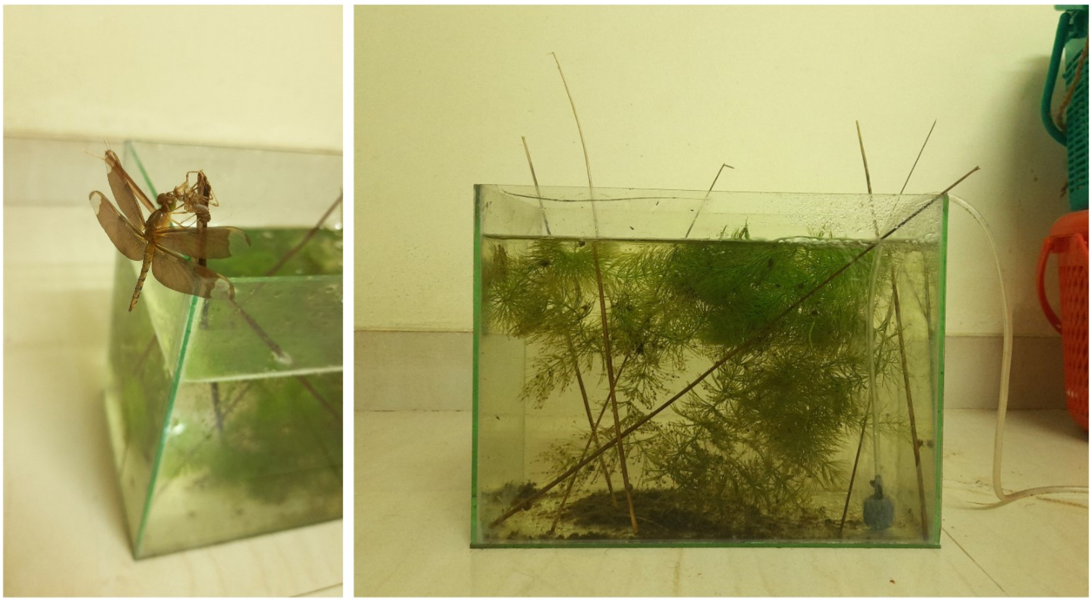


Figure 4.2: Larva of *Neurothemis fulvia* that was reared to adulthood in the laboratory.

4.4. Data analysis

The packages 'vegan' and 'ggplot2' of R v. 4.3.3 were used for the basic analysis and plotting respectively. A species accumulation curve was drawn to assess the completion of the sampling of odonate larvae. Boxplots for species richness and Shannon Index were drawn to represent the seasonal changes in the diversity of odonate larvae. A correlation heatmap was drawn to visualize how odonate larval diversity and habitat parameters were related. A multivariate Shapiro-Wilk test was performed to check the normality of the dataset. A Principal Component Analysis (PCA) was performed using the package 'factoextra' to study the effect of habitat variables on odonate larvae. The PCA plots were visualized using the package 'tidyverse'.

4.5. Results and discussion

A total of 163 Odonata larvae belonging to 33 species (21 Anisoptera & 12 Zygoptera species) were collected across the four seasons of a year (Figures 4.3 & 4.4). *Agriocnemis pygmaea* was the most abundant species, with larvae found in all seasons and the highest total count. *Urothemis signata* and *Brachydiplax chalybea* were the next most abundant species.

Figure 4.3: Larva of *Brachythemis contaminata* observed under the stereomicroscope.

Figure 4.4: Larva of *Copera marginipes* observed in the field.

Many species had very low counts, with some only appearing in one season. Winter (W) and Monsoon 2 (M2) seem to be the most productive seasons for most species. Some species, like *Rhodothemis rufa*, are only found in one season (Winter in its case). Some species appear to be seasonal specialists. For example, *Urothemis signata* is primarily found in M2 and W seasons (Figure 4.5). The seasonal variations could reflect differences in breeding patterns, habitat conditions, or resource availability across seasons. The varying abundance and seasonality of different species suggest that conservation efforts may need to consider seasonal patterns to protect biodiversity effectively.

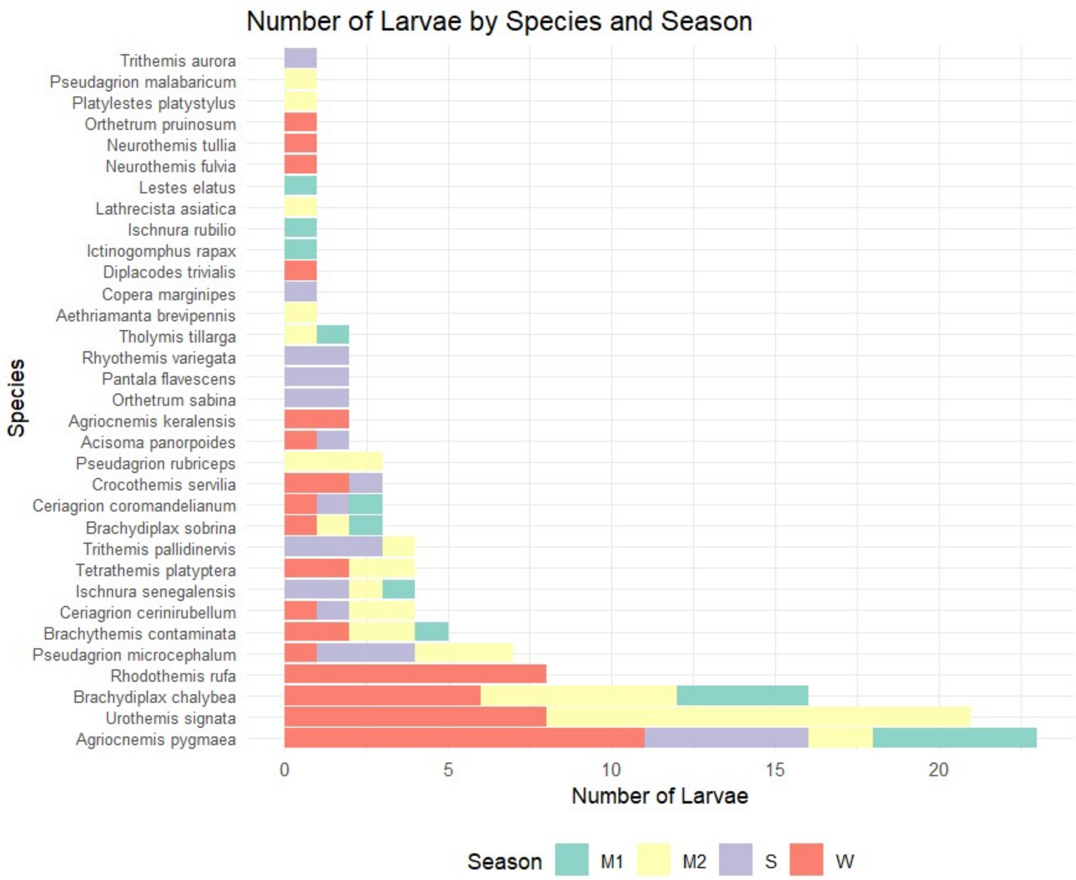


Figure 4.5: Seasonal abundance of Odonata larvae in Kole wetlands.

Notably, larvae of only 33 species of odonates could be recorded in the study, out of the 63 species recorded in the study of adults. Also, studying larvae did not increase the total species count, i.e., all the odonate species recorded as larvae were also detected as adults in the Kole wetlands. The lower number of larval species could be due to sampling limitations. Larval sampling is more challenging and may not have captured all species present. Some larval habitats like canals were difficult to access and sample effectively. Some species might use the Kole wetlands primarily for adult activities (feeding, mating) but breed elsewhere. This could explain why their larvae were not found. Also, because of logistic limitations, larval sampling was carried out for only one year, whereas adult sampling was done for two years.

The species accumulation curve shows a rapid initial increase, which then slows down but continues to rise (Figure 4.6). This pattern indicates that while the study has been successful in capturing most of the common species, some of the rare species could have been missed.

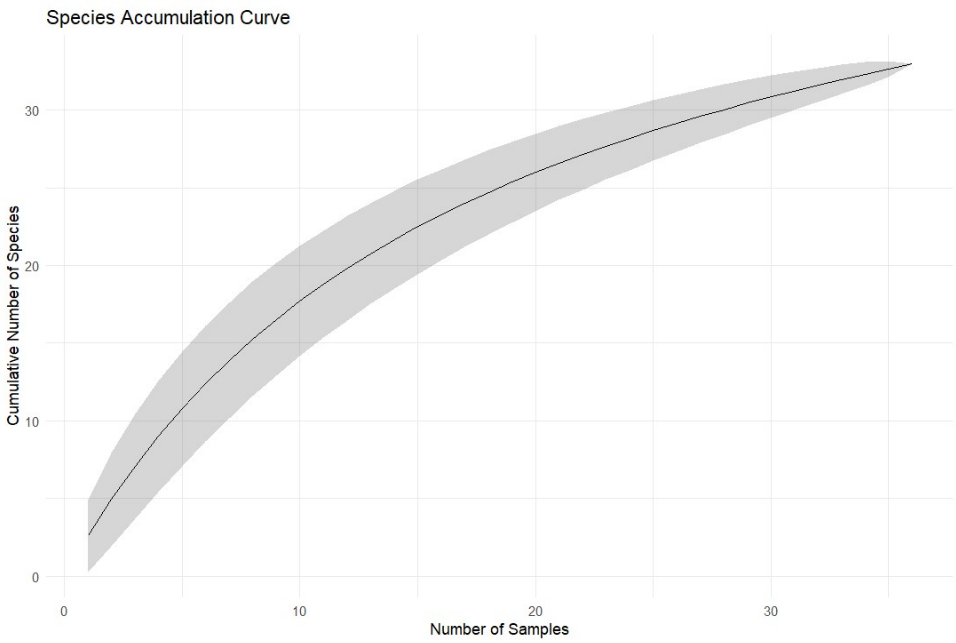


Figure 4.6: Species accumulation curve of Odonata larvae.

For a comprehensive inventory, more sampling might be beneficial, but for ecological analyses, the current sampling effort is likely sufficient to represent the community structure.

The graphs for species richness by season (Figure 4.7) and Shannon Index by season (Figure 4.8) show that M2 and W are the most diverse and species-rich seasons for odonate larvae. S and M1 consistently show lower diversity and richness. Summer (S) generally has low diversity but with some highly diverse outlier sites. The outlier sites in S might represent important refuge habitats during water scarcity. In contrast to the larval data, adult/exuviae data shows peaks in M1 (first monsoon) for both years of study (Chapter 2, Figure 2.8). This discrepancy suggests a potential time lag between larval development and adult emergence, with larvae developing during M2 and W potentially emerging as adults in the following M1. Both larval and adult/exuviae data show lower diversity in summer, with some exceptions (outliers in larval data, slight variation in adult data between years). Odonates in the tropics are known to siccatate as adults during the dry season (Corbet, 1999) when they await the rainy season away from water. This could be the reason for the dip in their detection from the wetlands during this period.

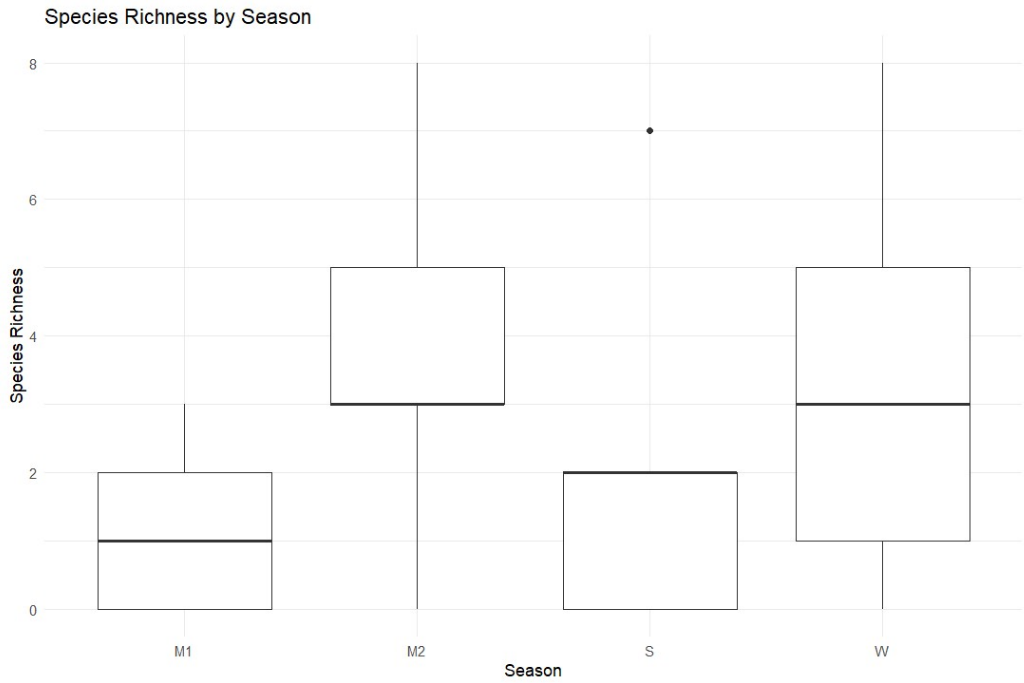


Figure 4.7: Species richness of odonate larvae in the four seasons.

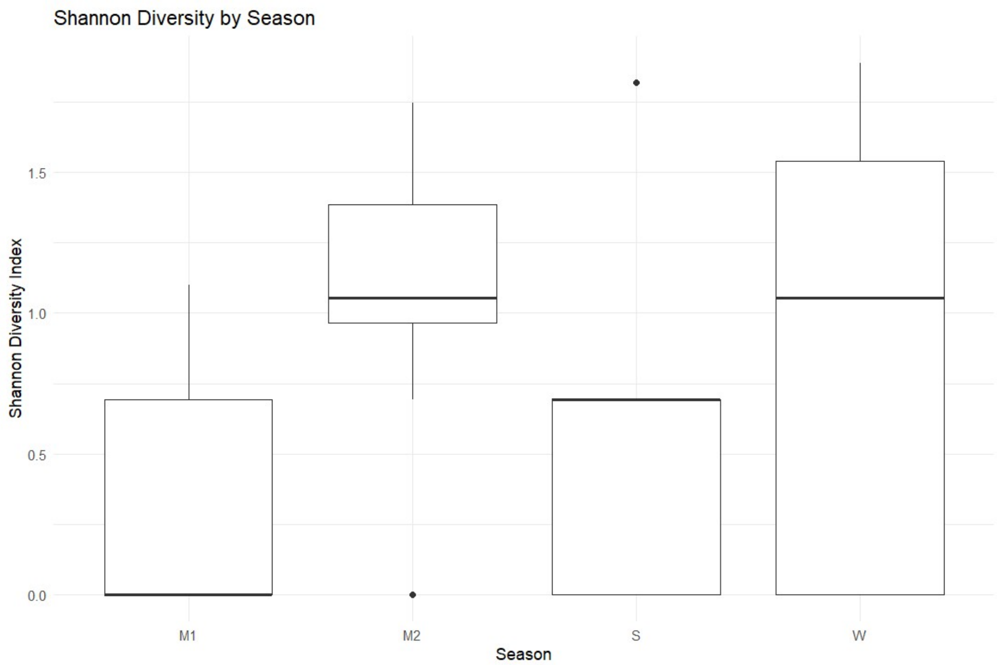


Figure 4.8: Diversity of odonate larvae as measured by Shannon Index in the four seasons.

The high larval diversity in M2 and W, followed by high adult diversity and exuviae counts in M1, suggests a possible pattern where larvae develop over M2 and W, with mass emergence in the following M1. The differences between larval and adult/exuviae patterns highlight the complex dynamics of odonate life cycles in this ecosystem, with different seasons playing crucial roles for different life stages. Comparing the larval data to the adult and exuvial data reveals this system's complex picture of odonate ecology. It highlights the importance of studying multiple life stages to fully understand population dynamics and emphasizes the need for comprehensive, year-round approaches to odonate conservation and management in these wetlands.

The correlation heatmap represents a correlation matrix between various environmental parameters and Odonata diversity (Figure 4.9). The variables are listed along both axes, showing how each variable correlates with every other variable. The diagonal is always dark blue (1.0) as it represents each variable's correlation with itself.

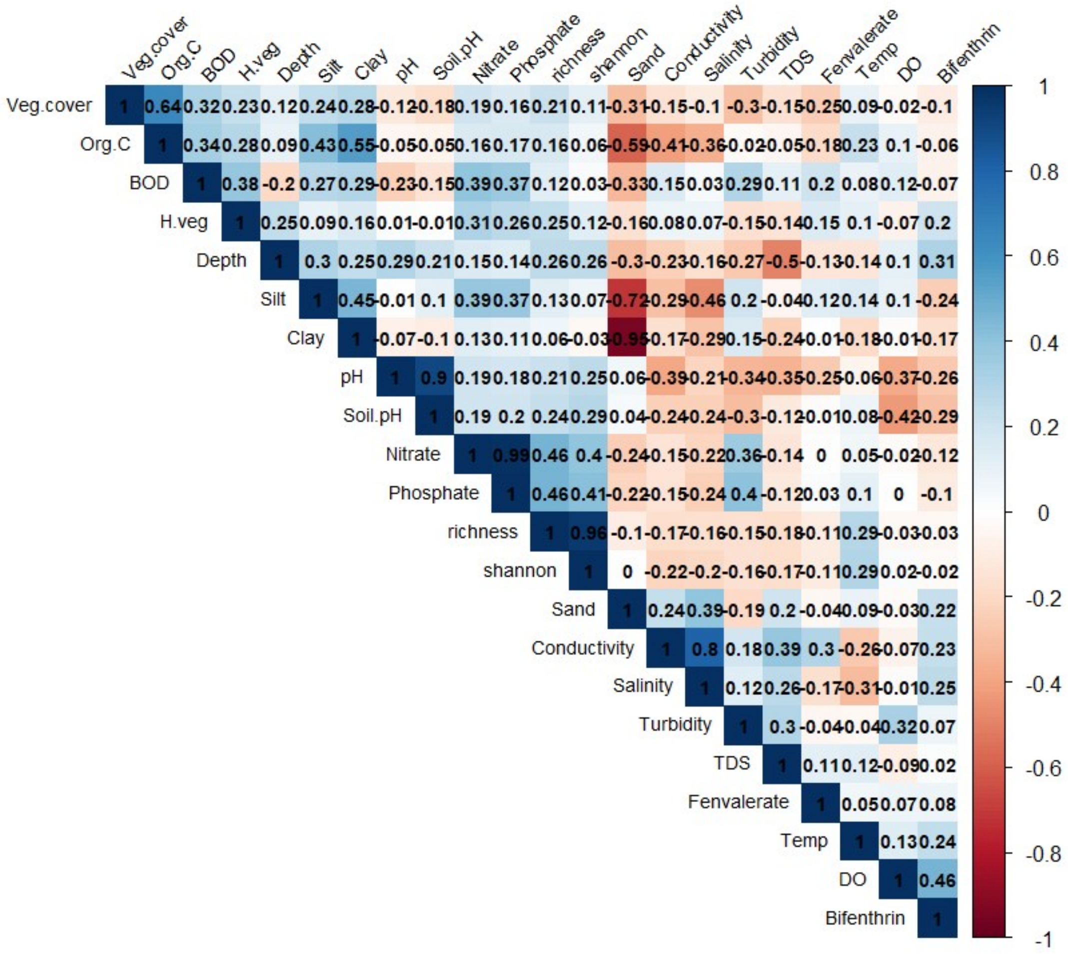


Figure 4.9: Correlation heatmap showing the relationships between the measured environmental parameters and odonate diversity.

The following are the key takeaways from the heatmap:

1. Vegetation cover (Veg.cover):
    - Strong positive correlation with organic carbon (Org C) and BOD.
    - Moderate positive correlation with H.veg (Shannon Index for vegetation) and depth.
    - This suggests that areas with more vegetation cover tend to have higher organic content, biological activity, and water depth.

2. Organic Carbon (Org C):
    - Strong positive correlations with BOD and vegetation cover.

- Moderate positive correlations with H.veg, depth, and silt content.
- This indicates that areas with higher organic carbon have more biological activity and tend to be in deeper, siltier areas with more vegetation.

3. Biodiversity metrics (richness and Shannon index):
    - Strong positive correlation with each other.
    - Moderate positive correlations with nitrate and phosphate levels.
    - This suggests that nutrient availability may be important for odonate diversity.
4. pH and Soil pH:
    - Strong positive correlation with each other.
    - Moderate positive correlations with nitrate and phosphate.
    - This indicates that pH levels in water and soil are linked and may influence nutrient availability.
5. Nitrate and Phosphate:
    - Strong positive correlation with each other.
    - Moderate positive correlations with biodiversity metrics.
    - This reinforces the importance of nutrients for odonate diversity.
6. Physical parameters:
    - Depth shows moderate positive correlations with vegetation metrics and organic carbon.
    - Silt and clay content have some opposing relationships with other variables.
7. Water quality parameters:
    - Conductivity shows a strong positive correlation with salinity and TDS.
    - DO (Dissolved Oxygen) has a moderate positive correlation with temperature.
8. Pesticides (Fenvalerate and Bifenthrin):

- Weak correlations with most variables, suggesting limited impact or presence in the study area.

This correlation matrix provides insights into the ecological relationships in the odonate habitat, highlighting the importance of vegetation, organic matter, and nutrients for odonate diversity in the studied wetland ecosystem. The high levels of nitrate and phosphate in the wetlands are most probably due to the application of chemical fertilizers that are widespread here for cultivating paddy. The odonate larvae recorded in this study seem to largely benefit from the high nutrient levels, as it may be causing an increased food supply in the form of small invertebrates and microorganisms. Also, the growth of aquatic plants and algae provides more complex habitats, offering hiding spots and hunting grounds for odonate larvae. It must also be noted that the high nutrient levels are not leading to hypoxic conditions in these wetlands as evidenced by the low correlations between dissolved oxygen and nutrient levels. This is probably because of high water flow and good mixing, partially contributed to by the agricultural practices that require water to be pumped in and out at different stages of paddy growth.

The pesticide residue analysis was focused only on soil because soil often acts as a major sink for pesticides due to its ability to adsorb and retain these chemicals. Also, pesticides tend to persist longer in soil due to lower degradation rates compared to other compartments (Dhuldhaj et al., 2022). The only pesticide residues detected in the study were fenvalerate and bifenthrin, which have weak correlations with most variables, suggesting limited impact and presence in the study area. Even though the use of pesticides is regular in these wetlands (Figure 4.10), they may degrade quickly in the wetland environment due to factors like sunlight, microbial activity, or hydrolysis, reducing their persistence and detectability.

Figure 4.10: Pesticides being applied to the paddy crop in Kole wetlands.

The multivariate Shapiro-Wilk test shows that the variables measured in this study are normally distributed (W = 97479, p-value = 0.5697). According to the quantile-quantile (Q-Q) plots, most variables show reasonably good alignment with the diagonal line, indicating approximate normality (Figure 4.11). Conductivity, Turbidity, and TDS show some right-skewness. Bifenthrin and Fenvalerate show severe non-normality. These are heavily zero-inflated variables, as evidenced by the horizontal lines in their plots. To explore the influence of environmental variables on odonate larvae, it was decided to proceed with Principal Component Analysis (PCA) since most variables conform to normality and PCA is not heavily influenced by non-normality, especially of a few parameters.

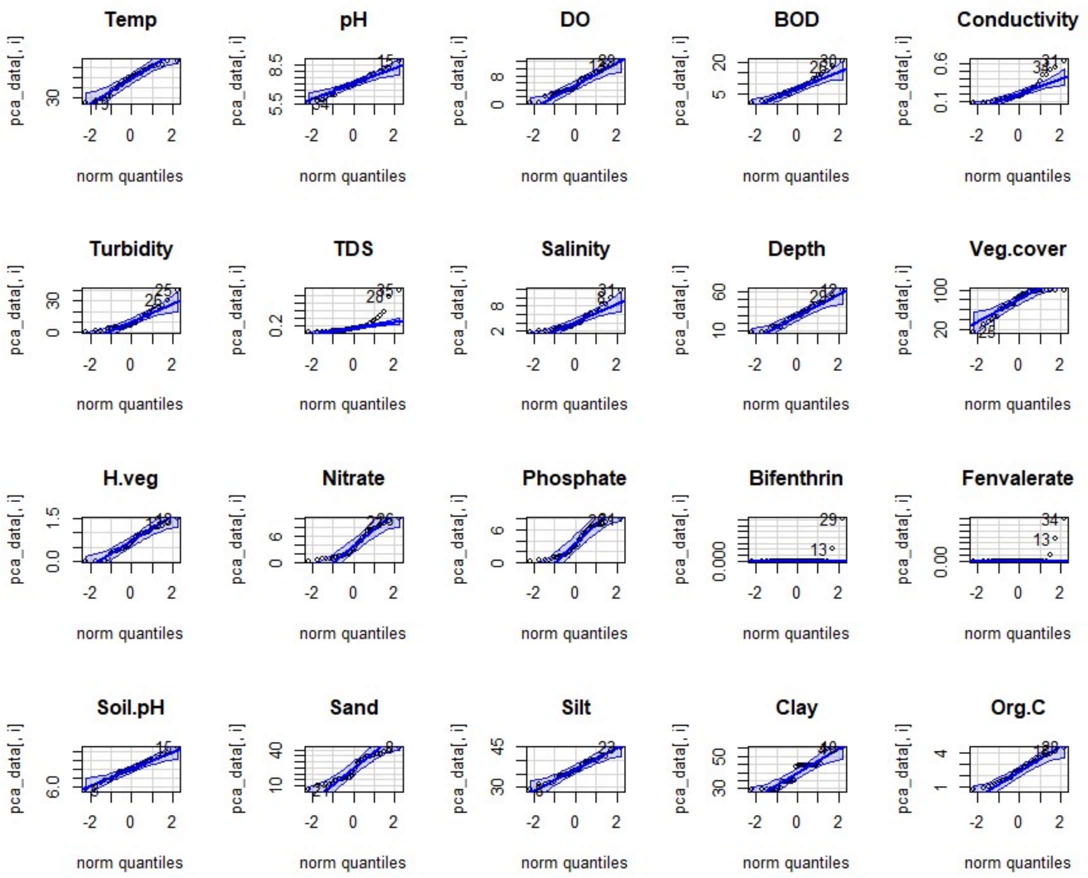


Figure 4.11: Q-Q plots of the measured environmental variables.

Principal Component Analysis (PCA) was conducted to elucidate the key environmental factors influencing the distribution of odonate larvae in the Kole wetlands across different seasons. The analysis incorporated 20 environmental variables, providing insights into the complex interactions between habitat characteristics and seasonal patterns.

1. Variance Explained and the Principal Components

The scree plot (Figure 4.12) illustrates that the first three principal components (PCs) collectively account for 49% of the total variance in the dataset. Specifically, PC1 explains 22.4%, PC2 explains 15.7%, and PC3 explains 10.9% of the variance. The gradual decline in explained variance suggests that multiple environmental factors contribute to habitat variability, reflecting the ecosystem's complexity.

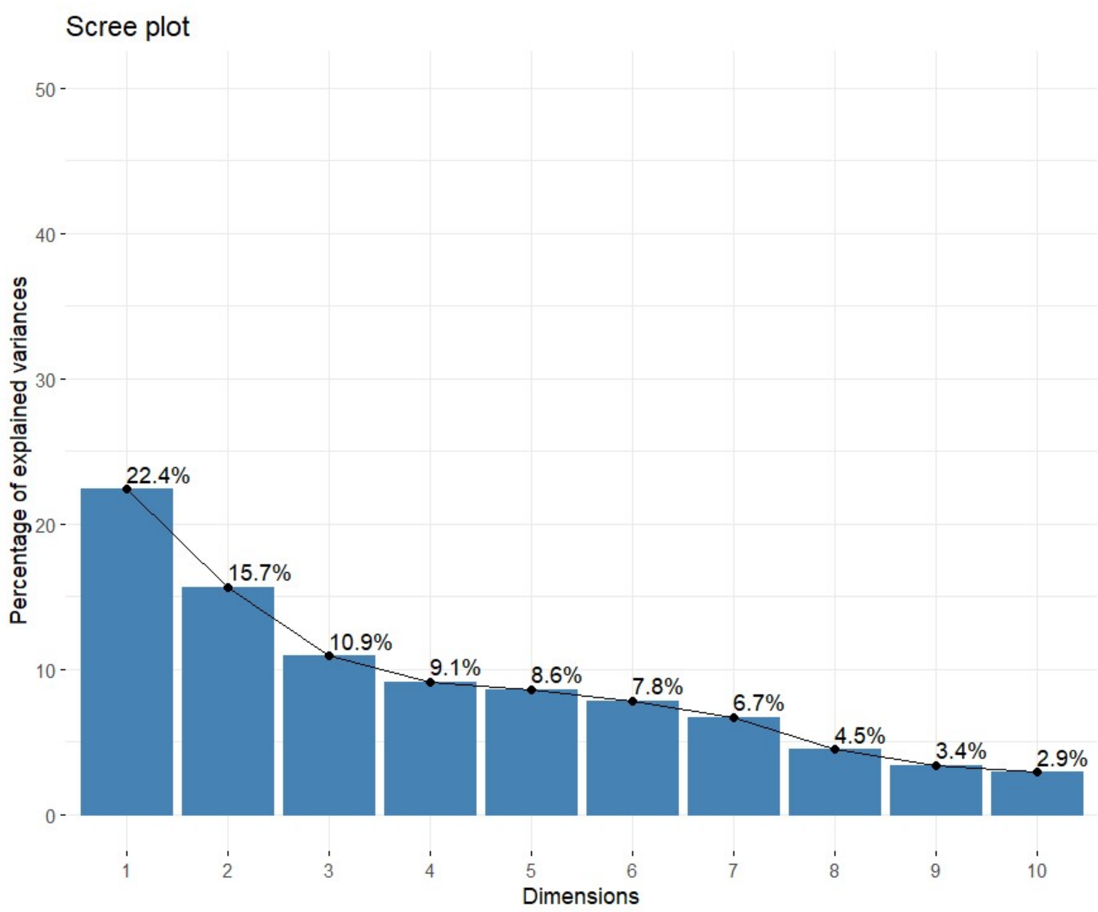


Figure 4.12: Scree plot of the Principal Component Analysis.

2. Principal Component Characteristics

PC1 (22.4% of variance): PC1 is primarily characterized by soil composition and organic content. According to the variable contributions (Table 4.1), sand (14.34%), silt (12.18%), clay (10.38%), and organic carbon (10.91%) are the highest contributors to this component. The loadings (Table 4.2) further confirm this, with sand strongly negatively correlated (-0.801) and silt (0.738), clay (0.681), and organic carbon (0.699) positively correlated with PC1. This suggests that substrate characteristics play a crucial role in differentiating odonate larval habitats.

Variable	PC1	PC2	PC3
Temp	0.371442	0.055127	0.001368
pH	1.100884	23.00878	3.334201
DO	0.000718	6.821509	2.740055
BOD	3.427184	10.21707	3.622077
Conductivity	6.957053	6.860022	2.535412
Turbidity	0.079644	11.34573	8.438895
TDS	2.964157	4.802456	2.861443
Salinity	8.716655	2.798441	0.57823
Depth	3.315888	2.853755	2.979501
Veg.cover	5.302237	0.778038	4.726453
H.veg	2.218381	0.949698	0.432738
Nitrate	7.823241	0.357341	21.83048
Phosphate	7.366664	0.419435	22.6297
Bifenthrin	1.554873	2.868477	2.068586
Fenvalerate	0.089662	1.896004	1.567577
Soil.pH	0.90005	18.24834	7.02794
Sand	14.33828	1.860532	2.453574
Silt	12.18422	0.782422	0.075204
Clay	10.3759	1.77691	4.529362
Org.C	10.91287	1.299907	5.567202

Table 4.1: Variable contributions to the principal components of PCA.

Variable	Dim.1	Dim.2	Dim.3	Dim.4	Dim.5
Temp	0.129	0.042	0.005	0.294	-0.598
pH	0.222	-0.849	0.27	0.058	0.121
DO	0.006	0.462	-0.245	0.455	-0.391
BOD	0.392	0.566	0.281	-0.044	0.181
Conductivity	-0.558	0.464	0.235	-0.043	0.502
Turbidity	0.06	0.596	0.429	-0.11	-0.258
TDS	-0.364	0.388	0.25	-0.363	-0.192
Salinity	-0.625	0.296	0.112	0.068	0.562
Depth	0.385	-0.299	-0.255	0.537	0.281
Veg.cover	0.487	0.156	-0.321	0.017	0.261
H.veg	0.315	0.172	0.097	0.442	0.467
Nitrate	0.592	0.106	0.69	0.24	0.042
Phosphate	0.574	0.115	0.703	0.252	-0.028
Bifenthrin	-0.264	0.3	-0.213	0.76	-0.042
Fenvalerate	-0.063	0.244	0.185	0.01	-0.078
Soil.pH	0.201	-0.756	0.392	-0.037	0.044
Sand	-0.801	-0.241	0.231	0.28	-0.139
Silt	0.738	0.157	0.041	-0.133	-0.169
Clay	0.681	0.236	-0.314	-0.296	0.255
Org.C	0.699	0.202	-0.349	-0.073	-0.026

Table 4.2: Loadings table of the PCA.

PC2 (15.7% of variance): PC2 is strongly associated with pH levels and water quality parameters. The highest contributors are pH (23.01%), soil pH (18.25%), turbidity (11.35%), and BOD (10.22%) (Table 4.1). The loadings (Table 4.2) show strong negative correlations for water pH (-0.849) and soil pH (-0.756), and positive correlations for turbidity (0.596) and BOD (0.566). This component likely represents a gradient of water and soil acidity coupled with organic pollution levels.

PC3 (10.9% of variance): PC3 is dominated by nutrient levels, with phosphate (22.63%) and nitrate (21.83%) as the primary contributors (Table 4.1). The loadings confirm strong positive correlations for phosphate (0.703) and nitrate (0.690) (Table 4.2). This component reflects the trophic status of the habitats, which is crucial for larval development.

3. Environmental Variable Relationships

The Variables - PCA plot (Figure 4.13) visually represents the relationships between environmental variables:

- Organic content, clay, vegetation cover, and nutrients (nitrate, phosphate) cluster together, indicating their positive associations.
- Conductivity, TDS, and salinity form another cluster, suggesting their interrelation in influencing water chemistry.
- pH and soil pH are closely aligned, reflecting their interconnected nature in the wetland ecosystem.
- Sand opposes the organic content-clay cluster, highlighting the inverse relationship between sandy substrates and organic-rich, finer sediments.

4. Seasonal Patterns and Habitat Characteristics

The PCA - Biplot (Figure 4.14) and Individuals - PCA plots (Figures 4.15 and 4.16) reveal distinct seasonal patterns in environmental conditions:

- Winter (W) samples are associated with higher turbidity and dissolved oxygen (DO) levels, possibly due to increased water movement and lower temperatures.
- Summer (S) samples tend to correlate with higher conductivity and salinity, likely resulting from increased evaporation and reduced freshwater input.
- Monsoon seasons (M1 and M2) show greater variability but generally associate with higher nutrient levels and vegetation cover. This could be attributed to increased runoff and favourable growth conditions.

5. Species Richness Patterns

The Individuals - PCA plot with species richness information (Figure 4.16) provides crucial insights into odonate larval distribution:

- Higher species richness (indicated by warmer colors) tends to be associated with M2 (second monsoon) and W (winter) seasons.
- These high-richness samples often correspond to areas with higher nutrient levels, vegetation cover, and organic content.
- The association suggests that odonate larvae prefer habitats with ample food resources (linked to higher nutrients and organic matter) and suitable microhabitats (provided by vegetation).

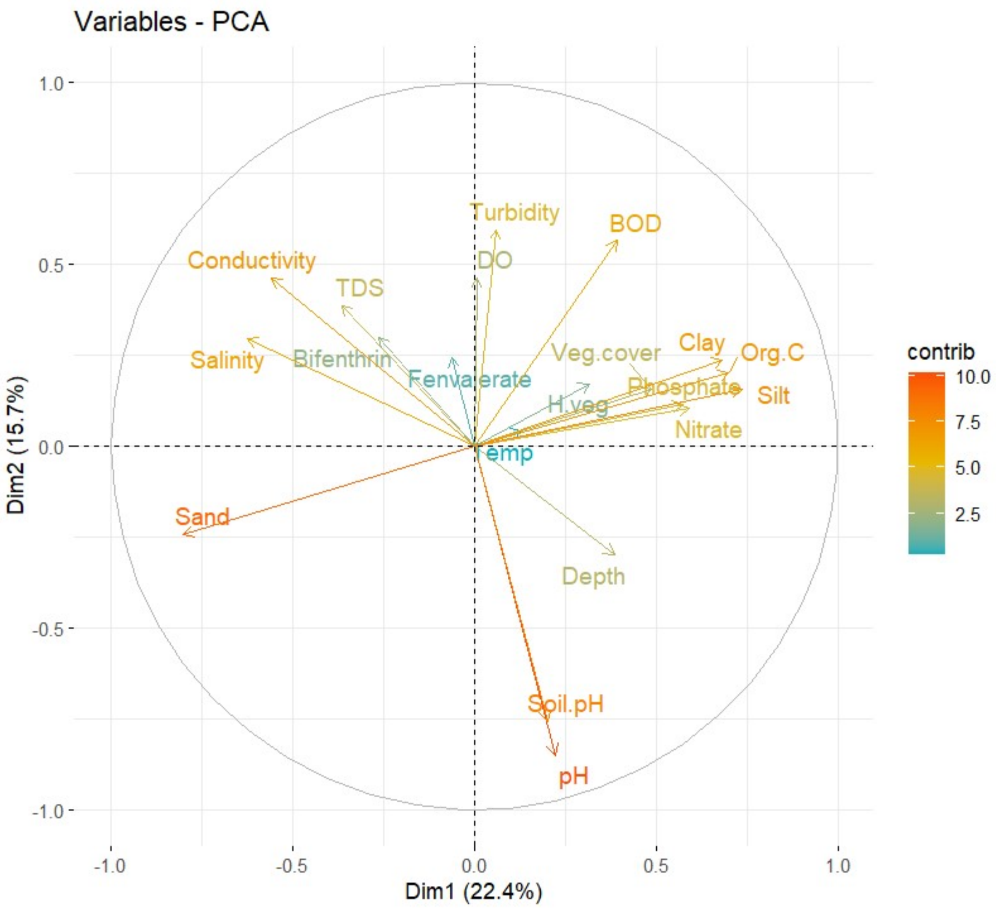


Figure 4.13: PCA plot for environmental variables.

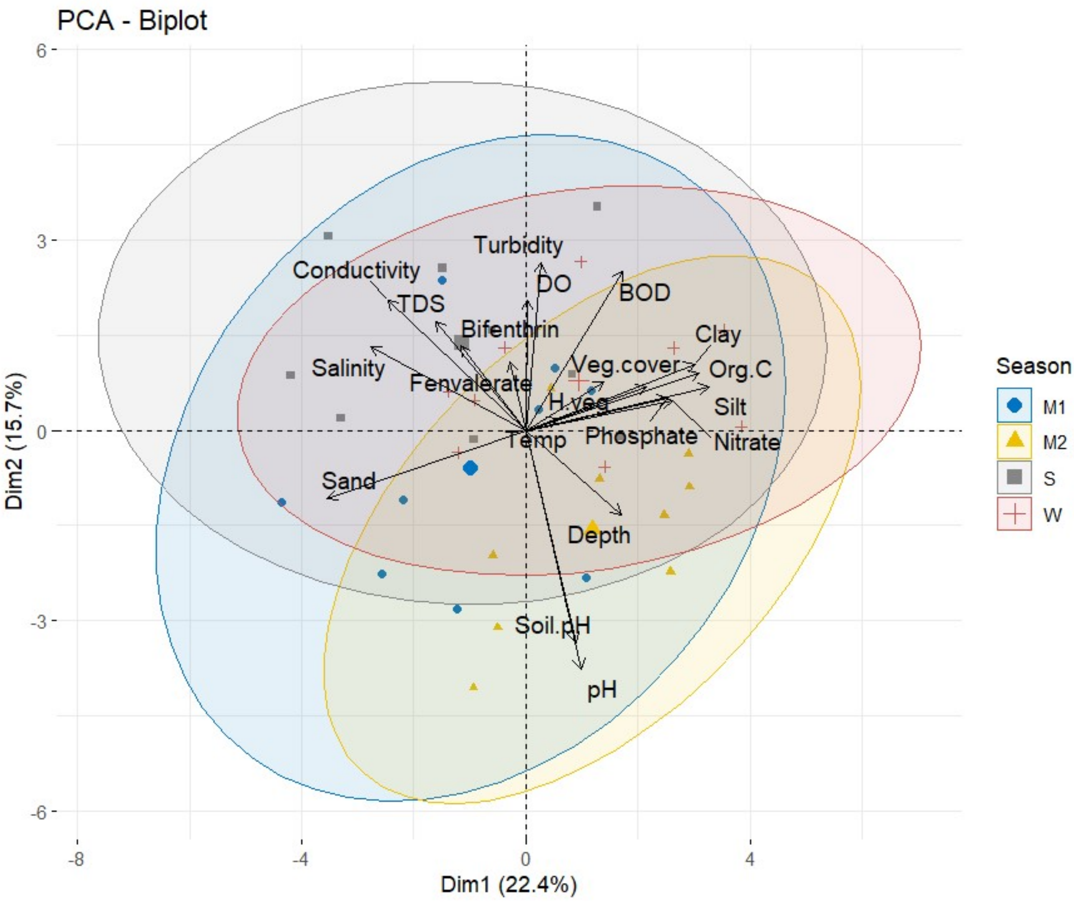


Figure 4.14: PCA biplot for environmental variables.

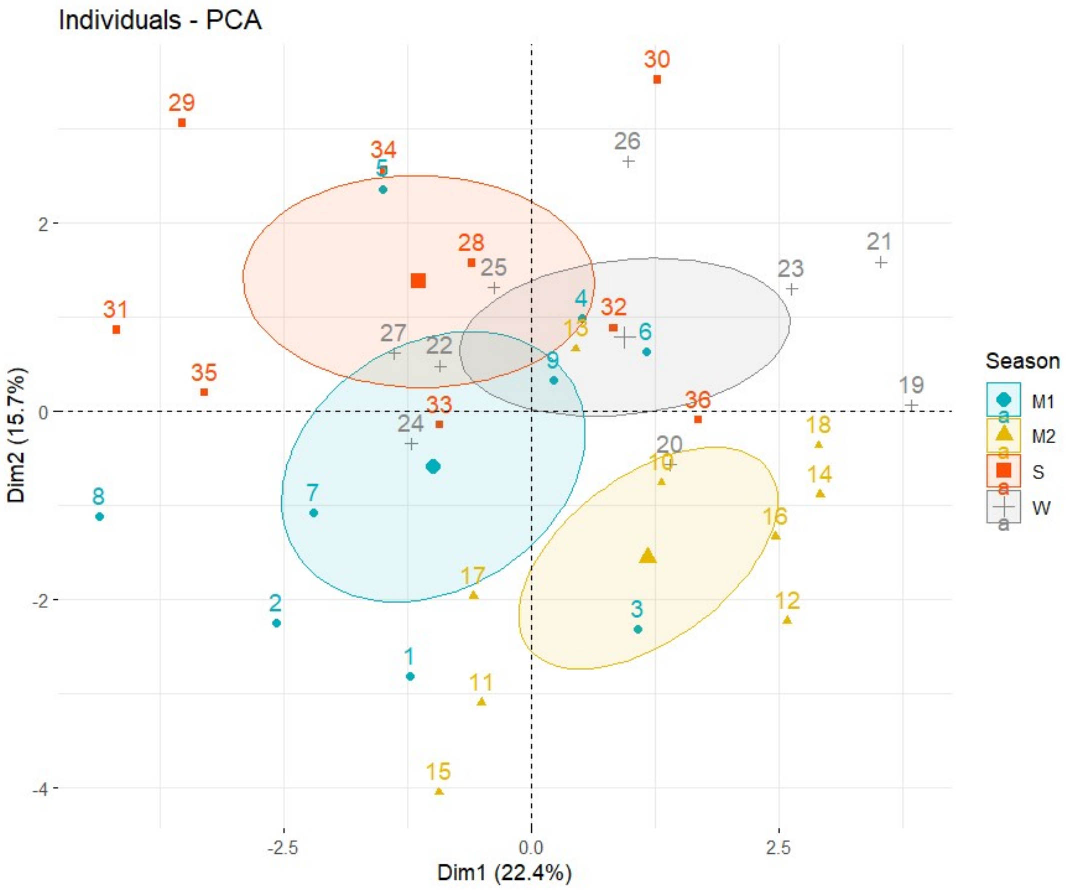


Figure 4.15: Individuals-PCA plot with seasonal groupings.

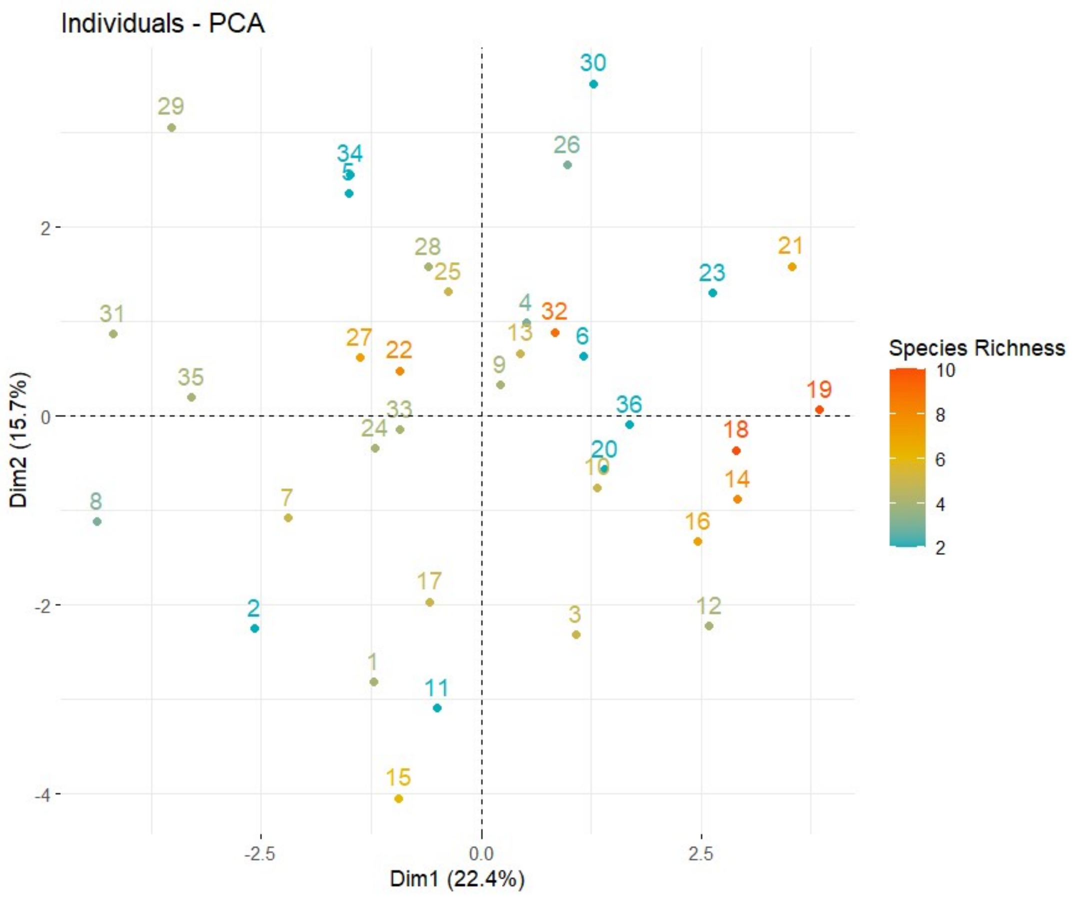


Figure 4.16: Individuals-PCA plot with species richness information.

Key Factors Influencing Odonate Larval Distribution:

Based on the PCA results, the primary factors influencing odonate larval distribution in the Kole wetlands are:

a) Substrate Composition: The strong influence of sand, silt, and clay on PC1 (Table 4.1 and 4.2) indicates that larval odonates have specific substrate preferences, likely related to their burrowing habits and prey availability.

b) Organic Content: Closely associated with finer sediments, higher organic content appears to favor larval diversity, as evidenced by its high loading (0.699) on PC1 (Table 4.2).

c) pH Levels: Both water and soil pH significantly contribute to habitat differentiation, with the highest contributions to PC2 (Table 4.1), suggesting that odonate larvae have specific pH tolerances or preferences.

d) Water Quality: Parameters like turbidity and BOD play a role in habitat suitability, as shown by their significant contributions to PC2 (Table 4.1), potentially affecting larval respiration and feeding efficiency.

e) Nutrient Levels: The strong influence of nitrate and phosphate on PC3 (Tables 4.1 and 4.2) highlights the importance of nutrient availability, likely due to its impact on primary productivity and food availability for larvae.

f) Vegetation Cover: Consistently associated with higher species richness, vegetation provides crucial microhabitats and protection for larval odonates.

g) Seasonal Dynamics: The clear seasonal patterns in the PCA plots underscore the importance of temporal changes in environmental conditions, with monsoon and winter seasons generally supporting higher diversity.

The PCA analysis reveals that odonate larval distribution in the Kole wetlands is influenced by a complex interplay of environmental factors that vary seasonally. The substrate composition, organic content, pH levels, water quality, nutrient availability, and vegetation cover emerge as key determinants of habitat suitability. The monsoon seasons, particularly the second monsoon (M2), and the winter season (W) appear to create the most favorable conditions for odonate larval diversity.

These findings have important implications for conservation and management of odonate habitats in wetland ecosystems. Efforts should focus on maintaining a mosaic of habitat types with varied substrate compositions, ensuring good water quality, managing nutrient levels to avoid eutrophication while maintaining productivity, and preserving natural vegetation cover. Additionally, the strong seasonal influences highlight the need for year-round habitat protection to support the full life cycle of odonate species.

Future research could delve deeper into the specific requirements of individual odonate species and investigate how climate change might affect these seasonal patterns and habitat characteristics in the long term.

4.6. Conclusion

This study investigated the ecology of Odonata larvae in the Kole wetlands. Larvae, water, macrophytes, and soil samples were collected across different seasons and locations. A total of 33 species of larvae were identified, which was fewer than the 63 adult species recorded in a previous study.

Key findings include:

1. Larval diversity peaked during the second monsoon (M2) and winter (W) seasons, while adult diversity was highest in the first monsoon (M1). This pattern suggests a temporal lag between larval development and adult emergence.

2. Principal Component Analysis revealed several environmental factors significantly influencing larval distribution:

    - Substrate composition (sand, silt, clay percentages)
    - Soil organic content
    - Water and soil pH
    - Water quality parameters (turbidity, biological oxygen demand)
    - Nutrient concentrations (nitrate, phosphate)
    - Vegetation cover

3. A positive correlation was observed between larval diversity and nutrient levels, potentially due to increased food availability and habitat complexity resulting from enhanced plant growth.
4. Pesticide residues (fenvalerate and bifenthrin) were detected in soil samples but demonstrated limited impact on larval diversity.
5. Seasonal variations were found to significantly affect environmental conditions and larval distribution patterns.

The study elucidates the complex interrelationships between Odonata larvae and their environment. It underscores the importance of examining multiple life stages to comprehensively understand Odonata ecology. The findings indicate that conservation strategies should prioritize maintaining heterogeneous habitats with diverse substrate types, optimal water quality, balanced nutrient levels, and natural vegetation cover.

The research also emphasizes the necessity of year-round habitat protection to support the complete life cycle of Odonata species. Recommendations for future research include investigating species-specific requirements and evaluating the potential long-term impacts of climate change on seasonal patterns and habitat characteristics.

This study contributes valuable insights for the management and conservation of wetland ecosystems to sustain Odonata populations, which serve as important bioindicators of environmental health. The findings have implications for broader wetland conservation efforts and highlight the need for integrated approaches in understanding and protecting these complex ecosystems.

4.7. References

Brito, J. S., Michelan, T. S., & Juen, L. (2020). Aquatic macrophytes are important substrates for Libellulidae (Odonata) larvae and adults. *Limnology*, *22*, 5-19. https://doi.org/10.1007/s10201-020-00643-x

Callisto, M., Mugnai, R., Castro, D. M. P., & Linares, M. S. (2021). Sampling methods for aquatic insects. In J. C. Santos & G. W. Fernandes (Eds.), *Measuring arthropod biodiversity* (pp. 523-543). Springer. https://doi.org/10.1007/978-3-030-53226-0_20

Calvert, P. P. (1893). Catalogue of the Odonata (Dragonflies) of the vicinity of Philadelphia, with an introduction to the study of this group of insects. *Transactions of the American Entomological Society,* 20(3), 153-272.

Corbet, P. S. (1962). *A biology of dragonflies*. Witherby.

Corbet, P. S. (1999). *Dragonflies: Behavior and ecology of Odonata*. Cornell University Press.

Corbet, P. S. (2002). Stadia and growth ratios of Odonata: A review. *International Journal of Odonatology*, *5*(1), 45-73. https://doi.org/10.1080/13887890.2002.9748176

Das, K. S. A., Subramanian, K. A., Emiliyamma, K. G., Palot, M. J., & Nishadh, K. A. (2013). Range extension and larval habitat of *Lyriothemis tricolor* Ris, 1919 (Odonata: Anisoptera: Libellulidae) from southern Western Ghats, India. *Journal of Threatened Taxa*, *5*(17), 5237-5246. http://dx.doi.org/10.11609/JoTT.o3716.5237-46

Dawn, P. (2019). Description of the last instar larva of *Calicnemia eximia* (Selys, 1863) (Odonata: Platycnemididae) from West Bengal, India. *Zootaxa*, *4657*(1), 183-187. https://doi.org/10.11646/zootaxa.4657.1.10

Dawn, P., & Chandra, K. (2016). Description of the larva of *Gynacantha millardi* Selys, 1891 (Odonata: Aeshnidae) from Chhattisgarh, India. *Zootaxa*, *4132*(2), 290-294. https://doi.org/10.11646/zootaxa.4132.2.12

Fraser, F. C. (1933). *The fauna of British India, including Ceylon and Burma: Odonata, Vol. I.* Taylor and Francis.

Fraser, F. C. (1934). *The fauna of British India, including Ceylon and Burma: Odonata, Vol. II.* Taylor and Francis.

Fraser, F. C. (1936). *The fauna of British India, including Ceylon and Burma: Odonata, Vol. III.* Taylor and Francis.

Jinguji, H., Sawada, D., & Morimoto, M. (2020). Suppression of Aedes mosquito larvae using dragonfly larvae released into ovitraps (Diptera: Culicidae; Odonata: Libellulidae). *Odonatologica, 49*(1/2), 67-84.

Johansson, F., & Brodin, T. (2003). Effects of fish predators and abiotic factors on dragonfly community structure. *Journal of Freshwater Ecology, 18*(3), 415-423.

Koparde, P., Dawn, P., & Darshetkar, A. (2019). Odonates across a tropical urbanization gradient (Mula River, Pune, Maharashtra, India). *International Dragonfly Fund Report*, *128*, 1-14.

Kumar, A. (1979). Studies on the life history of Indian dragonflies, *Pseudagrion rubriceps* Selys (Coenagrionidae: Odonata). *Records of the Zoological Survey of India*, *75*, 371-381.

Kumar, A. (1980). Studies on the life history of Indian dragonflies, *Ceriagrion coromandelianum* (Fabricius) (Coenagriidae: Odonata). *Records of the Zoological Survey of India*, *76*, 249-258.

Kumar, A. (1984). Studies on the life history of Indian dragonflies, *Diplacodes trivialis* (Rambur, 1842) (Libellulidae: Odonata). *Records of the Zoological Survey of India*, *81*(3 & 4), 13-22.

Kumar, A. (1989). Studies on the life history of Indian dragonflies: *Orthetrum sabina sabina* (Drury) (Odonata; Libellulidae). *Records of the Zoological Survey of India*, *85*(4), 573-581.

Kumar, A., & Khanna, V. (1983). A review of the taxonomy and ecology of Odonata larvae from India. *Oriental Insects*, *17*(1), 127-157.

Lawton, J. H. (1971). Ecological energetics studies on larvae of the damselfly Pyrrhosoma nymphula. *Journal of Animal Ecology, 40*(2), 385-419.

McCauley, S. J. (2008). Slow, fast and in between: habitat distribution and behaviour of larvae in nine species of libellulid dragonfly. *Freshwater Biology, 53*(2), 253-263.

Needham, J. G. (1901). Aquatic insects in the Adirondacks: A study conducted at the Entomologic field station, Saranac Inn, N.Y., under the direction of Ephraim Porter Felt, state entomologist. *New York State Museum Bulletin*, 47, 383-612.

Payra, A., Dawn, P., Subramanian, K. A., Deepak, C. K., Chandra, K., & Tripathy, B. (2021). New record of *Megalestes gyalsey* Gyeltshen, Kalkman & Orr, 2017 (Zygoptera: Synlestidae) from India, with first description of female and larva. *Zootaxa*, *4938*(2), 233-242. https://doi.org/10.11646/zootaxa.4938.2.4

Pierce, C. L., Crowley, P. H., & Johnson, D. M. (1985). Behavior and ecological interactions of larval Odonata. *Ecology, 66*(5), 1504-1512.

Silva, L. F. R., Castro, D. M. P., Juen, L., Callisto, M., Hughes, R. M., & Hermes, M. G. (2021). Functional responses of Odonata larvae to human disturbances in neotropical savanna headwater streams. *Ecological Indicators*, *133*, 108367. https://doi.org/10.1016/j.ecolind.2021.108367

Subramanian, K.A. (2005). *Dragonflies and damselflies of peninsular India-A field guide*. Project Lifescape. Centre for Ecological Sciences, Indian Institute of Science and Indian Academy of Sciences.

Subramanian, K. A., & Babu, R. (2020). Dragonflies and damselflies (Insecta: Odonata) of India. In S. Ramani, P. Mohanraj, & H. M. Yeshwanth (Eds.), *Indian insects: Diversity and science* (pp. 29-45). CRC Press.

Sutherland, W. J. (2006). *Ecological census techniques: A handbook* (2nd ed.). Cambridge University Press.

Tüzün, N., & Stoks, R. (2018). Pathways to fitness: carry-over effects of late hatching and urbanisation on lifetime mating success. *Oikos, 127*(7), 949-959.

Williamson, E. B. (1923). Notes on American species of Triacanthagyna and Gynacantha (Odonata). *Miscellaneous Publications of the Museum of Zoology*, University of Michigan, 9, 1-80.

Chapter 5

FIRST DESCRIPTIONS OF LIFE STAGES OF ODONATES

5.1. Introduction

The earliest known scientific description of an odonate that occurs in India is that of *Neurobasis chinensis* (Linnaeus, 1758), the specimens of which, however, were collected beyond the Indian boundaries. The first odonate species to be formally described using specimens gathered from India was *Rhyothemis variegata* (Linnaeus, 1763) (Subramanian & Babu, 2020). Drury (1770, 1773) and Fabricius (1775-1798) described many species from India in the 18th century. Many Indian species were later described by Selys-Longchamps (1853-1859) and Rambur (1842). In the early half of the twentieth century, Laidlaw (1914-1932) and Fraser (1933-1936) contributed significantly to the knowledge on Indian Odonata. After independence, descriptions of new species of Odonata of India were taken forward by the scientists of Zoological Survey of India (Lahiri, 1876, 2003; Mitra & Lahiri, 1975; Subramanian, Rangnekar & Naik, 2013; Emiliyamma & Palot, 2016). Many species have been described by researchers of other institutions also (Joshi & Kunte, 2017; Joshi & Sawant, 2019; Chandran et al. 2023). As a result of these studies, detailed taxonomic descriptions of adult forms of Indian Odonata are available, but for many species, description of only one sex is available, examples include *Idionyx periyashola* Fraser, 1939, *Macrogomphus wynaadicus* Fraser, 1924 and *Onychogomphus malabarensis* (Fraser, 1924). Further, a huge gap exists in the knowledge of Indian odonate larvae, the detailed descriptions for most species being unavailable. The paucity of this taxonomic data needs to be addressed if Indian odonatology has to be taken forward.

The genus *Macrogomphus* Selys, 1858 is widely distributed across Asia and currently includes 15 described species (Paulson et al., 2024). According to Subramanian and Babu (2017), there are five species known to exist in India, with *Macrogomphus wynaadicus* Fraser, 1924 being limited to the Western Ghats (Babu et al., 2013; Kalkman et al., 2020). Fraser's collection of a single female from

Masinagudi in the southern Western Ghats served as the basis for the initial description. Later, Fraser (1931) saw some males but did not go so far as to properly describe them, noting that they were not significantly different from the female. Numerous photographic records have since been made of the male (Subramanian et al., 2018; GBIF, 2023). However, in order to prevent any confusion in the future, this taxonomic gap should be filled as *M. wynaadicus* does not currently have a valid male description.

Five genera constitute the family Lestidae Calvert, 1901 on the Indian subcontinent: *Indolestes* Fraser, 1922; *Lestes* Leach, 1815; *Orolestes* McLachlan, 1895; *Playlestes* Selys, 1862; and *Sympecma* Burmeister, 1839 (Subramanian & Babu, 2017). Larval descriptions are available for some species in the genera *Indolestes* (Theischinger, 2009), *Lestes* (Kumar, 1972; Theischinger, 2009), *Orolestes* (Lien & Matsuki, 1985), and *Sympecma* (Dumont & Borisov, 1993), either from Indian species or other related species. There are only four species in the small genus *Platylestes* worldwide, and two of them are found in India*: Platylestes kirani* Emiliyamma, Palot & Charesh, 2020 (Emiliyamma et al., 2020) and *Platylestes platystylus* (Rambur, 1842) (Paulson et al., 2024). There is currently no description available for the larvae of this genus.

Aethriamanta Kirby, 1889 is a libellulid genus with only six species known worldwide (Paulson *et al*. 2024). Two species *Aethriamanta aethra* Ris. 1912 and *Aethriamanta gracilis* (Brauer 1878) are known from Southeast Asian Countries (Dow *et al.* 2024), two species *Aethriamanta nymphae* Lieftinck, 1949 and *Aethriamanta circumsignata* Selys, 1897 are known from Australian region (Theischinger 2009). One species each is known from African region and Asia, respectively *Aethriamanta rezia* Kirby, 1889 (Dijkstra & Clausnitzer 2014) and *Aethriamanta brevipennis* (Rambur, 1842) (Kalkman 2020). *A. brevipennis* has stray records from Southeast Asian countries and the larva remains undescribed (Kalkman 2020). Larvae of two species, viz. *A. circumsignata* and *A. nymphae* are known from Australia but not with a very detailed description (Hawking 1993, Theischinger & Endersby 2014).

This chapter fills important knowledge gaps about the developmental phases of odonate species from the Kole wetlands by offering the first official taxonomic descriptions of one adult male and two larval stages. In order to advance the taxonomy of odonates and evaluate their ecological roles and conservation status, it is imperative that their whole life stages be documented. This work creates a crucial baseline for species identification and further research by providing thorough morphological descriptions and ecological context. In addition to improving our knowledge of odonate diversity in the Kole wetlands, these findings support more extensive ecological and biogeographic research in areas with high biodiversity, such as the Western Ghats. Additionally, this work contributes to ongoing conservation efforts by offering useful information to guide species monitoring and habitat management.

5.2. Materials and methods

Adult

While sampling adult odonates in Kole wetlands, individuals that were difficult to identify were caught using an aerial net, examined and released. A male gomphid caught from Ounderchaal, Thrissur South Kole (10.3271° N, 76.1894° E, 12 m a.s.l.) did not match the descriptions of any in literature. This individual was collected, killed and preserved dry. This specimen was studied under a stereomicroscope (Labomed Luxeo 6Z) along with similar specimens collected from other parts of the Western Ghats region. They were identified as male *Macrogomphus wynaadicus* Fraser, 1924 and formally described.

Larvae

The larvae collected from Kole wetlands that were difficult to identify were reared *in vivo*. An aquarium aerated using a motor pump was used for the purpose. Soil from the collection site was used as substrate and aquarium plants were added to simulate a natural environment. The early instars were fed with live *Moina* obtained from a pet shop which were replaced with live mosquito wrigglers and cut earthworms as they grew, providing a progressively larger and more nutrient-rich diet to support their development through later instars and into adulthood. Sticks were introduced into the aquarium to facilitate the climbing out of the final instar larvae for eclosion. The whole set-up was covered with a mosquito-net for collecting the emerged adults. For species with undescribed larvae, identification was done on the basis of the emerged adults. Exuviae were studied under the stereomicroscope to give the formal description of these larvae. Larvae of two species, *Platylestes platystylus* (Rambur, 1842) and *Aethriamanta brevipennis* (Rambur, 1842) were thus described formally. The larvae of *A. brevipennis* collected from Kole wetlands did not survive. Hence, larvae of this species were collected from a pond in the same wetscape (Thumboor) and reared to adulthood for description.

5.3. Results and discussion

Adult male: *Macrogomphus wynaadicus* Fraser, 1924 (Chandran et al., 2023)

Material examined

1♂, Bolcornem, Dharbandhora, South Goa, Goa, India (15.1932°N, 74.1075°E, 82 m a.s.l.), 28-vi-2019, leg. O. Dharwadkar & P. Rangnekar; 1♂, Kanyakumari, Tamil Nadu, India (8.1803°N, 77.2508°E, 12 m a.s.l.), 15-v-2021, leg. C.R. Vivek; 1♂, Ounderchaal, Thrissur, Kerala, India (10.3271°N, 76.1894°E, 11 m a.s.l.), 9-vii-2021, leg. A.V. Chandran; 1♀, Palode, Thiruvananthapuram, Kerala, India (8.7245°N, 77.0246°E, 131 m a.s.l.), 10-vi-2023, leg. R. Chandran (Figure 5.1).

Remarks concerning the female

The female collected (Figure 5.2) is almost exactly as described by Fraser, but S9 is unmarked. It is a more robust insect compared to the male.

Measurements [mm] – Abdomen (including appendages) 47, HW 40

Description of male

First described♂. The description is based on the male from Ounderchaal, Thrissur, Kerala state (Figure 5.3).

Head – Lateral lobes of labium citron yellow, mid-lobe black. Labrum black with two yellow spots on either side of middle line. Base of mandible yellow. Post-frons yellow. Rest of face black. Vertex black. Ocelli dark brown. Antennae: pedicel pale yellow, remainder black. Occiput dark reddish brown, slightly raised in middle, with fine black hairs. Eyes bottle green in life.

Thorax – Prothorax black with a narrow yellow anterior collar. Thorax black marked with greenish yellow as follows- two parallel dorsal stripes on mesepisternum broadly confluent with a slightly interrupted mesothoracic collar, a broad stripe each on mesepimeron and metepimeron, spots just above coxae of legs. Legs black, stoutly built, coxae and trochanter marked with pale yellow.

Wings – Transparent. Basal cells of cubito-anal space and space between subcostal and median nervure enfumed with dark brown in both FW and HW. Pt black, braced, covering 6 underlying cells. Ax 19 and 17 in left and right FW respectively, 13 in both HW. Px 12 and 13 in left and right FW respectively, 11 in both HW. No cross-veins in median space and triangles in both wings. Two cubital nervures in all wings.

Abdomen – Black marked with citron yellow as follows- S1 and S2 broadly on side. S1 with a triangular dorsal spot, S2 with a dorsal streak a truncated arrow shape, broadened anteriorly as in Fig. 3c. S3 with large baso-lateral spots. S4 to S6 with similar, but smaller spots. Basal half of S7 yellow. S8 with a large baso-lateral stripe. S9 almost double length of S8, with a broad, baso-lateral stripe. S10 small and unmarked.

Secondary genitalia – Black. Auricles oval shaped, pale yellow, with fine serrations on inner margins when viewed ventrally. Anterior lamina rounded. Hamules long and curved at tip, with long yellowish-brown hairs in inner margin. Genital lobes leaf-shaped, with long brown hairs, margins ending in two long spines. *Vesica spermalis*– robust, segment 1 broad basally, segment 2 cylindrical. Segment 3 narrower, bifurcates into two lobes apically, upper lobe funnel-shaped and lower broader lobe ending in a small spine.

Anal appendages (Figure 5.4) – Cerci shorter than S10, conical, pale yellow, forked at middle, inner fork bent downwards, dark brown and wavy. Just before start of fork on each cercus, there is a long, incurved process with rounded tip. Epiproct black, horseshoe-shaped in dorsal view, thick, undulate and distally upturned in lateral view, not reaching tip of cerci.

Measurements [mm] – Abdomen (incl. appendages) 48, HW 37

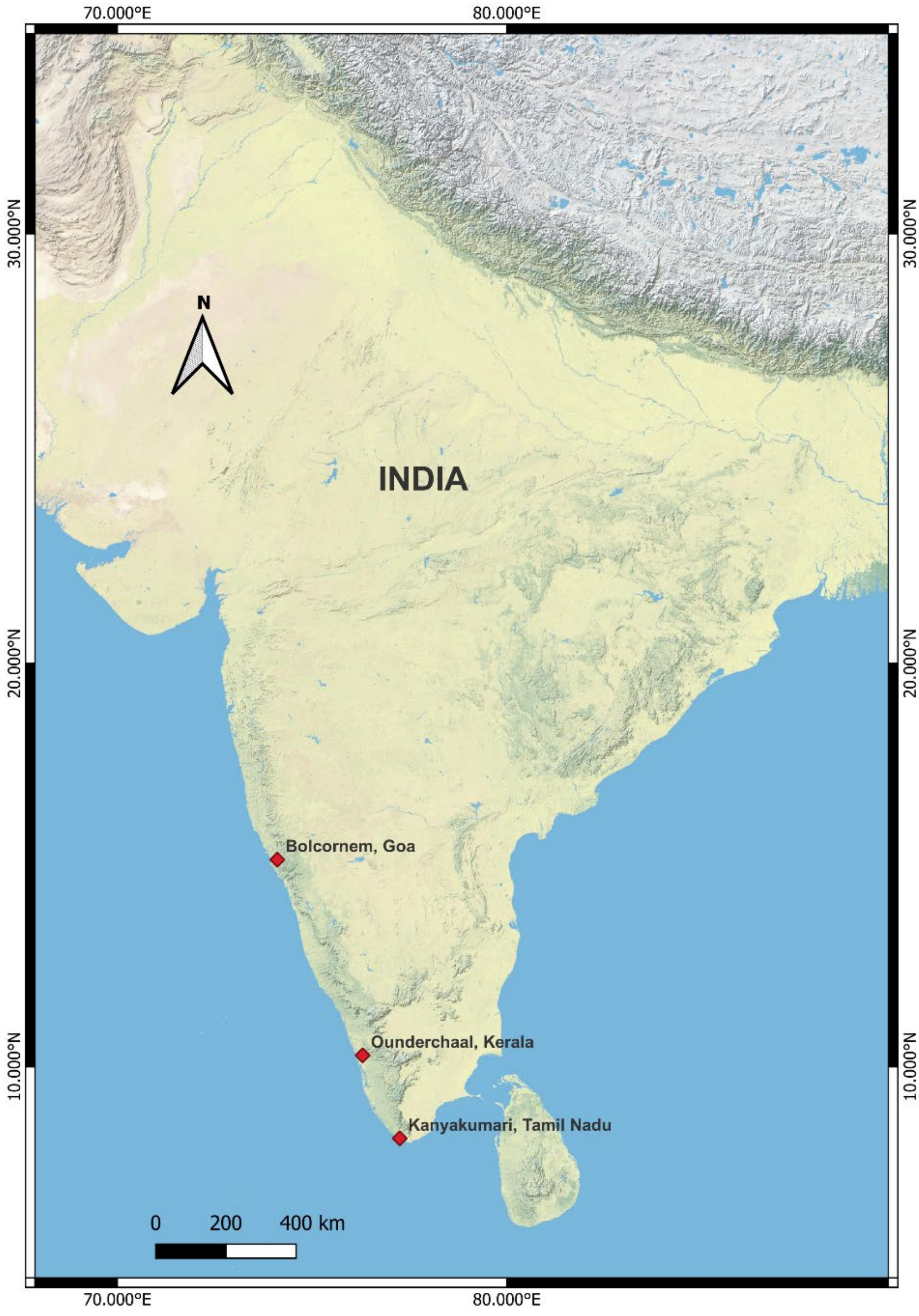


Figure 5.1: Collection locations of adult male *Macrogomphus wynaadicus* Fraser, 1924

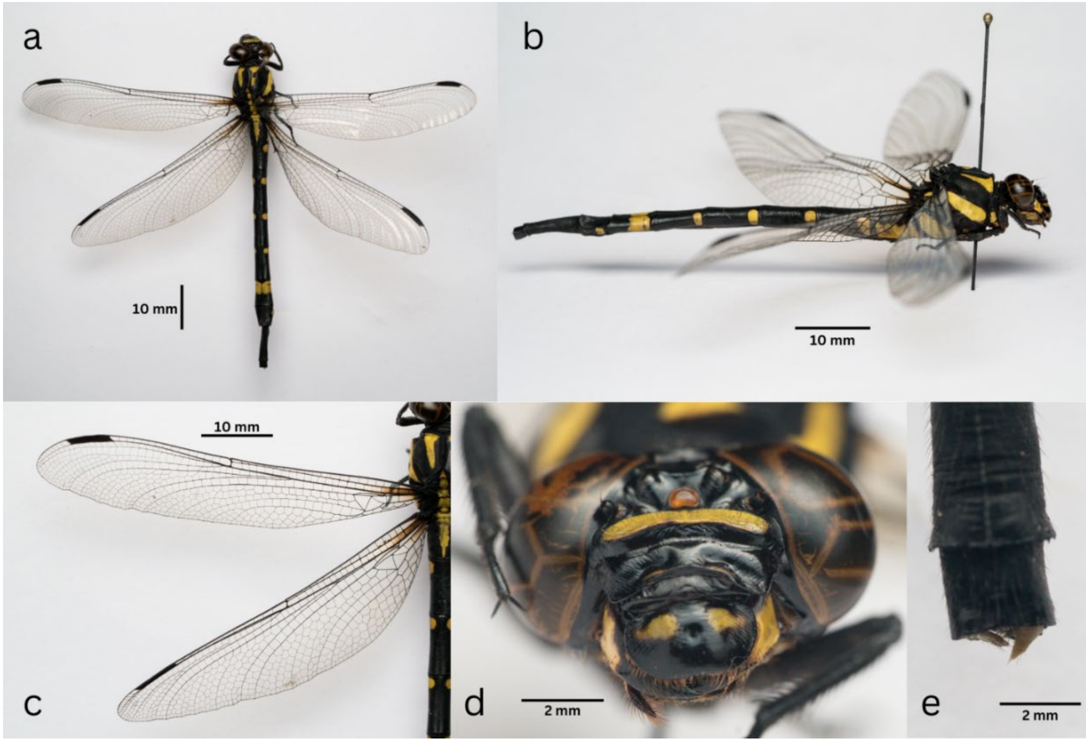


Figure 5.2: Female specimen of *Macrogomphus wynaadicus* Fraser 1924. a- habitus dorsal view, b- habitus lateral view, c- wings, d- head, e- last segments with anal appendages.

Morphological variation in males

The males from Tamil Nadu and Goa closely match the male from Kerala. The male from Goa is slightly larger than that of Kerala (abdomen including appendages 50 mm and HW 38 mm) and has the baso-lateral stripe on S9 reduced into a small oval spot.

Diagnosis

Macrogomphus wynaadicus can be easily separated from other gomphids occurring in the Western Ghats by its large size, robust build and elongated S9. The congeneric *M. annulatus* (Selys, 1854) occurring in the same landscape has complete yellow rings on the abdomen, which are reduced to large lateral spots in *M. wynaadicus*. Two other species, *M. montanus* Selys, 1869 and *M. seductus* Fraser, 1926 occur in the north-eastern part of India. The former is a more robust insect with very narrow thoracic stripes, while the latter can be distinguished by the shape of ante-humeral stripes. Another species recorded from Tibet, *M. robustus* (Selys, 1854) is distinguished by its entirely black labium, bifid tubercle on the occiput, and high nodal index. The congeneric from Sri Lanka, *M. lankanensis* Fraser, 1933 has lateral and dorsal spots on prothorax and differently shaped anal appendages.

Distribution

Till date, *Macrogomphus wynaadicus* has been recorded from the Western Ghats states of Kerala, Tamil Nadu, Karnataka (Subramanian et al. 2018) and Goa (collected in this study). It probably occurs throughout the range of the Western Ghats, breeding in streams and rivers with good vegetation cover. It is found from sea level upto an elevation of 1070 m a.s.l. There are no records of the species from stagnant water bodies. It is not uncommon as Fraser (1934) has rightly stated, but very seasonal. In the IUCN Red List of Threatened Species, it remains 'Data Deficient' (Subramanian 2011). With several new records available like in this study, and in biodiversity data portals such as iNaturalist, it is prudent to reassess its IUCN Red List status.

Habitat and ecology

Macrogomphus wynaadicus has been recorded from a variety of habitats including forests, groves and wetlands. All observations have been made near well-shaded running water bodies. It is seen on the wing from May to October and is most abundant during the peak of the southwest monsoon (July-August), when the region receives maximum rainfall. Adults are often seen perched on tree branches at heights of over 2 metres. It also enters households at dusk, attracted by electric lights. Mating and oviposition behaviours of the species remain unrecorded.

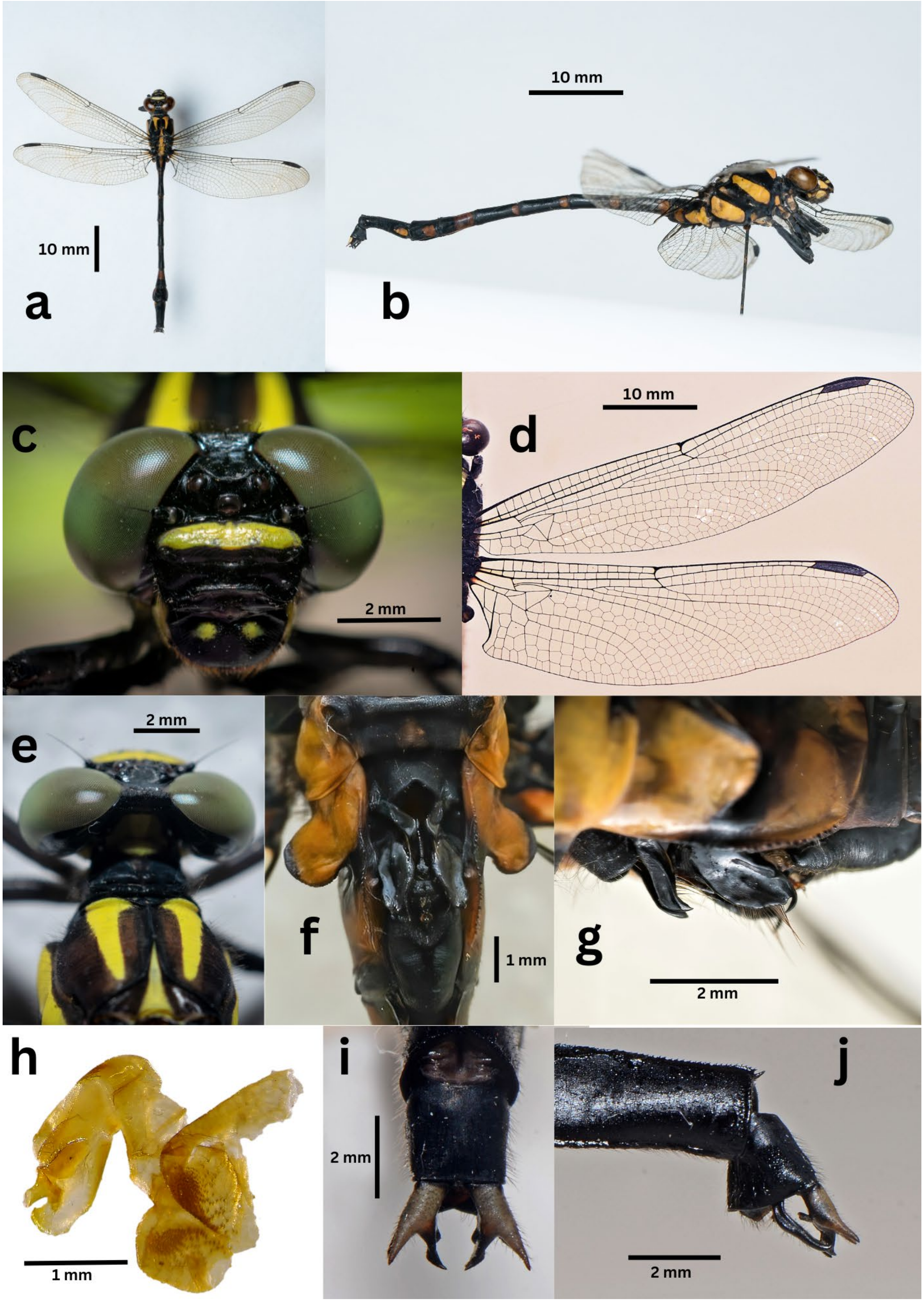


Figure 5.3: Male specimen of *Macrogomphus wynaadicus* Fraser 1924 from Ounderchaal, Kerala state. a- habitus dorsal view, b- habitus lateral view, c- face (in life), d- wings, e- head & prothorax from above (in life), f- secondary genitalia in ventral view of abdomen, g- secondary genitalia in lateral view of abdomen, h- vesica spermalis (dissected from the specimen from Kanyakumari, Tamil Nadu), i- anal appendages dorsal view, j- anal appendages lateral view.

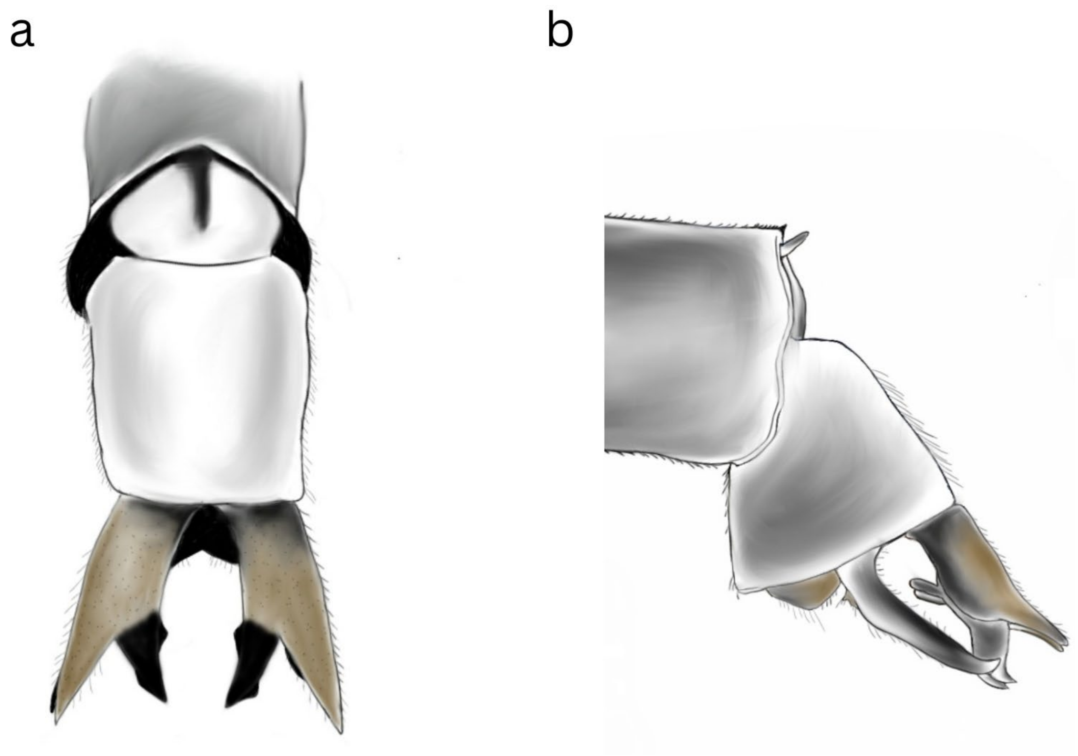


Figure 5.4: Anal appendages of male *Macrogomphus wynaadicus* Fraser 1924 illustrated. a- dorsal view, b- lateral view.

Larva: *Platylestes platystylus* (Rambur, 1842) (Chandran et al., 2023)

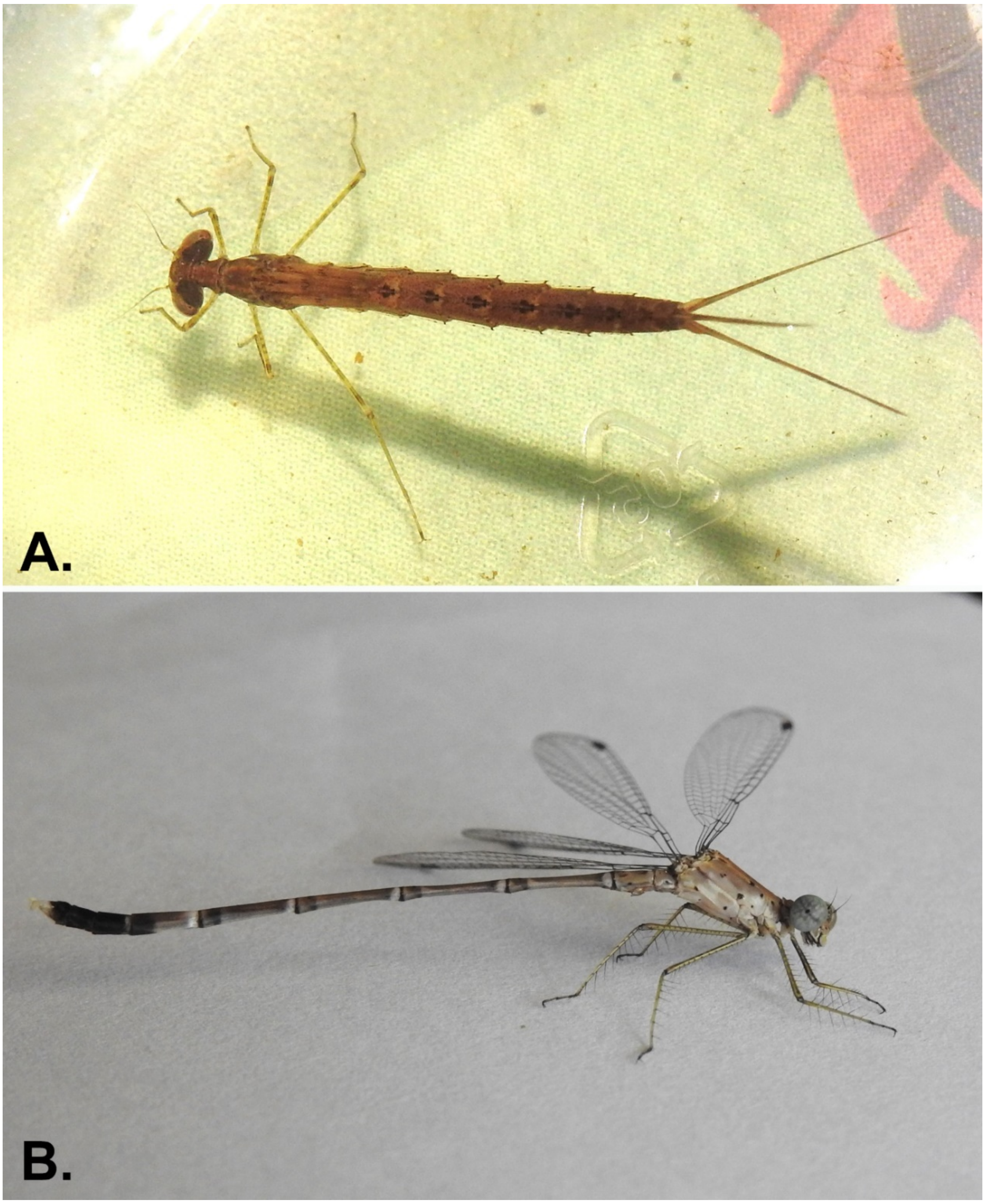


Figure 5.5: A. Last instar larva of the *Playlestes platystylus*. B. Adult emerged from the larva.

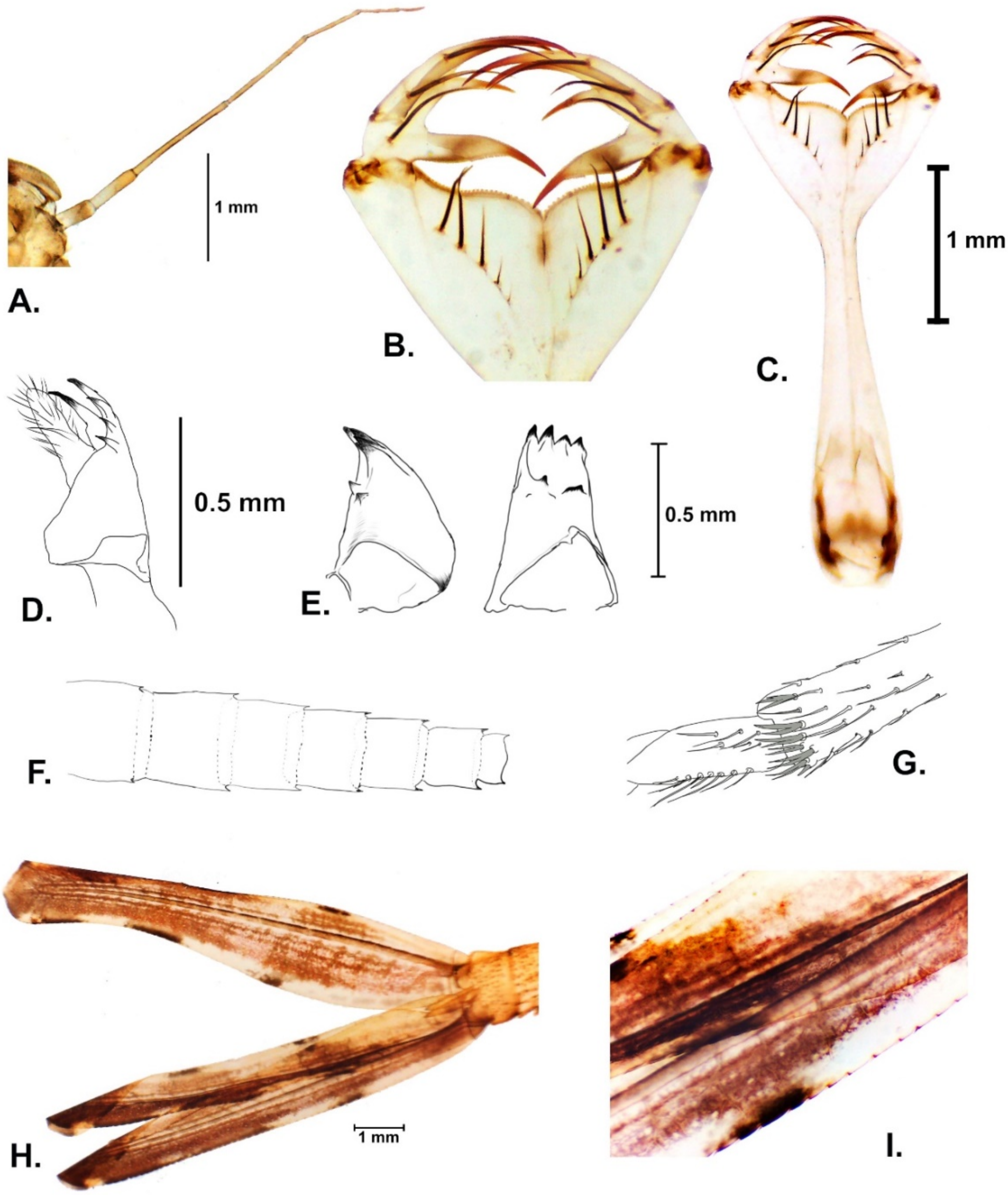


Figure 5.6: Detailed views of *Platylestes platystylus* larva- A. Antenna, B. Labial palps, C. Labium, D. Right maxilla, E. Right mandible – dorsal and inner view, F. Dorsal view of abdomen showing lateral spines, G. Tibial comb, H. Caudal appendages (the tip of the appendages are folded in this image), I. Magnified view of the caudal appendages showing small spines at margins.

Material Examined: 1 ♂ Exuvia [Emerged into adult (Figure 5.5 B) on 23/10/2021], Kerala: Malappuram district: Srayilkadavu: Kole wetlands (Figure 2.1), 10.7032°N & 76.0345°E, 29.ix.2021, Collected by AVC.

Description of the Final Instar Larva:

The larva was overall light greenish brown in colour in life, turning dark brown just before emergence (Figure 5.5 A).

Head – Bean shaped head light brown, darkest behind the eyes. Face overall light brown, without any prominent dark markings. Antennae seven segmented (Figure 5.6 A), without any prominent hair/setae; pedicel is longer than the base of the antenna; fourth segment the longest.

Labium – Prementum racket-shaped (Figure 5.6 C); comparatively shorter than in other lestids; reaches just beyond the base of the second pair of legs when retracted; length to maximum width ratio = 3.715/1.404. Anterior margin of the prementum with a deep cleft and the edge with dentitions of equal size. Premental setae 5 + 5, gradually shortened towards the inner margin. Palpal setae 3 + 3, two on movable hook and one at the base of the hook. Labial palp with a deep cleft resulting in three inwardly directed finger-like projections other than the movable hook; the innermost projection of the palp slightly bent towards the cleft and has dentitions in the inner margin; the second projection is the smallest and originates from almost the middle of the projection (Figure 5.6 B).

Mandible and Maxilla – four teeth in a row, upper two slightly shorter than the others; two blunt denticles of equal size at the inner wall (Figure 5.6 E). Maxillae with multiple small denticles and one hairy blunt lobe inward and downwardly directed (Figure 5.6 D).

Thorax – Thorax light brown in colour. The wing-pads reach just short of the distal border of the third abdominal segment. Legs lighter in colour and without any prominent banding pattern, except a faint brown pigmentation near the distal end of the femur. Tibial comb with bidentate setae (Figure 5.6 G).

Abdomen – Abdomen overall light brown in colour in the final instar larva, when alive. A pair of darker patches on the distal margin of dorsum on S2 to S9 which remain visible in the exuvia also. Lateral abdominal spines present on S4–9 (Figure 5.6 F). In the exuvia, the abdomen shows numerous minute dark brown spots overall. Cerci longer than the dorsal length of S10, but shorter than S9. Dorsal margin of S10 with numerous sharp spines.

Caudal Lamellae – Feather-like with brown patches throughout and three pairs of darker spots present along the margin (one pair at the distal end, one near the 2/3rd length towards the base and one in the middle); middle lamella is the broadest and it gradually narrows with a slight bend towards the tip; two lateral lamellae of equal width, slightly narrow in the middle (Figure 5.6 H); all lamellae with minute serrations along the edges and very fine spine on each serration (Figure 5.6 I).

Diagnosis

Among the Indian genera of the family Lestidae, this is the first larva described from this genus. The *Platylestes* larva is slightly longer than the larva of *Indolestes*. It superficially resembles the *Lestes* larvae, though close examination reveals that the labium is comparatively shorter than in *Lestes*. Also, in *Platylestes*, outer lobe of labial palp has sharp prominent spines in contrast with irregularly shaped inwardly directed spines of *Lestes*.

Habitat and ecology

The part of wetland from where the larva was collected was approximately 40.75 cm in depth, measured using a metre tape. Plants present nereby were *Limnophila heterophylla*, *Alternanthera phylloxeroides* and *Polygonum barbatum*. Other Odonata larvae caught along with it were of *Pseudagrion rubriceps* Selys, 1876 and *P. microcephalum* (Rambur, 1842). The soil was clayey and the water quality parameters measured during collection of specimens are as follows: Temperature: 33.4°C, pH 8.77, Dissolved Oxygen: 4 ppm, Conductivity: 0.11 mS/cm, Turbidity: 5 NTU, TDS: 0.06 ppt, Salinity: 2.2 ppt.

Platylestes platystylus was described by Jule Pierre Rambur in 1842. Earlier collections of the species were from Bengal and Myanmar (Fraser 1933). The present range of *P. platystylus* is depicted by the International Union for Conservation of Nature and Natural Resources (Sharma 2010) as India (West Bengal), Lao People's Democratic Republic, Myanmar, Thailand and Iraq. There are recent records of the species from Maharashtra (Mujumdar *et al.* 2021), West Bengal (Dawn 2022) and Kerala (Rison & Chandran 2020; Chandran *et al.* 2021; Gopalan *et al.* 2022). From the Kole wetlands, there are only scattered, occasional records of the species. Out of 163 larvae collected from various locations in Kole wetlands, only one belonged to *P. platystylus*.

Larva: *Aethriamanta brevipennis* Rambur, 1842 (Chandran et al., in press)

Material Examined: 2 ♂ Larvae (Emerged into adult on 14.xii.2023 and 15.xii.2023), 2 exuviae, Kerala: Thrissur district: Thumboor wetlands, Lat. 10.2976°N & Long. 76.2565°E, 25 m a.s.l, 19.xi.2023, Collected by A. Vivek Chandran (Figure 5.7).

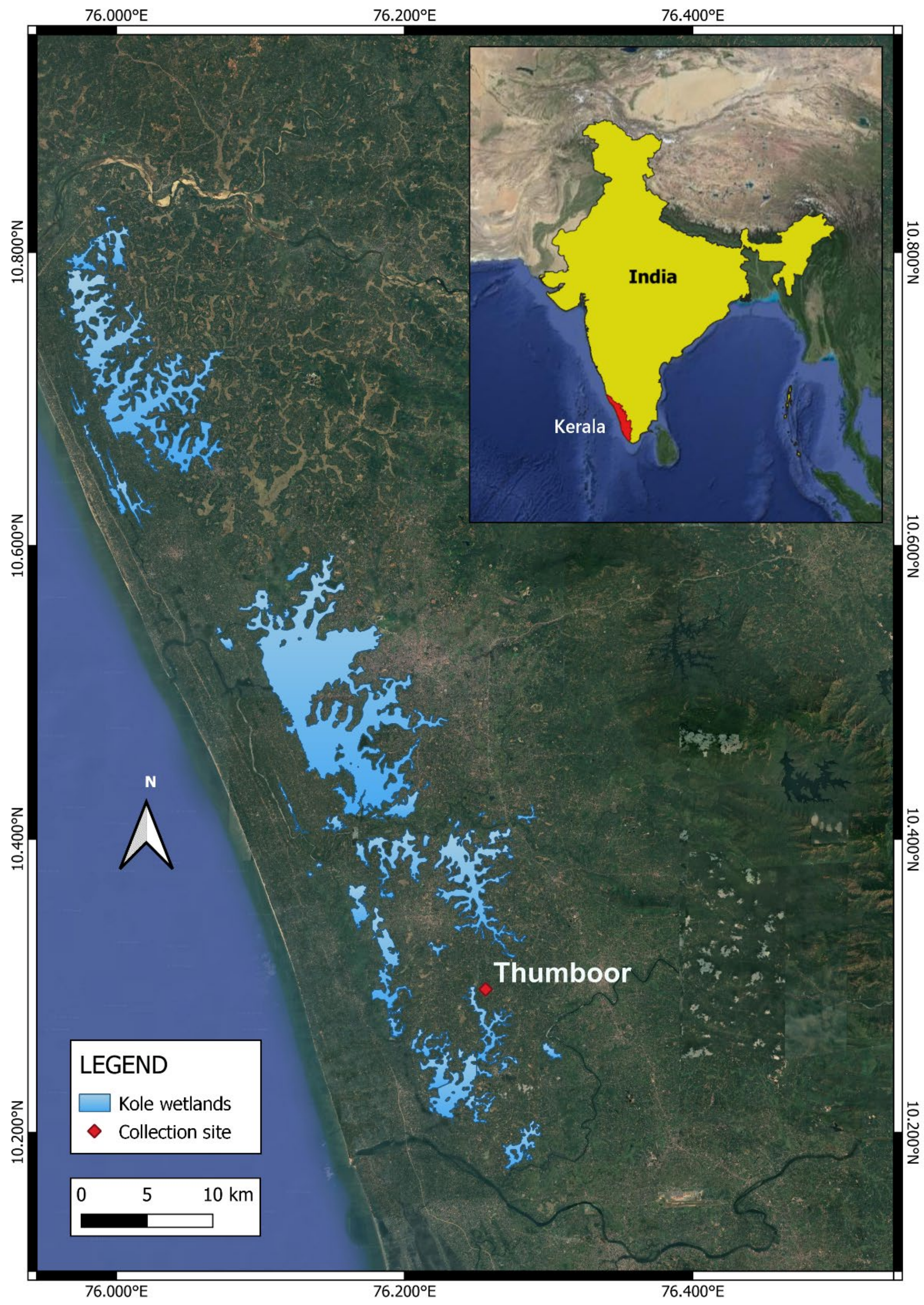


Figure 5.7: Map showing collection site (Thumboor) of *Aethriamanta brevipennis* larvae.

Description of the Larva/Exuvia:

Exuvia light to dark brown in colour, head and wing being darkest. Body length 13 mm.

Abdomen length 8.92 mm, abdomen width 5.6 mm (Figure 5.8 A & B).

Head – Light brown head with lighter portions marked with prominent dark minute spots. Back side of the head with numerous long hairs. Bulbous eyes more than half length of the head and projected laterally (Figure 5.9 A). Antennae seven segmented, with third segment being the longest.

Labium – Spoon shaped labium (Figure 5.9 B) short (length: width ratio = 1.2:1), light brown colour, densely spotted with darker brown. Distal margin of palpal lobe slightly wavy with prominent spines arranged in a group of three, among which two are longer and of same length. Inner margin has spines equally spaced. Anterior margin of the mentum angular in shape, forwardly projected and with minute spines of equal length on equal intervals. Premental setae 12-12 (6 longer and 6 shorter) and palpal setae 7-7, end hook of the labial palp not very strong and without any secondary spines on it.

Thorax – Pronotal folds bear laterally placed long hair-like setae (Figure 5.9 C). Base of the metapleural folds with 3-4 long setae closely arranged in a row and few minute setae scattered around the row. Ventrally thoracic part with more setae than the dorsal, anterior margin of meso-sternum with a dense row of setae, meta-sternum with much fewer setae. Wing pads of equal length, reaching the 6^{th} abdominal segment. Wing pads bear numerous setae on their dorsal margin, few are quite long hair like, rest resemble small spines.

Legs – Light brown with very faint banding patterns. Coxae with numerous rows of setae posteriorly placed on ventral side. Femur with a row of setae on both dorsal and ventral side; those at the ventral side being longer. Tibiae are the most setose part of the legs with parallel rows of long hair-like setae on the distal margin. Tarsi with rows of small spines ventrally. Tibial comb with monodentate setae.

Abdomen – Small dorsal spines present on S5-S8, those of S7 and S8 being most prominent (Figure 5.9 D), less than the dorsal length of the respective segments. S2-S4 with two long dark brown to black hair-like setae on the mid-dorsal line at distal margin of each segment. S7-S9 with numerous long setae and few minute spines serially arranged along the distal margin of the segments which gives the abdomen a hairy appearance (Figure 5.9 E). Lateral spines are present on S8 and S9, short, slightly bent inward. Anal pyramid not very protruded beyond the segment 9 in live condition whereas to some extent protruded beyond the S9 in the exuviae. Epiproct triangular in dorsal view, paraprocts slightly longer than the epiproct. Cerci comparatively long, more than 3/4th length of the epiproct (Figure 5.9 F). All anal appendages with numerous, very minute spines at the distal margins.

Diagnosis

The larvae described from Australian species of genus *Aethriamanta* are known to lack dorsal abdominal spines, whereas *Aethriamanta brevipennis* larvae or exuviae can be easily diagnosed by the presence of dorsal abdominal spines on S5-S8 and prominent long hairs almost all over the body. Other species from Southeast Asia probably bear dorsal spines (personal communication with Tosaphol Saetung).

Habitat and ecology

The larvae were collected from an open pond overgrown with *Salvinnia molesta*, near a paddyfield where several adult dragonflies were seen. The water quality parameters measured were as follows: temperature = 36.1°C, pH = 7.17, dissolved oxygen = 7 mg/L, conductivity = 0.17 µS/cm, turbidity = 14 NTU, total dissolved solids = 0.12 ppm, salinity = 3 ppt and depth =51.5 cm. Active foraging by larvae was observed mostly at night in the aquarium. They preferred to rest hidden among the plants during daytime.

The presence or absence and the number of dorsal abdominal spines are believed to be crucial characters for genus or species level identification (Suhling *et al.* 2014), but there seems to be a prominent variation in the presence of dorsal abdominal spines within the genus *Aethriamanta*, which is very interesting. Despite being a common dragonfly, this is the first proper description of the last instar larva or exuvia of this genus.

Figure 5.8 A. Last instar larva of the *Aethriamanta brevipennis.* B. Exuvia of *A. brevipennis*.

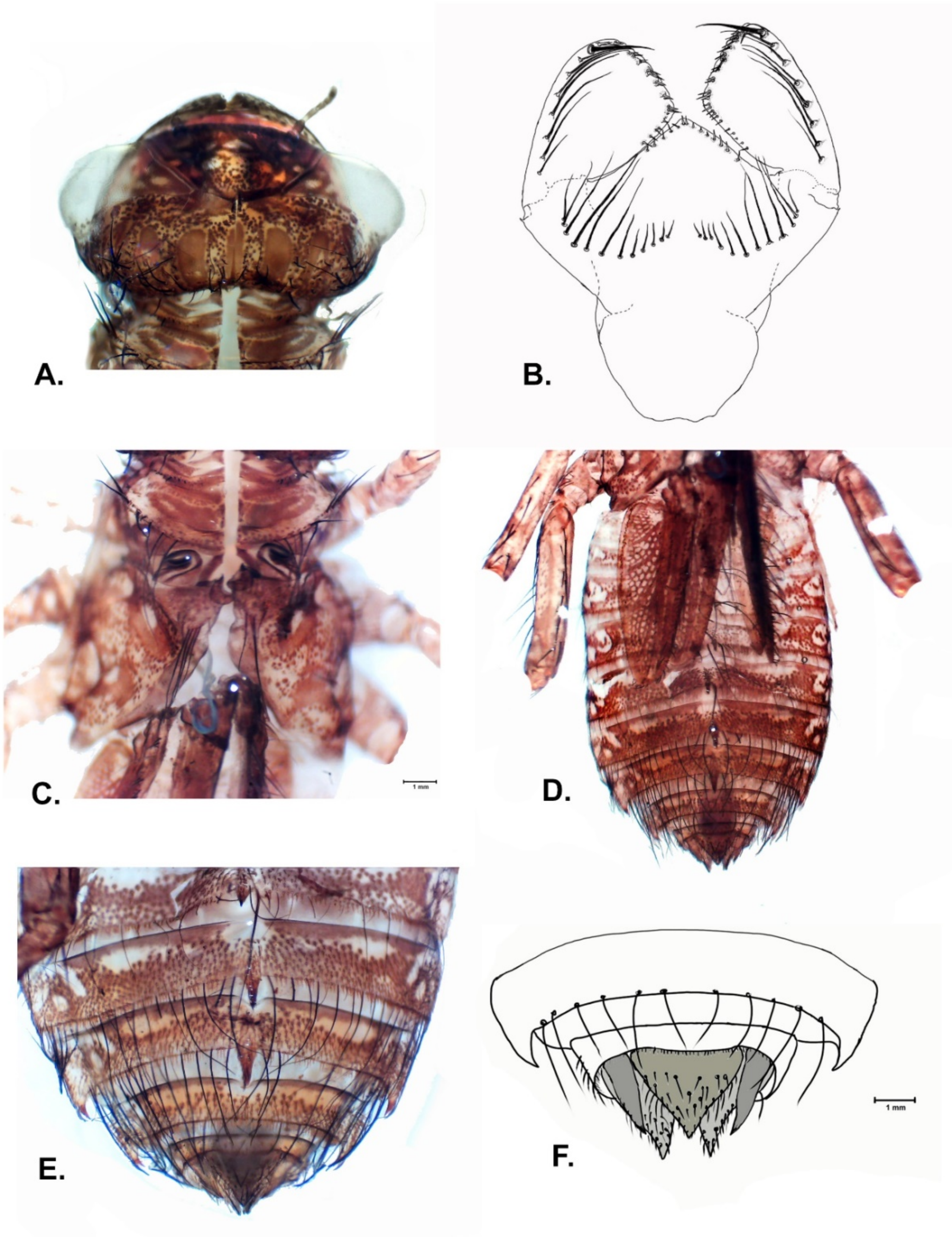


Figure 5.9: Detailed views of *Aethriamanta brevipennis* larva- A. Head, B. Labium, C. dorsal view of Thorax, D. Abdomen, E. Distal part of the abdomen, F. Anal pyramid in the exuvia.

5.4. Conclusion

This chapter has made significant contributions to the taxonomic knowledge of odonates from the Kole wetlands by providing the first formal descriptions of one adult male and two larval stages. The description of the adult male *Macrogomphus wynaadicus* Fraser, 1924 fills a crucial taxonomic gap, as previously only the female had been formally described. This comprehensive description, including detailed morphological characteristics and habitat preferences, enables more accurate species identification and supports the need for reassessing its current 'Data Deficient' IUCN Red List status.

The chapter also presents the first-ever larval description of *Platylestes platystylus* (Rambur, 1842) from the genus *Platylestes*, which was previously undocumented. This description provides valuable diagnostic features that distinguish it from other lestid genera, particularly noting its shorter labium compared to Lestes and the distinctive sharp prominent spines on the outer lobe of the labial palp. The detailed habitat data accompanying this description offers important ecological context for the species' presence in the Kole wetlands.

Additionally, the description of the larval stage of *Aethriamanta brevipennis* Rambur, 1842 reveals interesting morphological variations within the genus, particularly the presence of dorsal abdominal spines on segments 5-8, which contrasts with their Australian congeners. This finding suggests greater morphological diversity within the genus than previously known and highlights the importance of documenting regional variations in larval characteristics.

These descriptions collectively enhance our understanding of odonate diversity and development in the Kole wetlands while providing essential reference material for future ecological studies and conservation efforts. The detailed morphological descriptions, accompanied by precise measurements and habitat parameters, establish a strong foundation for future comparative studies and species identification work in the region. This work underscores the importance of continued taxonomic research in uncovering and documenting previously unknown life stages of odonates, particularly in biodiverse regions like the Western Ghats.

5.5. References

Babu, R., Subramanian, K. A., & Nandy, S. (2013). *Endemic odonates of India*. Zoological Survey of India.

Brauer, F. (1878). Über einige neue Gattungen und Arten aus der Ordnung der Neuropteren Lin [On some new genera and species from the order Neuroptera Lin]. *Sitzungsberichte der Kaiserlichen Akademie der Wissenschaften, Mathematisch-Naturwissenschaftliche Classe, 77*(1), 193–206.

Burmeister, H. (1839). *Handbuch der Entomologie: Zweiter Band. Besondere Entomologie. Zweite Abtheilung. Kaukerfe. Gymnognatha. (Zweite Hälfte; vulgo Neuroptera)* [Handbook of entomology: Second volume. Special entomology. Second section. Kaukerfe. Gymnognatha. (Second half; vulgo Neuroptera)]. Enslin.

Calvert, P. P. (1901). Family Odonata. In F. D. Godman & O. Salvin (Eds.), *Biologica Centrali-Americana: Insecta Neuroptera* (pp. 17–342).

Chandran, A. V., Jose, S. K., & Gopalan, S. V. (2021). Dragonflies and damselflies (Insecta: Odonata) of the Kole Wetlands, central Kerala, India. *Journal of Threatened Taxa, 13*(3), 17963–17971. https://doi.org/10.11609/jott.5885.13.3.17963-17971

Chandran, A. V., Raju, D. V., Jose, S. K., & Mirza, Z. A. (2023). A new species of *Epithemis* Laidlaw, 1955 (Odonata: Libellulidae), from the Western Ghats, India. *Journal of Asia-Pacific Biodiversity, 16*, 597-604. https://doi.org/10.1016/j.japb.2023.08.006

Dawn, P. (2022). Dragonflies and damselflies (Insecta: Odonata) of West Bengal, an annotated list of species. *Oriental Insects, 56*(1), 81–117. https://doi.org/10.1080/00305316.2021.1908188

Dijkstra, K. D. B., & Clausnitzer, V. (2014). *The dragonflies and damselflies of Eastern Africa: Handbook for all Odonata from Sudan to Zimbabwe. Studies in Afrotropical Zoology, Vol. 298*. Royal Museum for Central Africa.

Dow, R. A., Choong, C. Y., Grinang, J., Lupiyaningdyah, P., Ngiam, R. W. J., & Kalkman, V. J. (2024). Checklist of the Odonata (Insecta) of Sundaland and Wallacea (Malaysia, Singapore, Brunei, Indonesia and Timor Leste). *Zootaxa, 5460*(1), 1–122.

Drury, D. (1770). *Illustrations of natural history wherein are exhibited upwards of two hundred and forty figures of exotic insects* (Vol. 1). White and Elmsley.

Drury, D. (1773). *Illustrations of natural history wherein are exhibited upwards of two hundred and forty figures of exotic insects* (Vol. 2). White and Elmsley.

Dumont, H. J., & Borisov, S. N. (1993). Description of the full-grown larva of Sympecma gobica (Förster, 1900) (Odonata: Lestidae). *Bulletin et annales de la Société royale belge d'entomologie, 129*, 57–61.

Emiliyamma, K. G., & Palot, M. J. (2016). A new species of *Protosticta* Selys, 1885 (Odonata: Zygoptera: Platystictidae) from Western Ghats, Kerala, India. *Journal of Threatened Taxa, 8*(14), 9648–9652. https://doi.org/10.11609/jott.7792.14.7.21421-21431

Emiliyamma, K. G., Palot, M. J., & Charesh, C. (2020). A new species of Platylestes Selys (Odonata: Zygoptera: Lestidae) from the coastal area of Kannur District, Kerala, India. *Journal of Threatened Taxa, 12*(13), 16854–16860. https://doi.org/10.11609/jott.5209.12.13.16854-16860

Fabricius, J. C. (1775). *Systema entomologiae*. Flensburgi et Lipsiae.

Fabricius, J. C. (1787). *Mantissa insectorum sistens eorum species nuper detectas adiectis characteribus genericis, differentiis specificis, emendationibus, observationibus* (Vol. 1). Christ. Gottl. Proft.

Fabricius, J. C. (1793). *Entomologia systematica emendata et aucta: Secundum classes, ordines, genera, species, adjectis synonimis, locis, observationibus, descriptionibus* (Vol. 2). Christ. Gottl. Proft.

Fabricius, J. C. (1798). *Supplementum entomologiae systematicae*. Proft et Storch.

Fraser, F. C. (1922). New and rare Indian Odonata in the Pusa Collection. *Memoirs of Department of Agriculture of India (Entomology), 7*(7), 39–77.

Fraser, F. C. (1924). A survey of the odonate (dragonfly) fauna of Western India with special remarks on the genera *Macromia* and *Idionyx* and descriptions of thirty new species. *Records of the Indian Museum, 26*, 423–522, pls. xv–xvii.

Fraser, F. C. (1931). Additions to the survey of the odonate (dragonfly) fauna of western India, with descriptions of nine new species. *Records of the Indian Museum, 33*, 443–474.

Fraser, F. C. (1933). *The Fauna of British-India including Ceylon and Burma, Odonata. Vol. I.* Taylor and Francis Ltd.

Fraser, F. C. (1934). *The fauna of British India, including Ceylon and Burma: Odonata* (Vol. II). Taylor & Francis.

Fraser, F. C. (1936). *The fauna of British India, including Ceylon and Burma: Odonata, Vol. III*. Taylor and Francis.

Fraser, F. C. (1939). Additions to the family Corduliidae including descriptions of two new species and a new genus (Order: Odonata). *Proceedings of the Royal Entomological Society of London (B), 8*, 91-94.

GBIF.org. (2023). *GBIF occurrence download* [Data set]. https://doi.org/10.15468/dl.wd9xyg

Gopalan, S. V., Sherif, M., & Chandran, A. V. (2022). A checklist of dragonflies & damselflies (Insecta: Odonata) of Kerala, India. *Journal of Threatened Taxa, 14*(2), 20654–20665. https://doi.org/10.11609/jott.7504.14.2.20654-20665

Hawking, John H (1993) *A preliminary guide to the identification of dragonfly larvae (Odonata) from the Alligator Rivers region of the Northern Territory, Open File Record 102*, Murray-Darling Freshwater Research Centre, La Trobe University, Australia. 90pp. https://doi.org/10.26181/22240087.v1

Joshi, S., & Kunte, K. (2017). Two new dragonfly species (Odonata: Anisoptera: Aeshnidae) from north-eastern India. *Zootaxa, 4300*(2), 259–268. https://doi.org/10.11646/zootaxa.4300.2.7

Joshi, S., & Sawant, D. (2019). *Ceriagrion chromothorax* sp. nov. (Odonata: Zygoptera: Coenagrionidae) from Sindhudurg, Maharashtra, India. *Journal* *of Threatened Taxa, 11*(7), 13875-13885. https://doi.org/10.11609/jott.4753.11.7.13875-13885

Kalkman, V. J., Babu, R., Bedjanič, M., Conniff, K., Gyeltshen, T., Khan, M. K., Subramanian, K. A., Zia, A., & Orr, A. G. (2020). Checklist of the dragonflies and damselflies (Insecta: Odonata) of Bangladesh, Bhutan, India, Nepal, Pakistan and Sri Lanka. *Zootaxa, 4849*(1), 1–84.

Kirby, W. F. (1889). A revision of the subfamily Libellulinae, with descriptions of new genera and species. *Transactions of the Zoological Society of London, 12*, 249–348. https://doi.org/10.1111/j.1096-3642.1889.tb00016

Kumar, A. (1972). The life history of *Lestes praemorsa praemorsa* (Selys) (Odonata: Lestidae). *Treubia, 28*(1), 3–20.

Lahiri, A. R. (1976). *Calicnemia mukherjeei* spec. nov. from Khasi Hills, India (Zygoptera: Platycnemididae). *Odonatologica, 5*, 273–276.

Lahiri, A. R. (2003). On a new species of the genus *Bayadera* Selys (Odonata: Euphaeidae) from India with notes on its Indian representative. *Records of the Zoological Survey of India, 101*(3–4), 39–42.

Laidlaw, F. F. (1914). Zoological results of the Abor Expedition 1911-1912; XXV. Odonata. *Records of the Indian Museum, 8*, 335-349.

Laidlaw, F. F. (1915). Notes on Oriental dragonflies in the Indian Museum No. 3. *Records of the Indian Museum, 11*, 387-391.

Laidlaw, F. F. (1916a). Notes on Oriental dragonflies in the Indian Museum. No. 4. The genus Pseudagrion. *Records of the Indian Museum, 12*, 21-25.

Laidlaw, F. F. (1916b). Notes on Indian Odonata. *Records of the Indian Museum, 12*, 129-136.

Laidlaw, F. F. (1917a). A list of the dragonflies recorded from the Indian Empire with special reference to the collection of the Indian Museum Part I. The family Calopterygidae. *Records of the Indian Museum, 13*, 23-40.

Laidlaw, F. F. (1917b). A list of the dragonflies recorded from the Indian Empire with special reference to the collection of the Indian Museum Part I. The family Agrioninae. *Records of the Indian Museum, 13*, 321-348.

Laidlaw, F. F. (1919). A list of the dragonflies recorded from the Indian Empire with special reference to the collection of the Indian Museum Part II. *Records of the Indian Museum, 16*, 169-195.

Laidlaw, F. F. (1920). Description of a new species of the genus Pseudophaea (=Euphaea, Selys) from Western India with some remarks on the section dispar of the genus. *Records of the Indian Museum, 19*, 23-27.

Laidlaw, F. F. (1922). A list of the dragonflies recorded from the Indian Empire with special reference to the collection of the Indian Museum Part V. The subfamily Gomphinae. *Records of the Indian Museum, 24*, 367-426.

Laidlaw, F. F. (1924). Notes on Oriental dragonflies of the genus Aciagrion. *Proceedings of the United States National Museum, 66*(10), 1-9.

Laidlaw, F. F. (1932). A revision of the genus Coeliccia (Order Odonata). *Records of the Indian Museum, 34*, 7-42.

Leach, W. E. (1815). Entomology. In D. Brewster (Ed.), *The Edinburgh Encyclopaedia* (Vol. 9, pp. 57–172). William Blackburn.

Lieftinck, M. A. (1949). The dragonflies (Odonata) of New Guinea and neighbouring islands Part VII, Results of the third Archbold Expedition 1938–1939 and of the Le Roux Expedition 1939 to Netherlands New Guinea (II. Zygoptera). *Nova Guinea, 5*, 1–271.

Lien, J. C., & Matsuki, K. (1983). Description of the Larva of Orolestes selysi McLachlan from Taiwan (Lestidae: Odonata). *Tombo, 25*(1–4), 13–15.

McLachlan, R. (1895). Some new species of Odonata of the "Légion" Lestes, with notes. *Annals Magazine Natural History Series-6, 16*, 19–28. https://doi.org/10.1080/00222939508680221

Mitra, T. R., & Lahiri, A. R. (1975). A new species of *Gynacantha* Rambur, 1842 (Odonata: Aeshnidae) from India. *The Entomologist's Record and Journal of Variation, 87*, 148–149.

Mujumdar, N., Sawant, D., Sumanapala, A., Rangnekar, P., & Koparde, P. (2020). Rapid multi-taxa assessment around Dhamapur Lake (Sindhudurg, Maharashtra, India) using citizen science reveals significant odonate records. *Journal of Threatened Taxa, 12*(13), 16795–16818. https://doi.org/10.11609/jott.6028.12.13.16795-16818

Paulson, D., Schorr, M., Abbott, J., Bota-Sierra, C., Deliry, C., Dijkstra, K.-D., & Lozano, F. (2024). *World Odonata List*. Odonata Central, University of Alabama. https://www.odonatacentral.org/app/#/wol/

Rambur, J. P. (1842). *Histoire naturelle des insects, névroptères* [Natural history of insects, neuroptera]. Librairie encyclopédique de Roret, Fain et Thunot.

Ris, F. (1912). Neue Libellen von Formosa, Südchina, Tonkin und den Philippinen, *Supplementa entomologica*, 1, 44–85.

Rison, K. J., & Chandran, A. V. (2020). Observations of the damselfly *Platylestes* cf. *platystylus* Rambur, 1842 (Insecta: Odonata: Zygoptera: Lestidae) from peninsular India. *Journal of Threatened Taxa, 12*(10), 16392–16395. https://doi.org/10.11609/jott.5834.12.10.16392-16395

Selys-Longchamps, E. de. (1853). Synopsis des Caloptérygines. Bulletins de l'Académie Royale des Sciences, des Lettres et des Beaux-Arts de Belgique, 20(1), 1-73.

Selys-Longchamps, E. de. (1854). Monographie des Caloptérygines. Mémoires de la Société Royale des Sciences de Liège, 9, 1-291.

Selys-Longchamps, E. de. (1859). Additions au synopsis des Caloptérygines. Bulletins de l'Académie Royale des Sciences, des Lettres et des Beaux-Arts de Belgique, 2(7), 437-451.

Selys-Longchamps, E. (1897). Causeries odonatologiques. No. 9 [Odonatological discussions. No. 9]. *Annales de la Société Entomologique de Belgique, 41*, 68–87.

Selys-Longchamps, E. de (1862). *Synopsis des Agrionines 2e légion: Lestes* [Synopsis of Agrionines 2nd legion: Lestes] [includes contributions by Hagen]. *Bulletins de l'Académie royale des sciences, 2*(13), 288–338.

Selys-Longchamps, E. de (1876). *Synopsis des Agrionines, 5me legion: Agrion (suite). Le genre Agrion* [Synopsis of Agrionines, 5th legion: Agrion (continued). The genus Agrion]. *Bulletins de l'Académie royale des sciences, 42*(2), 490–531.

Sharma, G. (2010). Platylestes platystylus. *The IUCN Red List of Threatened Species*, Article e.T167261A6319472. https://www.iucnredlist.org/species/167261/6319472

Subramanian, K. A. (2011). *Macrogomphus wynaadicus*. The IUCN Red List of Threatened Species, Article e.T175174A7117358. https://dx.doi.org/10.2305/IUCN.UK.2011-1.RLTS.T175174A7117358.en

Subramanian, K. A., & Babu, R. (2017). *Checklist of Odonata (Insecta) of India* (Version 3.0). Zoological Survey of India.

Subramanian, K. A., Emiliyamma, K. G., Babu, R., Radhakrishnan, C., & Talmale, S. S. (2018). *Atlas of Odonata (Insecta) of the Western Ghats, India*. Zoological Survey of India.

Subramanian, K. A., Rangnekar, P., & Naik, R. (2013). *Idionyx* (Odonata: Corduliidae) of the Western Ghats with a description of a new species. *Zootaxa, 3652*(2), 277–288. https://doi.org/10.11646/zootaxa.3666.1.10

Subramanian, K. A., & Babu, R. (2020). Dragonflies and damselflies (Insecta: Odonata) of India. In S. Ramani, P. Mohanraj, & H. M. Yeshwanth (Eds.), *Indian insects: Diversity and science* (pp. 29-45). CRC Press.

Suhling, F., Müller, O., & Martens, A. (2014). The dragonfly larvae of Namibia (Odonata). *Libellula Supplement, 13*, 5–106.

Theischinger, G. (2009). *Identification Guide to the Australian Odonata*. Department of Environment, Climate Change and Water New South Wales.

Theischinger, G., & Endersby, I. (2014). Australian Dragonfly (Odonata) Larvae: Descriptive history and identification. *Memoirs of Museum Victoria, 72*, 73–120.

Chapter 6

RECOMMENDATIONS

This chapter synthesizes the findings from the previous chapters to provide concrete recommendations for both conservation and management of the Kole wetland ecosystem and directions for future research.

6.1. Habitat Protection and Enhancement

The natural vegetation of Kole wetlands is now dominated by exotic species in most places. While the spread of invasive submerged vegetation like *Cabomba* spp. showed negative correlation with odonate diversity, species like *Salvinnia molesta* seem to provide good microhabitat for the odonate larvae. However, the effect of these exotic plants on the native flora is clearly negative, and on other fauna is unclear. Since this was the pioneering study on odonates of this wetland system, the original odonate faunal composition of this wetland prior to human intervention is unknown. Invasive vegetation is, in general, known to be one of the gravest threats to native biodiversity (Langmaier & Lapin, 2020; Richardson et al., 2007). Hence, in this wetland system, they must be carefully managed after further investigation of their effects on native organisms. A buffer zone with native vegetation around the wetland margins can enhance odonate diversity by providing them perching and roosting sites. Planting trees on bunds and fallow areas can provide shade and attract shade-loving odonate species, along with other wildlife.

Regular monitoring of water quality parameters, particularly dissolved oxygen levels, is necessary for ensuring that the wetland ecosystem continues to support the rich biodiversity that it now hosts. Guidelines for agricultural practices that minimize impacts on water quality must be developed, especially regarding fertilizer and pesticide use. Strict measures to check their overuse and use of banned chemicals can help stop the mixing of these toxic chemicals in the waters of this aquatic system. Within the wetlands, regions unsuitable for cultivation can be maintained as refuge habitats for odonates and other aquatic fauna and flora. Further encroachment and land conversion in the wetlands must be stopped.

Regular monitoring of biodiversity can inform us about the changes happening in the wetland system. This can be supplemented with measurements of environmental parameters. A database of these diversity and environmental measures must be maintained for long-term studies. Involving stakeholders, especially farmers, in the biodiversity monitoring programmes can create widespread awareness which is crucial for the success of any conservation programme. By motivating the stakeholders, a nature interpretation centre focusing on wetland biodiversity can be established near the wetlands which can serve as a hub for knowledge sharing.

The introduction of exotic fish species, some by accident, and others intentionally for harvesting, has happened on a large scale in the Kole wetlands (Krishnakumar et al., 2011). Some of these have become invasive, decimating native biodiversity, including odonate species (Anupama et al., 2021). Steps to remove the invasive fishes must be taken after taking the local stakeholders into confidence. It is essential to convey that the cultivation of exotic species is an unsustainable practice that poses a significant risk of long-term collapse to native fisheries.

6.2. Future Research Directions

The present study has identified some odonate species as potential indicator organisms. These species must be subjected to experimental studies to understand how well they reflect the physico-chemical parameters in their environment. They can then be used to monitor ecosystem health. Numerous odonate species are observed in significant abundance within this wetland, providing opportunities for studies on behaviour, population dynamics, survival rates, and dispersal patterns. The presence of substantial populations of these predatory insects within this agricultural landscape likely plays a crucial role in regulating insect pest populations. The economic value of this ecosystem service can be assessed by estimating the crop yield benefits due to pest reduction and comparing these to the costs of alternative pest control methods. This can be done by studying their diet through gut content or DNA analyses, measuring predation rates in the field, and modelling their impact on pest population dynamics. Such studies highlight the importance of conserving odonates as a natural, sustainable means of enhancing agricultural productivity.

Odonates are integral to food web dynamics, functioning as both predators and prey across aquatic and terrestrial ecosystems. Studying their trophic interactions through methods like stable isotope analysis and gut content studies would provide insights into energy transfer and ecosystem stability, highlighting their role in maintaining ecological balance. There are several institutions around the Kole wetlands where research is being carried out on its biodiversity. These studies can be enhanced by fostering partnerships between research institutions and local authorities to align scientific studies with conservation and management goals. Collaborative efforts can focus on understanding odonates' ecological roles and their contributions to pest control and biodiversity. Developing sustainable funding mechanisms, such as grants, public-private partnerships, or community-driven initiatives, will support long-term monitoring programmes. These initiatives will not only enhance our knowledge of odonates but also promote the conservation of the wetlands as vital habitats and contributors to agricultural sustainability.

6.3. References

Krishnakumar, K., Ali, A., Pereira, B., & Raghavan, R. (2011). Unregulated aquaculture and invasive alien species: A case study of the African Catfish *Clarias gariepinus* in Vembanad Lake (Ramsar Wetland), Kerala, India. *Journal of Threatened Taxa,* *3*(5), 1737–1744. https://doi.org/10.11609/JoTT.o2378.1737-44

Langmaier, M., & Lapin, K. (2020). A systematic review of the impact of invasive alien plants on forest regeneration in European temperate forests. *Frontiers in Plant Science, 11*, 524969. https://doi.org/10.3389/fpls.2020.524969

Richardson, D. M., Pyšek, P., & Rejmánek, M. (2007). Invasive alien plants: Impacts on ecosystem services and human well-being. *Perspectives in Plant Ecology, Evolution, and Systematics,* *10*(3), 286–297. https://doi.org/10.1016/j.ppees.2007.10.002

Sreedevi, V., Raj, S., Devi, S. S., & Kumar, A. B. (2021). Diet of exotic pirapitinga *Piaractus brachypomus* (Cuvier, 1818) from Vembanad-Kole Wetland, India, as inferred from gut content analysis and DNA barcoding. *Asian Fisheries Science, 34*(1), 47–55. https://doi.org/10.33997/j.afs.2021.34.1.005

APPENDICES

Appendix I: Water quality parameters of ponds and wetland sites in the comparative study.

Sl no	Site	Type	Temp (°C)	pH	DO (mg/L)	BOD (mg/L)	Conductivity (µS/cm)	Turbidity (NTU)	TDS (ppm)	Salinity (ppt)	Nitrate (mg/L)	Phospate (mg/L)
1	Basketball court	Pond	26.7	6.78	3.8	0.4	40.6	5	12.4	0.5	2.5	4.5
2	Kuttamkulam	Pond	26.7	8.32	3.1	1	90.8	6	58.7	0.2	1.2	5
3	Thamarakulam	Pond	26.4	7.93	3.8	3.6	154.5	4	100.2	0.7	0.9	4.8
4	Mannathikulam	Pond	26.6	6.97	4.2	0.8	115.2	7	74.8	0.3	0.7	4.2
5	Njourikulam	Pond	26.6	7.83	3.8	0.4	100.2	6	65	0.8	2.6	5.5
6	Oomenkulam	Pond	27.7	7.14	3.6	3.8	219	8	142	1.1	0.4	5.2
7	Brahmakulam	Pond	28	6.21	3.6	0.4	33.6	7	21.9	1.6	1.7	6
8	Thekkekulam	Pond	31.3	6.24	4	1.2	103.7	3	67.2	0.7	0.8	5.7
9	Kesavankulangara	Pond	30.8	6.33	9.6	5.6	57.9	8	37.6	0.4	3.5	3.2
10	Parakulam	Pond	29.1	4.43	8	5.4	159.1	5	104.5	0.6	1.5	2
11	Thrithanni	Pond	28.9	5.68	8.4	2.8	52.1	9	120.6	0.9	2.3	6.2
12	Padmanabhakulam	Pond	29	6.15	8.4	1.2	87.6	7	56.9	1.2	1.1	8
13	Korumbissery	Pond	29.3	6.38	7.2	4.4	192.1	10	124.6	0.87	4	6.5
14	Porathissery	Pond	29.3	6.78	4.3	5.2	151.5	6	98.4	0.93	3.7	8
15	Kizhuthani	Pond	29.3	6.85	6	1.2	172.7	9	97.2	1.8	5	3
16	Manthripulam	Pond	30.6	7.4	4.8	0.8	79.4	5	51.8	1.9	1.6	4.7
17	Avittathur	Pond	30.6	5.46	4.8	1.2	82.1	7	53.4	0.62	2.4	2.7
18	Irrigation pond	Pond	30.4	7.13	3.8	0.4	43.1	3	28	0.84	0.7	4.8
19	Thazhekkad	Pond	30.6	7.55	3.6	1.6	89.6	10	57.6	0.49	1.3	1.7
20	Karakulam	Pond	30.5	6.56	2.8	0.8	132.4	5	120.9	0.62	1	4.6
21	Thommana	Wetland	29.1	8.15	3.5	4	27	1	15.9	0.65	8.5	3.5
22	Thottipal	Wetland	36.4	7.19	5.2	2	15	5	9	0.92	1.8	3
23	Anandapuram	Wetland	33.9	8.24	7.9	2.6	22.3	0	7.9	2.5	4.6	1.8
24	Muriyad	Wetland	34.2	7.04	3	5.2	13.2	4	80.2	3.1	7	3
25	Kallettumkara	Wetland	31.7	7.94	4	2	102	1	9.4	3.7	5.6	2.2
26	Kattur	Wetland	32.5	7.77	2.2	4.4	90.6	6	6.3	2	6	3.5
27	Konthipulam	Wetland	36.5	7.7	9	1.6	13.8	6	80.2	3	6.8	4.5
28	Thazhekkad	Wetland	35.5	7.51	4	3	142.3	4	90.4	2.8	6.9	5.5
29	Chemmanda	Wetland	33.4	8.77	4	5.3	111.7	5	90.1	2.2	3.2	3.6
30	Ounderchaal	Wetland	37.1	7.26	3.2	4	80.8	3	5.8	1.8	2	5
31	Palakuzhi	Wetland	33.1	7.72	3.9	4.1	16.7	3	9.4	3.8	5.8	2.3
32	Kuriyadi	Wetland	35.8	7.72	3	6.3	114	6	69.6	3.1	10	3
33	Poomangalam	Wetland	36.1	7.17	7	5.7	117.5	14	112.4	3	9	6
34	Pazhuvil	Wetland	33.6	7.8	6.3	3	129.6	19	111.8	3.2	2.4	4.1
35	Mapranam	Wetland	30.3	6.61	3.2	4.6	150	20	110.7	2.8	7	3.2
36	Pullur	Wetland	34.1	6.17	7.6	2	23.7	6	15.8	3.8	3.5	6
37	Kottanelloor	Wetland	32.3	6.92	7.4	3.8	41.9	5	30.4	8.7	1.5	5.2
38	Vellangallur	Wetland	32.7	7.19	8	1.4	43.7	8	18.4	5.9	5.3	2.6
39	Ashtamichira	Wetland	34.6	6.62	7.4	0	21	6	1.15	3.8	4.4	6.5
40	Kizhupadam	Wetland	34.6	6.85	2.6	5.9	30.3	12	59.1	6.8	10.2	6

Appendix II: Shannon Index of odonate diversity and weather parameters recorded for the period May 2019 - April 2021.

Season	Shannon Index	Rainfall (total in mm)	Temperature (average in °C)	RH (average in %)	Windspeed (average in m/s)
I-M1	2.64	1221.3	27.69	83.41	2.59
I-M2	2.16	1398.8	26.03	88.88	2.08
I-W	0.76	86.1	26.82	77.59	1.73
I-S	1.41	136	30.04	63.7	1.73
II-M1	2.14	1089.2	27.19	85.65	2.39
II-M2	2.02	1448.8	25.9	89.06	2.27
II-W	0.77	90.4	26.19	78.8	1.72
II-S	1.47	126.4	28.72	67.21	1.54

Appendix III: Environmental parameters monitored for studying odonate larvae.

Sl no	Quadrat	Season	Temp (°C)	pH	DO (mg/L)	BOD (mg/L)	Conductivity (µS/cm)	Turbidity (NTU)	TDS (ppm)	Salinity (ppt)	Depth (cm)	Veg cover (%)	H veg	Nitrate (mg/L)	Phosphate (mg/L)	Bifenthrin (ppm)	Fenvalerate (ppm)	Soil pH	Sand (%)	Silt (%)	Clay (%)	Org C (%)
1	Palakkal	M1	29.1	8.15	3.5	3	0.27	1	0.15	6.5	45	30	0	0.8	0.45	0	0	7.8	18.3	36.7	45	1.8
2	Uppungal	M1	36.4	7.19	0.5	2	0.15	5	0.09	2.9	15	60	0	0.3	0.28	0	0	6.9	33.8	31.2	35	0.9
3	Thommana	M1	33.9	8.24	9	5.4	0.11	0	0.07	2.5	35	90	0.4505	1.2	0.62	0	0	7.9	16.5	38.9	44.6	2.5
4	Mulloorkayal	M1	30.3	6.8	8.1	8	0.29	3	0.18	6	36	100	1.0114	1.5	0.95	0	0	6.5	11.2	33.6	55.2	3.2
5	Biyyam	M1	31.8	5.63	5.5	12	0.31	8	0.19	7	14	85	1.2397	2	1.2	0	0	5.8	29.7	35.1	35.2	2.8
6	Thottipal	M1	34.8	6.11	7.7	7.2	0.08	9	0.06	2.7	46.25	90	0.5447	1.1	0.78	0	0	6.3	14.8	41.3	43.9	2.7
7	Kanjani	M1	35.3	6.73	7.4	4	0.09	3	0.06	2.1	8.25	70	0	0.7	0.53	0	0	6.6	36.4	33.8	29.8	1.5
8	Naranipuzha	M1	29.8	7.21	2.3	3.3	0.45	4.2	0.21	9.9	23.75	60	0.9248	0.5	0.38	0	0	7	41.6	28.9	29.5	1.2
9	Kattur	M1	29.1	6.73	7.3	10	0.16	11	0.11	3.6	43	65	0.8189	1.8	1.1	0	0	6.5	16.9	38.7	44.4	1.7
10	Mulloorkayal	M2	34.2	7.04	3	2	0.13	4	0.08	3.1	28	90	0.4633	3.2	3.25	0	0	6.8	9.8	34.9	55.3	3
11	Biyyam	M2	31.7	7.94	0.3	1.1	0.15	1	0.09	3.7	33	80	0.7022	2.8	2.8	0	0	7.6	31.3	34.2	34.5	2.6
12	Thottipal	M2	32.5	7.77	2.2	4	0.09	6	0.06	2	63	95	0.9877	4.5	4.2	0	0	7.5	15.7	39.8	44.5	3.1
13	Kanjani	M2	36.5	7.27	11	15	0.13	6	0.08	3	30	70	1.378	7.2	6.5	0.01	0.036	7.1	34.9	35.6	29.5	2.2
14	Kattur	M2	35.5	7.51	4	8	0.14	4	0.09	2.8	44.5	100	1.1615	5.6	5.4	0	0	7.3	14.6	41.1	44.3	3.5
15	Naranipuzha	M2	33.4	8.77	4	6.9	0.11	5	0.06	2.2	40.75	35	0.7622	4.8	4.8	0	0	8.2	39.4	31.2	29.4	1
16	Thommana	M2	37.1	7.26	3.2	9	0.08	3	0.05	1.8	45.25	70	1.1986	6.1	5.7	0	0	7.4	16.2	39.4	44.4	2.4
17	Uppungal	M2	33.1	7.72	3.9	5.5	0.16	3	0.09	3.8	25.75	85	0.3251	4.2	4.1	0	0	7.3	34.1	31.7	34.2	2.8
18	Palakkal	M2	35.8	7.72	3	14	0.14	6	0.09	3.1	18.25	100	1.5057	7.8	6.8	0	0.009	7.6	19.5	35.8	44.7	4.2
19	Thottipal	W	36.1	7.17	7	10	0.17	4	0.12	3	51.5	100	1.0114	8.4	7.2	0	0	7.2	11.4	43.9	44.7	3.8
20	Biyyam	W	33.6	7.8	6.3	8.6	0.19	19	0.12	3.2	27.75	70	0.8891	7.5	6.8	0	0	7.4	24.3	41.2	34.5	2.3
21	Mulloorkayal	W	30.3	6.61	3.2	12	0.15	20	0.1	2.8	37	90	1.2594	9.2	8	0	0	6.4	6.7	38.6	54.7	3.3
22	Naranipuzha	W	34.1	6.17	7.6	6.8	0.23	6	0.15	3.8	28.75	100	0.2326	6.9	6.4	0	0	6.3	36.8	34.1	29.1	1.5
23	Kanjani	W	32.3	6.92	7.4	7	0.18	25	0.3	2.7	26.25	100	0.0808	7.1	6.7	0	0	6.8	10.9	44.7	44.4	3.6
24	Kattur	W	32.7	7.19	9	5	0.13	25	0.18	5.9	32.25	45	0	5.8	5.9	0	0	7	33.7	36.5	29.8	1.4
25	Thommana	W	34.6	6.62	10.6	2.3	0.21	41	0.15	3.8	19.5	15	0.3958	4.7	5.3	0	0	6.8	18.9	36.4	44.7	2
26	Palakkal	W	34.6	6.85	3.2	18	0.37	31	0.59	6.8	12	65	0.9974	9.8	7.8	0	0	7	16.1	39.6	44.3	1.8
27	Uppungal	W	29.8	6.92	3.9	10.7	0.52	16	0.34	8.4	34	97	0.2816	8.6	7.4	0	0	7.2	31.6	34.2	34.2	0.7
28	Thottipal	S	37.2	5.97	6.5	8	0.15	12	0.97	2.6	8.25	95	0.3665	1.4	1.8	0	0	6.8	29.2	36.3	34.5	4.5
29	Biyyam	S	36.2	5.76	12.2	4.4	0.45	16	0.28	8.5	55.25	65	0.9974	0.7	1.2	0.036	0	6	34.5	31.3	34.2	2.1
30	Mulloorkayal	S	31.5	6.11	9.2	20.6	0.24	26	0.16	4.6	14.75	97	0.4129	2.8	3.2	0	0	6.2	11.8	33.7	54.5	3.9
31	Naranipuzha	S	34.2	6.83	3.7	7.5	0.64	8	0.41	11.8	14	80	1.0528	1.2	1.5	0	0	6.9	38.9	31.6	29.5	1.3
32	Kanjani	S	36	6.93	4.5	14	0.28	16	0.18	5.5	29.25	85	0.469	2.1	2.4	0	0	7	15.4	40.2	44.4	2.9
33	Kattur	S	33.5	6.6	7.2	5.4	0.17	1	0.2	5.6	27.5	95	0.7172	0.9	1.3	0	0	6.7	28.7	37.1	34.2	2.5
34	Palakkal	S	32.6	5.55	4.4	10	0.56	11	0.48	2.8	19.25	40	0.6109	1.6	2.1	0	0.07	6.8	15.8	40.1	44.1	1.1
35	Uppungal	S	34.5	6.97	2.77	6.7	0.26	16	1.15	5.3	8	45	0.3958	1.1	1.4	0	0	7.1	35.7	34.9	29.4	1.6
36	Thommana	S	35.5	7.38	4.25	15.8	0.22	7	0.14	4.4	28	100	0.5736	2.5	2.8	0	0	7.5	16.4	39.2	44.4	3.7

PLATES

PLATES

Collection of odonate larvae using quadrat method.

A female *Urothemis signata* perched against the backdrop of wetland reclamation.

Collection of adult odonates using an aerial net.

Researcher picking odonate larvae from the debris collected.

An ant examining the exuvia of *Anax guttatus*.

The loss of aquatic vegetation due to herbicide spray in wetlands.

The loss of vegetation on bunds as a result of burning.

A flooded paddyfield in Kole wetlands.

Researcher interacting with students to increase their awareness about odonates.

Researcher photographing odonates in Kole wetlands.

Researcher estimating water quality parameters in the field.

List of articles published in peer-reviewed journals

1. **Chandran, A.V.**, Jose, S.K., & Gopalan, S.V. (2021). Dragonflies and damselflies (Insecta: Odonata) of the Kole Wetlands, central Kerala, India. *Journal of Threatened Taxa*, *13*(3), 17963–17971. https://doi.org/10.11609/jott.5885.13.3.17963-17971

2. **Chandran, A.V.**, Karakuth, A.K., Jose, S.K., & Wildermuth, H. (2021). First record of gynandromorphism in *Trithemis aurora* (Odonata: Libellulidae). *Odonatologica 50*(1/2), 55-63. https://doi.org/10.5281/zenodo.4746240

3. **Chandran, A.V.**, Jose, S.K., Rangnekar, P., & Chenthamarakshan, B. (2023). Description of the male *Macrogomphus wynaadicus* Fraser, 1924, from the Western Ghats, India (Odonata: Gomphidae). *Odonatologica*, *52*(3–4). https://doi.org/10.60024/odon.v52i3-4.a8

4. **Chandran, A.V.**, Jose, S.K., & Dawn, P. (2023). Description of the Last Instar Larva of *Platylestes platystylus* (Rambur, 1842) from Kerala, India (Odonata: Lestidae). *Zootaxa*, *5380*(6), 587–594. https://doi.org/10.11646/zootaxa.5380.6.6

5. **Chandran, A.V.**, Chandran, R., Jose, S.K., Payra, A., & Koparde, P. (2024). *Melanoneura agasthyamalaica* sp. n. (Odonata, Platycnemididae) from the Western Ghats, India. *International Journal of Odonatology*, *27*, 213-226. https://doi.org/10.48156/1388.2024.1917298

6. **Chandran, A.V.**, Muneer, P.K., Madhavan, M., & Jose, S.K. (2024). Description of *Protosticta sexcolorata* sp. nov. (Odonata, Platystictidae) from the Western Ghats, India. *Journal of Asia-Pacific Biodiversity*, *17*, 295-302. https://doi.org/10.1016/j.japb.2023.11.010

7. **Chandran, A.V.**, Chandran, R., Suraj, S.R., Jose, S.K., & Koparde, P. (2024). Description of *Phylloneura rupestris* sp. n. (Odonata,

Platycnemididae) from the Western Ghats, India, with notes on its reproductive behaviour. *International Journal of Odonatology*, *27*, 26–36. https://doi.org/10.48156/1388.2024.1917259

8. Munner, P.K., Babu, S.N., **Chandran, A.V.**, & Jose, S.K. (2023). Odonata checklist of Wayanad Wildlife Sanctuary, Kerala State, Southern India. *International Journal of Tropical Insect Science*, *44*(1), 369–384. https://doi.org/10.1007/s42690-023-01135-y

9. **Chandran, A.V.**, Raju, D.V., Jose, S.K., & Mirza, Z.A. (2023). A new species of *Epithemis* Laidlaw, 1955 (Odonata: Libellulidae), from the Western Ghats, India. *Journal of Asia-Pacific Biodiversity*, *16*(4), 597–604. https://doi.org/10.1016/j.japb.2023.08.006

10. **Chandran, A.V.**, Muneer P.K., Madhavan, M., & Jose, S.K. (2025). Odonata diversity of the Kuruva Islands, southern India, with notes on the ecology of *Disparoneura apicalis* (Fraser, 1924) (Odonata: Platycnemididae) *Journal of Insect Biodiversity and Systematics*, 11(1), 207-226. https://doi.org/10.61186/jibs.11.1.207

Papers communicated

1. **Chandran, A.V.** & Jose, S.K. (2025). Odonata diversity of Kole wetlands, Kerala, India (Indian Journal of Entomology).

2. **Chandran, A.V.**, Subin, K.S., Siji, P.K. & Jose, S.K. (2025). Environmental factors influencing larval Odonata assemblages in tropical wetland agroecosystems (Tropical Ecology).

3. **Chandran, A.V.** & Jose, S.K. (2025). Water Quality and Adult Odonata Diversity: A Comparative Study of Tropical Wetlands and Ponds (International Journal of Environmental Studies).

Journal of Threatened Taxa | www.threatenedtaxa.org | 26 March 2021 | 13(3): 17963–17971

ISSN 0974-7907 (Online) | ISSN 0974-7893 (Print)

https://doi.org/10.11609/jott.5885.13.3.17963-17971

#5885 | Received 21 March 2020 | Final received 11 November 2020 | Finally accepted 05 March 2021

PLATINUM OPEN ACCESS

COMMUNICATION

Dragonflies and damselflies (Insecta: Odonata) of the Kole Wetlands, central Kerala, India

A. Vivek Chandran [1], Subin K. Jose [2] & Sujith V. Gopalan [3]

[1,2] Department of Geology and Environmental Science, Christ College, Irinjalakuda, Thrissur, Kerala 680125, India.
[3] Department of Zoology, University College, Research Centre, University of Kerala, Thiruvananthapuram, Kerala 695034, India.
[1] avivekchandran@gmail.com, [2] josesubin@gmail.com, [3] sujith.vg@gmail.com (corresponding author)

Abstract: A year-long study was conducted at the Kole Wetlands, a Ramsar site in central Kerala to document the diversity of dragonflies and damselflies and understand their seasonality. Checklist survey method was used to sample adult odonates in 30 randomly chosen locations. A total of 44 species (30 dragonflies and 14 damselflies) belonging to 33 genera and eight families were recorded in the study area. Species richness showed a peak in the post-monsoon season and a dip in the summer. The observations support the value of the Kole Wetlands in providing valuable resources for Odonata.

Keywords: Conservation, insect diversity, Ramsar site, seasonality, wetlands.

Editor: Ashish D. Tiple, Vidyabharati College, Wardha, India. **Date of publication:** 26 March 2021 (online & print)

Citation: Chandran, A.V., S.K. Jose & S.V. Gopalan (2021). Dragonflies and damselflies (Insecta: Odonata) of the Kole Wetlands, central Kerala, India. *Journal of Threatened Taxa* 13(3): 17963–17971. https://doi.org/10.11609/jott.5885.13.3.17963-17971

Funding: This work was partially supported by Kerala State Biodiversity Board through WWF-India and C Achutha Menon - T R Chandra Dutt Fellowship 2019 of Centre of Science and Technology for Rural Development (COSTFORD) awarded to A. Vivek Chandran.

Competing interests: The authors declare no competing interests.

Author details: A. Vivek Chandran is a PhD scholar at the Department of Geology and Environmental Science, Christ College (Autonomous), Irinjalakuda. His specific fields of interest are taxonomy and ecology of odonates. Subin K. Jose is an Assistant Professor at the Department of Geology and Environmental Science, Christ College (Autonomous), Irinjalakuda. His research interests are remote sensing, GIS and landscape ecology. Sujith V. Gopalan is a conservation biologist with research focused on evolution, ecology, population genetics, phylogeny and systematics of amphibians and odonates of the Western Ghats.

Author contribution: SKJ and SVG designed the study. AVC and SVG collected data from the field. AVC analysed the data. AVC, SKJ and SVG wrote the paper.

Acknowledgements: We thank Subin K.S. for helping us in the field. We are indebted to Society for Odonate Studies (SOS), Kerala for the encouragement and technical support. SVG and AVC are thankful to Kerala State Biodiversity Board and Centre of Science and Technology For Rural Development (COSTFORD), Thrissur, respectively, for providing the financial support for the fieldwork.

1st June 2021

First record of gynandromorphism in *Trithemis aurora* (Odonata: Libellulidae)

Ayikkara Vivek Chandran[1,4], Ajay Krishna Karakuth[2], Subin Kaniyamattathil Jose[1] & Hansruedi Wildermuth[3]

[1] Department of Geology and Environmental Science, Christ College, Thrissur, Kerala, India

[2] Karakuth house, Changaleeri, Mannarkkad, Palakkad, Kerala, India

[3] Haltbergstrasse 43, 8630 Rüti, Switzerland; <hansruedi@wildermuth.ch>

[4] Corresponding author: <avivekchandran2@gmail.com>

Received 23rd November 2020; revised and accepted 23rd January 2021

Abstract. A gynandromorphic individual of *Trithemis aurora* is reported from a garden in Palakkad district, Kerala state, India. Its eyes, thorax, legs, wings, and abdomen show mosaic gynandromorphy. The abdomen is mostly gynochromic with the tip bearing female appendages. Detailed study of the specimen shows that female characters predominate but significant areas exhibit male characters.

Further key words. Dragonfly, Anisoptera, mosaic gynander, androchromism

Introduction

Gynandromorphs are genetically chimeric individuals consisting of adjacent male and female tissues, thus differing from intersexes which are genetically uniform (Narita et al. 2010). Gynandromorphism is a rare phenomenon in nature and is readily detected in species that show sexual dimorphism. In arthropods, gynandromorphs have been recorded in crustaceans (Farmer 2004), arachnids (*e.g.*, Palmgren 1979; Cokendolpher & Sisson 1988; Labruna et al. 2002) and insects (*e.g.*, Morgan & Bridges 1919; Nielsen 2010; Gjershaug et al. 2016). In dragonflies, gynandromorphism has been reported in at least 55 cases (*cf.* review by Martens & Wildermuth 2021). This phenomenon is conspicuous in species that exhibit marked sexual colour dimorphism such as *Crocothemis servilia* (Drury, 1770) (Yokota & Asahina 1953; Futahashi 2017; Renjith & Chandran 2020), *Brachythemis contaminata* (Fabricius, 1793) (Joshi et al. 2020) or *Neurothemis tullia* (Drury, 1770) (Shome et al. 2019). Here we report on a case of phenotypical mo-

1st December 2023

Description of the male *Macrogomphus wynaadicus* Fraser, 1924, from the Western Ghats, India (Odonata: Gomphidae)

Ayikkara Vivek Chandran[1,4,5], Subin Kaniyamattathil Jose[1], Parag Rangnekar[2] & Bijoy Chenthamarakshan[3]

[1] Aqua Research Lab, Department of Geology and Environmental Science, Christ College (Autonomous), Irinjalakuda, Thrissur, Kerala, India-680125

[2] Foundation for Environment Research & Conservation. #407, III-A, Susheela Seawinds, Alto-Vaddem, Vasco-da-Gama, Goa, India-403802

[3] Shadpada Entomology Research Lab, Department of Zoology, Christ College (Autonomous), Irinjalakuda, Thrissur, Kerala, India-680125

[4] Society for Odonate Studies, Vellooparampil, Kuzhimattom PO, Kottayam, Kerala, India-686533

[5] Corresponding author: avivekchandran2@gmail.com

Received 18th July 2023; revised and accepted 18th October 2023

Abstract. Description of the male *Macrogomphus wynaadicus* Fraser, 1924, is given based on specimens collected from different localities of the Western Ghats, India. Photographs and illustrations detailing the taxonomic characters are provided.

Further key words. Dragonfly, Anisoptera, South Asia

Introduction

The genus *Macrogomphus* Selys, 1858, is widely distributed in Asia and currently has 15 described species (Paulson *et al.* 2023). Five species are known to occur in India (Subramanian & Babu 2017), of which *Macrogomphus wynaadicus* Fraser, 1924, is restricted to the Western Ghats (Babu *et al.* 2013; Kalkman *et al.* 2020). It was described based on a single female collected by Fraser (1924) from Masinagudi in the southern Western Ghats. Fraser (1931: 459) later came across some males and noted that they do not differ in any respect from the female but stopped short of formally describing the male. Later, he simply referred to the male as unknown (Fraser 1934). The

Zootaxa 5380 (6): 587–594
https://www.mapress.com/zt/

Article

ISSN 1175-5326 (print edition)
ZOOTAXA
ISSN 1175-5334 (online edition)

https://doi.org/10.11646/zootaxa.5380.6.6
http://zoobank.org/urn:lsid:zoobank.org:pub:AE1CE5D5-DBE4-4906-968B-88CA1A035173

Description of the Last Instar Larva of *Platylestes platystylus* (Rambur, 1842) from Kerala, India (Odonata: Lestidae)

AYIKKARA VIVEK CHANDRAN[1,2], SUBIN KANIYAMATTATHIL JOSE[1] & PROSENJIT DAWN[3]
[1]*Aqua Research Lab, Department of Geology and Environmental Science, Christ College (Autonomous), Irinjalakuda, Thrissur, Kerala 680125, India*
[2]*Society for Odonate Studies, Vellooparampil, Kuzhimattom PO, Kottayam, Kerala 686533, India*
[3]*Department of Zoology, Shyampur Siddheswari Mahavidyalaya, Ajodhya, Howrah – 711312*
[3]*Corresponding author. prosenjit.dawn@gmail.com*
https://orcid.org/0000-0003-2149-2502
https://orcid.org/0000-0003-4784-2312
https://orcid.org/0000-0001-9473-6702

Abstract

The description of the final instar larva and the subsequent exuvia of *Platylestes platystylus* (Rambur, 1842) is given based on a single male larva collected from Kerala and reared in the laboratory. A brief account of the habitat of the damselfly and an updated key to the larvae of genera of Family Lestidae Calvert, 1901 are also provided.

Key words: Damselfly, Exuvia, Larvae, Lestidae, Life History

Introduction

In India, Family Lestidae Calvert, 1901 is represented by only five genera, viz. *Indolestes* Fraser, 1922, *Lestes* Leach, 1815, *Orolestes* McLachlan, 1895, *Playlestes* Selys, 1862 and *Sympecma* Burmeister, 1839 (Subramanian & Babu 2017). Larval descriptions are available for some species of the genera *Indolestes* (Theischinger 2009), *Lestes* (Kumar 1972; Theischinger 2009), *Orolestes* (Lien & Matsuki 1985) and *Sympecma* (Dumont & Borisov 1993) either from Indian species or from other congeneric species. *Platylestes* is a small genus with only four species worldwide, and only two species from India, *Platylestes platystylus* (Rambur, 1842) and *Platylestes kirani* Emiliyamma, Palot & Charesh, 2020 (Emiliyamma *et al.* 2020) listed in Paulson *et al.* (2023). The larvae of this genus remained undescribed so far, though a set of images of the exuviae is claimed to be of *P. platystylus* by Thumboor (2023). This current paper deals with the description of the final instar larva and exuvia of *P. platystylus* from Kole wetlands, Kerala.

Material and methods

The Kole wetlands are spread over Thrissur and Malappuram districts in Kerala, covering an area of 13,632 ha. The wetlands are bound by Chalakkudy River in the south and Bharathapuzha River in the north. The flood waters in the Kole are mainly brought by the two rivers, Kechery and Karuvannur which finally drain into the Arabian sea. These wetlands remain submerged for about six months in a year during southwest monsoon when water level rises up to 5.5 metres. Paddy is cultivated from September to April and these wetlands together contribute about 40% of the paddy production of Kerala. The term 'kole' in Malayalam refers to the bumper harvest that is usually obtained from here. People living around the wetlands also engage in fishery for subsistence as well as for commercial purpose (Johnkutty & Venugopal 1993). These wetlands are rich in biodiversity and have been declared as a Ramsar site since 2002 (Islam & Rahmani 2008), an important bird area since 2004 (Islam & Rahmani 2004),

Accepted by M. Marinov: 21 Nov. 2023; published: 5 Dec. 2023

International Journal of Odonatology
2024, Vol. 27, pp. 213–226
doi:10.48156/1388.2024.1917298

Melanoneura agasthyamalaica sp. n. (Odonata, Platycnemididae) from the Western Ghats, India

A. Vivek Chandran [a,b,*], Reji Chandran [b], Subin K. Jose [a], Arajush Payra [c] & Pankaj Koparde [c]

[a] Aqua Research Lab, Department of Geology and Environmental Science, Christ College (Autonomous), Irinjalakuda, Thrissur, Kerala 680125, affiliated to the University of Calicut, Thenhipalam, Kerala 673635, India

[b] Society for Odonate Studies, Vellooparampil, Kuzhimattom PO, Kottayam, Kerala 686533, India

[c] Department of Environmental Studies, Dr. Vishwanath Karad MIT World Peace University, Kothrud, Pune, India

*Corresponding author: Email: avivekchandran2@gmail.com

Abstract. *Melanoneura* Fraser, 1922 is a genus of damselflies which was, to date, regarded as monotypic. It is represented by the nominate species, *Melanoneura bilineata* Fraser, 1922 which is endemic to the Western Ghats in India. We describe the population of *Melanoneura* in the Agasthyamalai landscape of the Western Ghats as a species new to science based on differences in the structure of male cerci, mesostigmal plates, genital ligulae, and the structure and marking of the prothorax. Subtle differences in body markings are also documented. Further, we demonstrate a significant genetic distance (7.2–7.4%) between the new species and *M. bilineata*, based on mitochondrial Cytochrome Oxidase I analysis. Our study combines morphological and genetic evidence to describe a new species belonging to the genus *Melanoneura*, cancelling its monotypic nature.

Keywords. Zygoptera, bambootail, biodiversity, damselfly, dragonfly, endemic, monotypic, new species, taxonomy

https://zoobank.org/NomenclaturalActs/6D2ED1AF-65EE-4DD9-BDB7-F73FA4000F56

Research Article

Published: 8 October 2024
Received: 30 July 2024
Accepted: 30 September 2024

Citation:
Chandran, Chandran, Jose, Payra & Koparde (2024): *Melanoneura agasthyamalaica* sp. n. (Odonata, Platycnemididae) from the Western Ghats, India. *International Journal of Odonatology, 27,* 213–226
doi:10.48156/1388.2024.1917298

Data Availability Statement:
All relevant data are within the paper.

Introduction

Melanoneura bilineata Fraser, 1922 is a damselfly species belonging to the Family Platycnemididae (Jacobson & Bianchi, 1905). It is a rare species confined to the hill streams of the Western Ghats of India and has been considered monotypic since its description (Subramanian et al., 2018). It is categorized as Near Threatened by IUCN (Subramanian, 2011). Recently, it has been listed as a 'High Priority Threatened Species' in a regional threat assessment of Odonata (Subramanian et al., 2022). According to Fraser (1924), it is found only in Coorg (in Karnataka) and "Malabar Wynaad" (Wayanad in Kerala). The species was recently recorded from Maharashtra, which remains its northernmost record (Koli & Dalvi, 2021). The southernmost record of this species is from Thiruvananthapuram, in the Agasthyamalai hill range of the Western Ghats (Subramanian et al., 2018). The genus is distinguishable from all other 'black and blue' platycnemidids of the Western Ghats by the absence of anal bridge veins in its wings (Fraser, 1922). Also, the caudal appendages are peculiar, the cerci resembling a hand curled to catch a ball (Fraser, 1933).

While exploring the odonate fauna of the Western Ghats, we came across a population of *Melanoneura* at Aryanad in Thiruvananthapuram district, Kerala, at the foothills of the Agasthyamalai hill range, that showed some morphological dif-

Journal of Asia-Pacific Biodiversity 17 (2024) 295–302

Contents lists available at ScienceDirect

Journal of Asia-Pacific Biodiversity

journal homepage: http://www.elsevier.com/locate/japb

Original Article

Description of *Protosticta sexcolorata* sp. nov. (Odonata, Platystictidae) from the Western Ghats, India

Ayikkara Vivek Chandran [a,b,*], Puthukudy Kunjamu Muneer [c], Maran Madhavan [c,d], Subin Kaniyamattathil Jose [a]

[a] *Aqua Research Lab, Department of Geology and Environmental Science, Christ College (Autonomous), Irinjalakuda, Thrissur, Kerala 680125, India*
[b] *Society for Odonate Studies, Vellooparampil, Kuzhimattom PO, Kottayam, Kerala 686533, India*
[c] *Ferns Nature Conservation Society, PB No. 28, Mananthavady, Wayanad, Kerala, India*
[d] *Tholpetty Eco-development Committee, Wayanad Wildlife Sanctuary, Kerala 670646, India*

ARTICLE INFO

Article history:
Received 25 September 2023
Received in revised form
9 November 2023
Accepted 24 November 2023
Available online 14 December 2023

Keywords:
biodiversity
endemic
shadowdamsel
taxonomy
Zygoptera

ABSTRACT

Protosticta Selys, 1885 is a speciose genus of damselflies distributed in the tropical and subtropical forests of Asia. During an ongoing study to document the odonate diversity of the Western Ghats, we came across a colony of *Protosticta* species in Wayanad, Kerala, that appeared different from all other species hitherto described. We describe this population as a new species after detailed morphological comparison with closely similar species occurring in the region.

Introduction

Platystictidae Kennedy, 1920 is a family of damselflies that are commonly known as shadowdamsels, distributed throughout Asia, Central America and South America (Paulson 2009). Most members of this family are forest dwellers and breed in small streams. *Protosticta* Selys, 1885 is a genus of shade-loving, slender representatives of this family found in the tropical and subtropical forests of south and southeast Asia. These damselflies inhabit the undergrowth of dense jungle, usually near hill streams. They are dark, with long, thin abdomen and structurally complex caudal appendages. They have relatively small interspecific differences, mostly in their prothorax and caudal appendages. It is a diverse group with 55 species described till date (Paulson et al. 2023). The Western Ghats of India has 15 described *Protosticta* species, many of which were discovered only recently (Joshi et al. 2020; Sadasivan et al. 2022; Vijayakumaran et al. 2022; Payra et al. 2023). Most of these damselflies have highly restricted distribution ranges within the Western Ghats, and are hence, of conservation concern.

In our endeavor to investigate the odonate diversity of the Western Ghats, we came across a population of *Protosticta* in Vellarimala, Wayanad, which had the following remarkable characters observable in the field: relatively small size for members of the group, considerable difference in coloration between the sexes which were of the same size, pale purple prothorax in male with black markings (Figures 1–2). We collected some individuals of this population and performed a detailed morphological comparison with published descriptions of all *Protosticta* species of the Western Ghats and other closely similar species collected from Wayanad, which allowed us to describe the population from Vellarimala as a species new to science.

Material and methods

Protosticta species were collected using a butterfly net, from three locations in Wayanad district of Kerala state, India (Figure 3). Three male and two female specimens of *Protosticta sexcolorata* sp. nov. were collected from Vellarimala, Meppadi Forest Range, Wayanad (11.468920° N, 76.148280° E, 1352 m above MSL). One of the male specimens was put in 99% ethanol and the remaining

* Corresponding author. ORCID.: 0000-0003-2149-2502
E-mail address: avivekchandran2@gmail.com (AV Chandran)
Peer review under responsibility of National Science Museum of Korea (NSMK) and Korea National Arboretum (KNA).

https://doi.org/10.1016/j.japb.2023.11.010
pISSN2287-884X eISSN2287-9544/

International Journal of Odonatology
2024, Vol. 27, pp. 26–36
doi:10.48156/1388.2024.1917259

Description of *Phylloneura rupestris* sp. n. (Odonata, Platycnemididae) from the Western Ghats, India, with notes on its reproductive behaviour

A. Vivek Chandran [a,b,*], Reji Chandran [b], S. R. Suraj [c], Subin K. Jose [a] & Pankaj Koparde [d]

[a] Aqua Research Lab, Department of Geology and Environmental Science, Christ College (Autonomous), Irinjalakuda, Thrissur, Kerala 680125, India

[b] Society for Odonate Studies, Vellooparampil, Kuzhimattom PO, Kottayam, Kerala 686533, India

[c] Shola Nature Society, SRS Bhavan, Choodal, Meenmutty PO, Palode, Thiruvananthapuram

[d] Department of Environmental Studies, Dr. Vishwanath Karad MIT World Peace University, Kothrud, Pune, Maharashtra, 411038, India

*Corresponding author: E-mail: avivekchandran2@gmail.com

Abstract. *Phylloneura* Fraser, 1922 is a genus of damselflies that, to date, has been regarded as monotypic, represented solely by *Phylloneura westermanni* (Hagen in Selys, 1860) which is endemic to the Western Ghats of India. In our study, we happened upon a population of *Phylloneura* near the Ponmudi Hills, Thiruvananthapuram, which was notable for displaying morphological and behavioural differences from *P. westermanni*. Here, we describe it as a species new to science, providing detailed photographs and illustrations. We also provide notes on its reproductive behaviour.

Key words. Zygoptera, damselfly, dragonfly, bambootail, biodiversity, endemic, new species, oviposition

https://zoobank.org/NomenclaturalActs/bd99d1cb-219c-4a64-9fff-fa061956f73f

Research Article

Published: 13 February 2024
Received: 3 October 2023
Accepted: 6 February 2024

Citation:
Chandran, Chandran, Suraj, Jose & Koparde (2024): Description of *Phylloneura rupestris* sp. n. (Odonata, Platycnemididae) from the Western Ghats, India, with notes on its reproductive behaviour. *International Journal of Odonatology*, *27*, 26–36 doi:10.48156/1388.2024.1917259

Data Availability Statement:
All relevant data are within the paper.

Introduction

Phylloneura westermanni (Hagen in Selys, 1860) is a species of damselfly belonging to the family Platycnemididae (Jacobson & Bianchi, 1905). Its populations are associated with *Myristica* swamps and associated streams, and hence is known by its common name Myristica Bambootail (Subramanian, 2009). To date, it has remained the sole described species of the genus *Phylloneura* and is considered to be Near Threatened as per the IUCN Red List of Threatened Species (Subramanian, 2011). It is endemic to the Western Ghats of India and has been recorded only from the area between the Nilgiri Hills and Sharavathi Valley, north of the Palghat Gap (Subramanian et al., 2018). The body of *P. westermanni* is jet black marked with azure blue. It is distinguishable from other bambootails of the Western Ghats (*Caconeura, Disparoneura, Elattoneura, Esme, Melanoneura* and *Prodasineura* species) by the following features: segment 7 of the abdomen with a broad blue apical ring, greater number of postnodal nervures (28–31 in the forewings and 26–27 in the hindwings), and the presence of many double cells between the main nervures (Fraser, 1933).

As part of our ongoing study on the odonate fauna of the Western Ghats, we happened upon a population of *Phylloneura* near the Ponmudi Hills in Thiruvananthapuram District, Kerala, which is part of the Agasthyamalai Hill Range, that differed from *P. westermanni* in their markings on the 7th abdominal segment. This population also exhibited a peculiar breeding behaviour, and we observed

International Journal of Tropical Insect Science
https://doi.org/10.1007/s42690-023-01135-y

SHORT COMMUNICATIONS

Odonata checklist of Wayanad Wildlife Sanctuary, Kerala State, Southern India

Muneer P. K.[1] · Narendra Babu S.[2] · A. Vivek Chandran[3] · Subin K. Jose[3]

Received: 11 May 2023 / Accepted: 6 November 2023

Abstract

A preliminary study of the odonate fauna of Wayanad Wildlife Sanctuary, Kerala, southern India was carried out from August 2020 to November 2020. Ponds, streams, and swamps in the sanctuary were sampled using Visual Encounter Surveys (VES). A total of 85 species (49 dragonflies and 36 damselflies) from 11 families were recorded, out of which 14 species are endemic to the Western Ghats. *Orthetrum pruinosum* was found to be the most common species in the sanctuary. *Indolestes pulcherrimus*, an endemic species with no recent records, is being reported for the first time with photographs from the wild. The highest number of species was recorded in the ponds (56 species), followed by streams (46 species) and swamps (33 species). However, the number of endemic species was highest in the streams (8 species), followed by swamps (3 species) and ponds (2 species).

Keywords Odonata checklist · Endemic species · Western Ghats · *Indolestes pulcherrimus* · India

Introduction

Odonata are helpful indicators of freshwater as well as terrestrial habitat conditions. Several studies have shown changes in odonate species richness and/or community composition as responses to deforestation, suggesting their potential as bioassessment tools in the tropics (Šigutová et al. 2019). Larvae of many odonate species are highly specific to particular aquatic habitats and this makes them an ideal model system to address questions in ecology, evolutionary biology, and biogeography, and for monitoring the health of freshwater ecosystems (Subramanian and Babu 2020). Odonates are ubiquitous in all freshwater ecosystems, but in the first global assessment of this insect order, it was found that one in 10 species of dragonflies and damselflies is threatened with extinction (Clausnitzer et al. 2009). Though the Indian odonate fauna is well described in terms of adult taxonomy, their ecology is poorly known (Subramanian 2005). The impact of landscape changes happening in peninsular India for the past fifty or more years on odonate distribution and status is not known. This knowledge gap can only be filled by more current field surveys to assess the changes in the population status and distribution of the species (Subramanian 2009).

Currently, 6392 species of Odonata are recognized worldwide (Paulson et al. 2023). In India, 493 species and 27 subspecies in 154 genera and 18 families have been identified (Subramanian and Babu 2020). The Western Ghats hosts 193 species (Subramanian et al. 2018) of which, 183 have been currently recorded from Kerala (Society for Odonate Studies 2023). The highest diversity and endemism of Odonata in the Western Ghats has been reported from the Nilgiri–Wayanad–Kodagu complex 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, extremely rare specimens 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 and Anooj 2020). In addition, three-day Odonata surveys conducted by Malabar Natural History Society and Kerala Forests and Wildlife

✉ A. Vivek Chandran
avivekchandran@gmail.com

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

2 Kerala Forests and Wildlife Department, Deputy Conservator of Forests and Wildlife Warden, Wayanad Wildlife Sanctuary, Sulthan Bathery, Wayanad, Kerala 673592, India

3 Department of Geology and Environmental Science, Christ College (Autonomous) Affiliated to the University of Calicut, Irinjalakuda, Thrissur 680002, India

Published online: 20 December 2023

Journal of Asia-Pacific Biodiversity 16 (2023) 597–604

Contents lists available at ScienceDirect

Journal of Asia-Pacific Biodiversity

journal homepage: http://www.elsevier.com/locate/japb

Original Article

A new species of *Epithemis* Laidlaw, 1955 (Odonata: Libellulidae), from the Western Ghats, India

Ayikkara Vivek Chandran [a,b,*], David Valiyaparambil Raju [b,c], Subin Kaniyamattathil Jose [a], Zeeshan Ayaz Mirza [d]

[a] *Aqua Research Lab, Department of Geology and Environmental Science, Christ College (Autonomous), Irinjalakuda, Thrissur, Kerala 680125, India*
[b] *Society for Odonate Studies, Vellooparampil, Kuzhimattom PO, Kottayam, Kerala 686533, India*
[c] *Valiyaparambil House, Kuzhimattom PO, Kottayam, Kerala 686533, India*
[d] *Max Planck Institute for Biology, Max-Planck-Ring 5, 72076 Tübingen, Germany*

ARTICLE INFO

Article history:
Received 19 April 2023
Received in revised form
23 July 2023
Accepted 6 August 2023
Available online 9 September 2023

Keywords:
Anisoptera
barcode
biodiversity
dragonfly
endemic

ABSTRACT

The monotypic genus *Epithemis* Laidlaw, 1955, is endemic to the Western Ghats and is represented by the nominate species *Epithemis mariae* (Laidlaw, 1915). *Epithemis mariae* is distributed across the Western Ghats, and as part of an ongoing study, we identified a distinct population from Wayanad. Morphological and molecular data for *E. mariae* and the population from the Wayanad plateau affirm that the two are distinct taxa and allow us to describe a new species. *Epithemis wayanadensis* sp. nov. is described based on male specimens collected from Wayanad, a part of the Western Ghats in Kerala state, southern India.

Introduction

The genus *Epithemis* Laidlaw, 1955 was hitherto considered to be monotypic. The sole described species was *Epithemis mariae* (Laidlaw, 1915), which is endemic to the Western Ghats in India (Paulson et al. 2022). This is a dragonfly of small size and slight build that inhabits marshes and pools at the foot of forested hills (Fraser 1936). The male is colored blackish-brown and red, whereas the female is colored golden-yellow and black. It occurs in small colonies and is highly seasonal; the adults are seen only during the southwest monsoon period (Subramanian 2009). It is a weak flier and generally does not stray far from the marshes in which it breeds. It has been recorded from the states of Kerala, Tamil Nadu, Karnataka, and Maharashtra in India (Sawant and Ogale 2022; Subramanian et al. 2018).

In the course of an ongoing study of the odonates of Kerala state, we collected specimens of a population that resembles *E. mariae* but differs in having darker pigmentation, restricted red coloration on the abdomen, and lacking the yellow antehumeral stripes (Figure 1). Further investigation of morphological and molecular data of the two populations in question revealed that the population from the Wayanad plateau are distinct. Based on this database of evidence, we describe the population from the Wayanad plateau as a new species with notes on its distribution and natural history.

Material and methods

Morphological data

Two males of *Epithemis wayanadensis* sp. nov. were caught using a butterfly net and were stored in molecular-grade alcohol. Later, one of these specimens was preserved dry, and the other was retained in alcohol. Legs of one side of the specimen in alcohol were used for molecular study. A male *E. mariae* was collected from a home yard at Kuttampuzha, a village near the forested Anamalai hills of the Western Ghats, for morphological and molecular comparison (Figure 2). Morphological data for the specimens were made using a stereomicroscope (SkiHi TDLED-1005, India), and they were photographed using a mirror-less digital camera (Sony a7III body, Sony 90 mm macro lens and Raynox DCR-250 super macro lens). Descriptive terminology follows Garrison et al. (2006). All measurements were taken using a digital Vernier caliper (ZHART CT-ZT-VERNIER).

* Corresponding author. ORCID.: 0000-0003-2149-2502
E-mail address: avivekchandran2@gmail.com (A Vivek Chandran)
Peer review under responsibility of National Science Museum of Korea (NSMK) and Korea National Arboretum (KNA).

https://doi.org/10.1016/j.japb.2023.08.006
pISSN2287-884X eISSN2287-9544/

J. Insect Biodivers. Syst. 11 (1), 207–226

https://jibs.modares.ac.ir

OPEN ACCESS

Tarbiat Modares University Press
Entomological Society of Iran

Research Article
Biodiversity

https://doi.org/10.61186/jibs.11.1.207 **ISSN**: 2423-8112

https://zoobank.org/urn:lsid:zoobank.org:EB78D41E-FC75-4D50-988D-75B1EF661963

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*

Received:
December 01, 2023

Accepted:
October 25, 2024

Published:
January 01, 2025

Subject Editor:
Zohreh Eslami

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.

Keywords: Autecology, Black-tipped Bambootail, conservation, endemic, Wayanad

Citation: Chandran, A.V., Muneer, P.K., Madhavan, M. & Jose, S.K. (2025) Odonata diversity of the Kuruva Islands, southern India, with notes on the ecology of *Disparoneura apicalis* (Fraser, 1924) (Odonata: Platycnemididae). *Journal of Insect Biodiversity and Systematics*, 11 (1), 207–226.

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*

List of books published

1. Jose, S.K., Sreejith, A.C., **Chandran, A.V.**, & Antony, I. (2019). Environmental Science (Basics & Concepts). Christ Publishers. ISBN: 978-81-8424-906-4.

2. **Chandran, A.V.** & Jose, S.K. (2021) Dragonflies of Irinjalakuda. Kindle Edition, Amazon Asia-Pacific Holdings Private Limited. ASIN : B09479Z6KL.

3. Jose, S.K., Vincent, N.S., Shaju, K.Y., & **Chandran, A.V.** (2022). Drought Hazard Mapping in Thrissur District Using Geoinformation Science and Technology. Kindle Edition, Amazon Asia-Pacific Holdings Private Limited. ASIN : B0B52JCM53.

4. Jose, S.K., Vincent, N.S., Shaju, K.Y., & **Chandran, A.V.** (2023). Flood Hazard Assessment and Mapping in Thrissur District Using Geoinformatics. Christ Publishers. ISBN: 979-83-7251-688-5

5. Jose, S.K., Gopakumar, P.G., & **Chandran, A.V.** (2023). Urban Sprawl Detection Using Remote Sensing. Christ Publishers. ISBN: 979-88-6799-091-6.

6. Vincent, E.J., Vincent, N.S., **Chandran, A.V.**, & Jose, S.K. (2024). Soil Erosion and Modeling. Christ Publishers. ISBN: 979-83-4339-173-2.

ENVIRONMENTAL SCIENCE

[BASICS AND CONCEPTS]

Based on the compulsory syllabus of University of Calicut for Audit Course

SUBIN K. JOSE
SREEJITH A.C.
VIVEK CHANDRAN A
IGNATIUS ANTONY

ENVIRONMENTAL SCIENCE
[BASICS AND CONCEPTS]

Dr.Subin K. Jose
Assistant Professor, Environmental Science, Christ College, Irinjalakuda, Thrissur

Sreejith A.C
Researcher studying man-animal conflicts in Athirappilly-Malakkappara region.

Vivek Chandran A
Researcher studying dragonflies and their use as indicators of water quality.

Dr. Ignatius Antony : Retd. Principal, St. Thomas College, Thrissur.

ISBN 978-81-930507-8-1
9 788193 050781

Christ Publishers, Christ College, Irinjalakuda
2019

Price Rs. 200/-

DRAGONFLIES OF IRINJALAKUDA

Subin K. Jose & Vivek Chandran A

Subin K. Jose
Vincent N.S.
Shaju K.Y.
Vivek Chandran A

DROUGHT HAZARD MAPPING IN THRISSUR DISTRICT, KERALA- USING GEOINFORMATION SCIENCE AND TECHNOLOGY

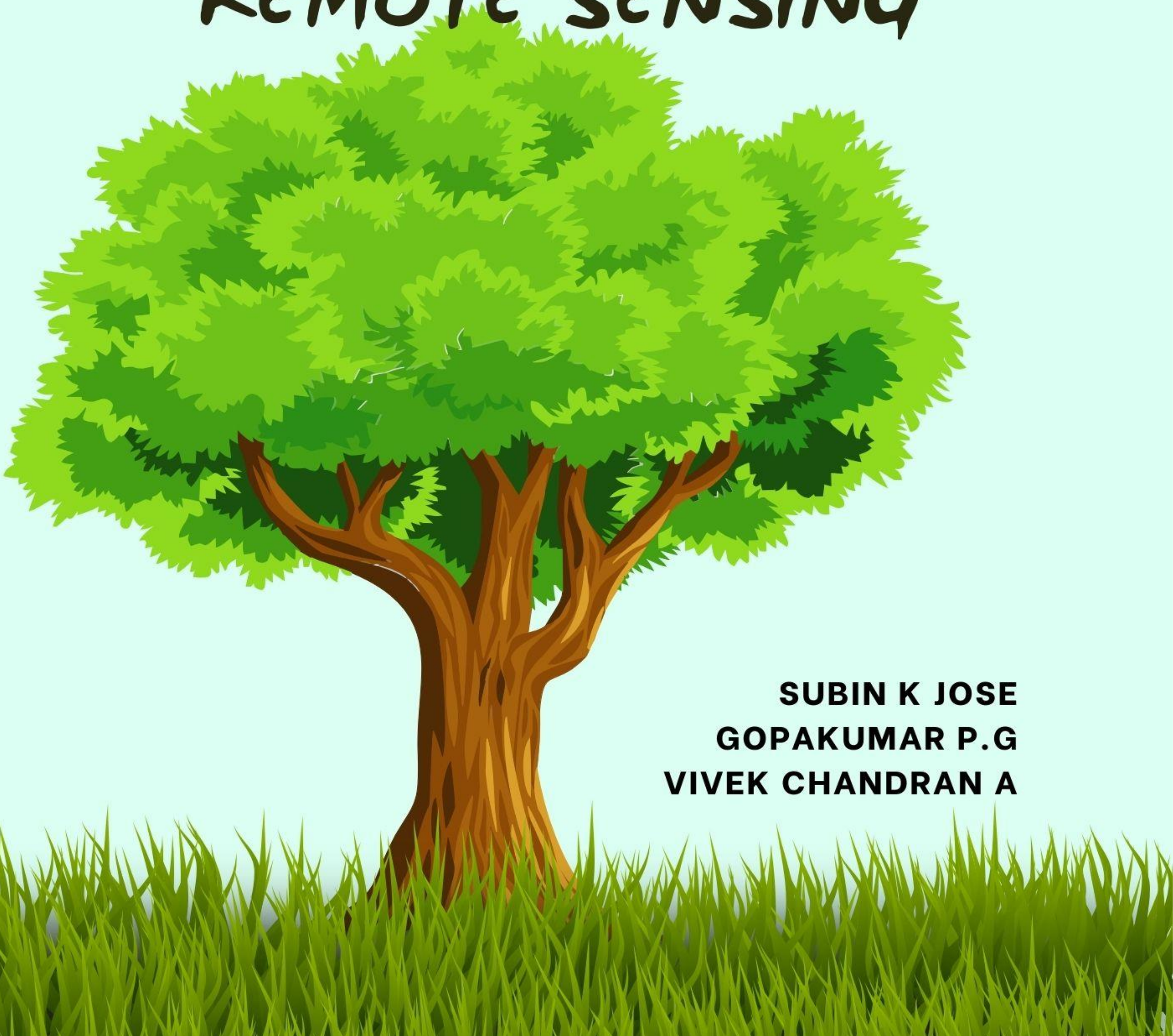
2023

SUBIN K JOSE
VINCENT N.S
SHAJU K.Y
VIVEK CHANDRAN A

FLOOD HAZARD ASSESSMENT AND MAPPING IN THRISSUR DISTRICT USING GEOINFORMATICS

ISBN-13 : 979-8372516885
ASIN : B0BRLVQQ3B

URBAN SPRAWL DETECTION USING REMOTE SENSING



SUBIN K JOSE
GOPAKUMAR P.G
VIVEK CHANDRAN A

SOIL EROSION AND MODELING

E.J VINCENT
VINCENT N.S
VIVEK CHANDRAN A
SUBIN K JOSE

2024

List of popular articles published

1. Jose, S.K. & **Chandran, A.V.** (2023). അഗസ്ത്യമല വനമേഖല സംരക്ഷണം: ഒരു ശാസ്ത്രീയ നിരീക്ഷണം. അരണ്യം (Kerala Forests & Wildlife Department), 43(12), 42-45.

2. Jose, S.K. & **Chandran, A.V.** (2024). തുമ്പികൾ: ജലാർദ്ര ഭൂമികളിലെ മാലാഖമാർ. അരണ്യം (Kerala Forests & Wildlife Department), 44(06), 46-47.

3. Jose, S.K. & **Chandran, A.V.** (2024). ഉലകം ചുറ്റും തുലാത്തുമ്പി. അരണ്യം (Kerala Forests & Wildlife Department), 44(09 & 10), 52-54.

അഗസ്ത്യമല വനമേഖല സംരക്ഷണം: ഒരു ശാസ്ത്രീയ നിരീക്ഷണം

സുബിൻ കെ ജോസ്, വിവേക് ചന്ദ്രൻ എ

യുനെസ്കോയുടെ മാൻ ആൻഡ് ബയോസ്ഫിയർ പ്രോഗ്രാമിന്റെ (MAB) ഭാഗമായി 2001 നവംബർ പന്ത്രണ്ടാം തീയ്യതിയാണ് അഗസ്ത്യമല ബയോസ്ഫിയർ റിസർവ്വ് രൂപീകൃതമായത്. ജൈവ വൈവിധ്യത്തിന്റെയും സമ്പന്നമായ സാംസ്ക്കാരികതയുടെയും കേന്ദ്രമായ അഗസ്ത്യമല ബയോസ്ഫിയർ റിസർവ്വിൽ നെയ്യാർ, പേപ്പാറ, ശെന്തുരുണി എന്നീ വന്യജീവി സങ്കേതങ്ങളും, അച്ചൻ കോവിൽ, തെന്മല, കോന്നി, പുനലൂർ, തിരുവനന്തപുരം എന്നീ ടെറിട്ടോറിയൽ ഡിവിഷനുകളും, കൂടാതെ അഗസ്ത്യമല സ്പെഷ്യൽ ഡിവിഷനും ഉൾപ്പെടുന്നു. പശ്ചിമഘട്ടത്തിന്റെ ശ്രദ്ധേയമായ ജൈവവൈവിധ്യ സാംസ്ക്കാരിക പൈതൃക ത്തിന്റെ സാക്ഷ്യപത്രമായി അഗസ്ത്യമല ബയോസ്ഫിയർ റിസർവ്വ് നിലകൊള്ളുന്നു. റിസർവ്വിന്റെ പ്രാധാന്യം അതിന്റെ ജൈവ സമ്പത്തിൽ മാത്രമല്ല, ശാസ്ത്രീയ ഗവേഷണം, സുസ്ഥിരവികസനം, തദ്ദേശീയ വിജ്ഞാന സംരക്ഷണം എന്നിവയ്ക്ക് അത് നൽകുന്ന അവസരങ്ങളിലും പ്രതിഫലിക്കുന്നു. ജൈവവൈവിധ്യം സംരക്ഷിക്കുന്നതിലൂടെ വംശനാശ ഭീഷണി നേരിടുന്ന ജീവികളുടെ നിലനിൽപ്പും, പരമ്പരാഗത ചികിത്സാരീതികളുടെ തുടർച്ചയും, അതുല്യമായ ഒരു സാംസ്ക്കാരിക പൈതൃകത്തിന്റെ സംരക്ഷണവുമാണ് റിസർവ്വ് ഉറപ്പാക്കുന്നത്. വരും തലമുറകൾക്കായി നമ്മുടെ ഗ്രഹത്തിന്റെ പ്രകൃതിദത്ത അത്ഭുതങ്ങളെ സംരക്ഷിക്കാനും പരിപോഷിപ്പിക്കാനും അഗസ്ത്യമല ബയോസ്ഫിയർ റിസർവ്വ് പ്രചോദിപ്പിക്കുന്നു.

വിദൂര സംവേദന പഠനം

ലേഖകരുടെ പഠനത്തിൽ ഭൗമ വിദൂരസംവേദന സംവിധാനത്തിന്റെ (Geographic Information System) സഹായത്തോടുകൂടി അഗസ്ത്യമല ബയോസ്ഫിയർ റിസർവ്വിലെ വനശോഷണ ഘടകങ്ങളെക്കുറിച്ച് മനസ്സിലാക്കാൻ സാധിച്ചിരുന്നു. ഭൂവിനിയോഗത്തിലെ വ്യതിയാനം, കാട്ടുതീ മൂലമുണ്ടാകുന്ന അപകട സാധ്യത, മണ്ണൊലിപ്പ്, വനത്തിന്റെ ഫലപ്രദമായ പരിപാലനം

വരയാട്ടുമുടിയിൽ വിശ്രമിക്കുന്ന വരയാട്ടിൻ കൂട്ടം

Crocothemis servilia

തുമ്പികൾ

ജലാർദ്ര ഭൂമികളിലെ മാലാഖമാർ

ഡോ. സുബിൻ കെ. ജോസ്, വിവേക് ചന്ദ്രൻ

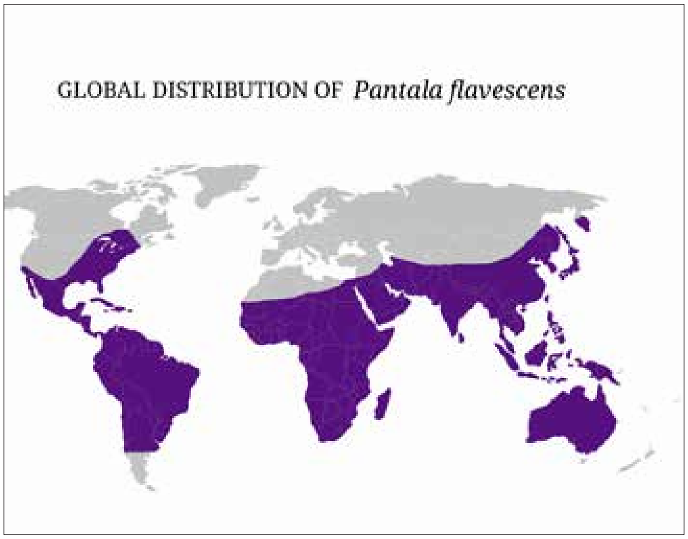
തുമ്പികളെക്കുറിച്ച് പറയുമ്പോൾ പാടത്തും പറമ്പിലുമൊക്കെ ഓടിനടന്ന് ചെലവഴിച്ച കുട്ടിക്കാലമായിരിക്കും മുൻതലമുറയിലുള്ളവർക്ക് ഓർമ്മ വരിക. ഏറെ പാരിസ്ഥിതിക പ്രാധാന്യമുള്ള ജീവികളായിരുന്നിട്ടുപോലും പുതുതലമുറയിലെ മിക്കവരും ഈ പറക്കുന്ന വൈരങ്ങളെപ്പറ്റി അജ്ഞരാണ് എന്നത് ആശങ്കാജനകമാണ്.

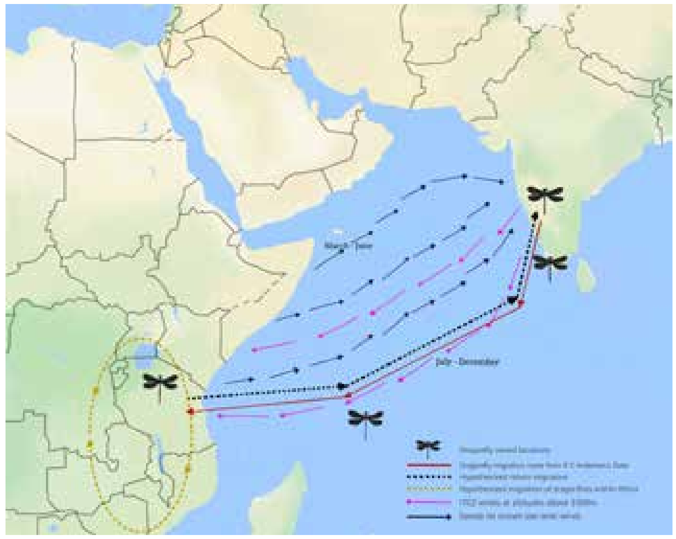
ഉറമ്പുകൾ, വണ്ടുകൾ, പുൽച്ചാടികൾ എന്നീ ജീവികളെപ്പോലെ ഷഡ്പദങ്ങളാണ് തുമ്പികൾ. തല, ഉരസ്സ് (നെഞ്ചു ഭാഗം), ഉദരം എന്നീ മൂന്ന് ഭാഗങ്ങളായാണ് ഇവയുടെ ശരീരം ഉള്ളത്. തലയുടെ ഭൂരിഭാഗവും രണ്ട് വലിയ കണ്ണുകളാണ്. ആയിരക്കണക്കിന് സൂക്ഷ്മനേത്രങ്ങൾ കൊണ്ട് നിർമ്മിക്കപ്പെട്ടവയാണ് തുമ്പികളുടെ വലിയ കണ്ണുകൾ (Compound eyes). ചെറിയൊരു അനക്കം പോലും വളരെ പെട്ടെന്ന് തിരിച്ചറിയാനും അതിനനുസരിച്ച് പ്രതികരിക്കാനുമുള്ള കഴിവ് തുമ്പികൾക്ക് കൊടുക്കുന്നത് ഈ കണ്ണുകളാണ്. ഇതുകൊണ്ടാണ് ഒരു കൊതുകിനെയോ പൂമ്പാറ്റയെയോ പിടിക്കുന്ന എളുപ്പത്തിൽ തുമ്പികളെ പിടിക്കാൻ പറ്റാത്തത്. ഇരയെ കടിച്ചു മുറിച്ചു തിന്നാൻ പാകത്തിനുള്ളതാണ് തുമ്പികളുടെ വായയും അനുബന്ധ ഭാഗങ്ങളും. തുമ്പികൾ ഇരപിടിയന്മാരാണ്. ഉരസ്സിൽ രണ്ട് ജോഡി ചിറകുകളും മൂന്ന് ജോഡി കാലുകളും ഉണ്ടായിരിക്കും. ചില്ല് പോലെ സുതാര്യമായ ചിറകുകളിൽ നിരവധി സിരകൾ കാണാം. ഈ സിരകളുടെ എണ്ണവും വിന്യാസവും തുമ്പികളുടെ ശാസ്ത്രീയ വർഗ്ഗീകരണത്തിൽ വലിയ പങ്ക് വഹിക്കുന്നു. 5-6 ചെറിയ ഖണ്ഡങ്ങൾ ചേർന്നാണ് തുമ്പികളുടെ ഓരോ കാലും. കാലുകളിലുള്ള മുള്ള് പോലുള്ള രോമങ്ങൾ വായുവിൽ പറന്ന് ചെറുപ്രാണികളെ പിടിക്കാൻ സഹായിക്കുന്നു. ഒരു തീവണ്ടിയുടെ കമ്പാർട്ടുമെന്റുകൾ പോലുള്ള 10 ഖണ്ഡങ്ങൾ ചേർന്നതാണ് തുമ്പികളുടെ ഉദരം. തുമ്പികളുടെ ഉദരത്തിനെയാണ് നമ്മൾ തെറ്റായി 'വാല്' എന്ന് പറയുന്നത്. ഉദരത്തിന്റെ അറ്റത്ത് വിരലുകൾ പോലുള്ള ചെറുവാലുകൾ കാണാം. ഇവയുടെ നീളവും ആകൃതിയും തുമ്പിവർഗ്ഗങ്ങളെ തമ്മിൽ തിരിച്ചറിയാൻ സഹായിക്കുന്നു.

നമ്മുടെ നാട്ടിൽ കാണുന്ന തുമ്പികൾ രണ്ട് തരക്കാരാണ്-കല്ലൻ തുമ്പികളും (Dragonflies) സൂചിത്തുമ്പികളും (Damselflies). കല്ലൻതുമ്പികൾ താരതമ്യേന വലിപ്പം കൂടിയവയും ദൃഢഗാത്രരുമാണ്. വിശ്രമിക്കുമ്പോൾ ഇവ ചിറകുകൾ വിടർത്തി വയ്ക്കുന്നു. കല്ലൻതുമ്പികളുടെ പിൻചിറകുകൾക്ക് മുൻചിറകുകളെ അപേക്ഷിച്ച് വീതി കൂടുതലായിരിക്കും. വളരെ വേഗത്തിൽ പറക്കാൻ കഴിവുള്ളവയാണ് ഇവ. സൂചിത്തുമ്പികൾ നേർത്ത് ലോലമായ പ്രാണികളാണ്. വിശ്രമിക്കുമ്പോൾ ഇവ സാധാരണ ചിറകുകൾ ശരീരത്തോട് ചേർത്ത് വെക്കുന്നു. സൂചിത്തുമ്പികളുടെ എല്ലാ ചിറകുകൾക്കും ഒരേ വലിപ്പവും ആകൃതിയും ആയിരിക്കും. ഇവ വളരെ പതുക്കെയാണ് പറക്കുക.

തുമ്പികൾ ജലജന്യ ജീവികളാണ്. അവയ്ക്ക് മുട്ടയിടാൻ ശുദ്ധജലം വേണം. പുഴകൾ, അരുവികൾ, തോടുകൾ, നീർച്ചാലുകൾ, കുളങ്ങൾ, തടാകങ്ങൾ എന്നീ ശുദ്ധജല സ്രോതസ്സുകളെല്ലാം തുമ്പികളുടെ പ്രജനനകേന്ദ്രങ്ങളാണ്. വെള്ളത്തിന് അടുത്തായിത്തന്നെ അവയുടെ ഇണചേരൽ കാണാം. ഒരല്പം സങ്കീർണ്ണമാണ് തുമ്പികളുടെ ഇണചേരൽ പ്രക്രിയ. ആദ്യം ഒരു ആൺതുമ്പി ശുദ്ധജലമുള്ള ഒരു ചെറിയ പ്രദേശം സ്വന്തം അധീനതയിൽ ആക്കുന്നു. ഇവിടെ നിന്ന് മറ്റ് ആൺതുമ്പികളെ തുരത്തിയോടിക്കുന്നു. താത്പര്യം പ്രകടിപ്പിച്ചോ അറിയാതെയോ ഒരു പെൺതുമ്പി ആ വഴി വന്നാൽ തന്റെ ഉദരത്തിന്റെ അറ്റത്തുള്ള ചെറുവാലുകൾ വച്ച് ആൺതുമ്പി അവളുടെ കഴുത്തിന് പുറകിലായി പിടിക്കുന്നു. എന്നിട്ട് ആൺതുമ്പി സ്വന്തം ഉദരം വളച്ചുകൊണ്ട് പത്താം ഖണ്ഡത്തിലുള്ള ബീജം രണ്ടാം ഖണ്ഡത്തിലെ അവയവത്തിലേക്ക് കൈമാറുന്നു. പെൺതുമ്പി സ്വന്തം ഉദരം വളച്ച് അവസാന ഖണ്ഡം ആൺതുമ്പിയുടെ രണ്ടാം ഖണ്ഡത്തിൽ ചേർത്തുവെക്കുന്നതോടെ 'ഇണചേരൽ ചക്രം' (mating wheel) പൂർത്തിയാകുന്നു. ഇണചേരൽ കഴിഞ്ഞയുടൻ വെള്ളത്തിൽ മുട്ടകൾ നിക്ഷേപിക്കലായി. പെൺതുമ്പി മുട്ടയിടുമ്പോഴും ആൺതുമ്പി കഴുത്തിന് പിടിച്ചുകൊണ്ട് തന്നെ ഇരിക്കും. ഇല്ലെങ്കിൽ തൊട്ടടുത്ത ചെടിയിൽ കാവലിരിക്കും. മറ്റ് ആൺതുമ്പികൾ തന്റെ ഇണയെ തട്ടിയെടുക്കാതിരിക്കാൻ ആണിത്. അങ്ങനെ സംഭവിച്ചാൽ തന്റെ പ്രത്യുത്പാദന അവയവം കൊണ്ട് രണ്ടാമൻ ആദ്യ ആൺതുമ്പി നിക്ഷേപിച്ച ബീജം ചുരണ്ടിക്കളഞ്ഞ് സ്വന്തം ബീജം നിക്ഷേപിക്കും. ഇതൊഴിവാക്കാനാണ് ഇണചേരൽ കഴിഞ്ഞുള്ള ആൺതുമ്പിയുടെ കാവൽ! എല്ലാ സൂചിത്തുമ്പികളും ജലത്തിൽ വീണുകിടക്കുന്ന സസ്യങ്ങളോ ജീർണ്ണാവശിഷ്ടങ്ങളോ തുളച്ചുകൊണ്ട് അവയ്ക്കുള്ളിലാണ് മുട്ടകൾ നിക്ഷേപിക്കുക. കല്ലൻതുമ്പികളിലെ ഒരു കുടുംബക്കാർ മാത്രം (Aeshnidae- സൂചിവാലൻ കല്ലൻതുമ്പികൾ) ഇത്തരത്തിൽ മുട്ടകൾ നിക്ഷേപിക്കുന്നു. ഇങ്ങനെ മുട്ടകൾ നിക്ഷേപിക്കുന്ന പെൺതുമ്പികളുടെ ഉദരത്തിന്റെ അറ്റത്ത് കുന്തമുന പോലുള്ള ഒരു അവയവം (ovipositor) കാണാം. ഇതുപയോഗിച്ചാണ് ഇവ സസ്യങ്ങളിലും മറ്റും സുഷിരങ്ങൾ സൃഷ്ടിച്ച് മുട്ടകൾ നിക്ഷേപിക്കുന്നത്. മിക്ക കല്ലൻതുമ്പികളും ജലപ്രതലത്തിലോ പായലുകൾക്കിടയിലോ മുട്ടകൾ നേരിട്ട് നിക്ഷേപിക്കുകയാണ് ചെയ്യുക.

മുട്ടകൾ വിരിഞ്ഞുവരുന്ന തുമ്പി ലാർവ്വകൾ കരുത്തുറ്റ ഇരപിടിയന്മാരാണ്. വെള്ളത്തിൽ ജീവിക്കുന്ന ചെറുജീവികളാണ് ഇവയുടെ ഇരകൾ. ഇതിൽ കൊതുകിന്റെ കൂത്താടികൾ മുതൽ വാൽമാക്രികളും ചെറുമൽസ്യങ്ങളും വരെ ഉൾപ്പെടും. ഏതാനും





തുലാത്തുമ്പികളുടെ ദേശാടന പഥം

ഉലകം ചുറ്റും **തുലാത്തുമ്പി**

സുബിൻ കെ ജോസ്, വിവേക് ചന്ദ്രൻ

ജന്തുലോകത്ത് നടക്കുന്ന ദേശാടനങ്ങൾ മനുഷ്യരെ സംബന്ധിച്ച് അത്ഭുത പ്രതിഭാസങ്ങളാണ്. തൊട്ടടുത്ത കവലയിൽ ചെല്ലാൻ പോലും ഏതെങ്കിലും വാഹനം ഉപയോഗിക്കുന്ന ആധുനിക മനുഷ്യന് തന്നെക്കാൾ ബുദ്ധിസാമർത്ഥ്യം കുറഞ്ഞ ജീവികൾ ദിശതെറ്റാതെ കാതങ്ങൾ താണ്ടുന്നു എന്നത് ഗ്രഹിക്കാൻ ബുദ്ധിമുട്ടാണ്. ജല ലഭ്യതയ്ക്കനുസരിച്ച് കാട്ടുമൃഗങ്ങൾ സഞ്ചരിക്കുന്നതും വർഷാവർഷം തണ്ണീർത്തടങ്ങളിൽ ദേശാടനപക്ഷികൾ വന്നു നിറയുന്നതും അതിശയത്തോടെ അല്ലാതെ മനുഷ്യന് നോക്കി നിൽക്കാൻ കഴിഞ്ഞിട്ടില്ല. ഇതിനിടയ്ക്കാണ് തുമ്പികൾ കടൽ താണ്ടി സഞ്ചരിക്കുന്നതിന് തെളിവുകളുമായി ശാസ്ത്രജ്ഞർ വരുന്നത്. മഹാത്ഭുതം എന്നല്ലേ ഇക്കാര്യത്തെ വിശേഷിപ്പിക്കാനാവൂ!

ഭൂമിയിൽ അന്റാർട്ടിക്ക ഒഴികെ എല്ലാ ഭൂഖണ്ഡങ്ങളിലും കാണപ്പെടുന്ന തുമ്പിയിനമാണ് പന്റാല ഫ്ലേവസൻസ് എന്ന് ശാസ്ത്രനാമമുള്ള 'ഗ്ലോബ് സ്കിമ്മർ'. കേരളത്തിൽ ഇവയെ ഏറ്റവും കൂടുതൽ കാണുന്നത് തുലാമാസത്തിൽ (ഒക്ടോബർ-നവംബർ) ആയതിനാൽ മലയാളത്തിൽ തുലാത്തുമ്പി എന്നാണ് പേര്. അഞ്ചു സെന്റിമീറ്റർ മാത്രം വലിപ്പമുള്ള ഈ തുമ്പിയുടെ ശരീരത്തിന് ചുവപ്പ് കലർന്ന മഞ്ഞ നിറമാണ്. ആൺതുമ്പികൾക്ക് ശരീരത്തിൽ ചുവപ്പ് കൂടുതലായിരിക്കും. ചില പ്രത്യേക കാലങ്ങളിൽ മാത്രം വളരെ അധികം എണ്ണത്തിൽ കാണപ്പെടുന്ന ഈ തുമ്പികൾ ദേശാടനം നടത്തുന്നുണ്ട് എന്നത് ബ്രിട്ടീഷ് മിലിറ്ററി ഉദ്യോഗസ്ഥനും ഇന്ത്യൻ തുമ്പിഗവേഷണത്തിന്റെ പിതാവുമായ ഡോക്ടർ എഫ്. സി. ഫ്രേസർ 1920-കളിൽത്തന്നെ രേഖപ്പെടുത്തിയിരുന്നു. എന്നാൽ, പ്രജനനം നടത്താൻ കടലിനെ ലക്ഷ്യമാക്കി പറക്കുന്ന ആയിരക്കണക്കിന് തുമ്പികൾ വെറുതെ ചത്തൊടുങ്ങുന്നുണ്ടാവാം എന്ന അനുമാനത്തിലാണ് ഫ്രേസർ എത്തിയത്.

മാലിദ്വീപ് ആസ്ഥാനമാക്കി ഗവേഷണം നടത്തി വന്നിരുന്ന ചാൾസ് ആൻഡേഴ്സൺ എന്ന മറൈൻ ബയോളജിസ്റ്റാണ് ഈ നൂറ്റാണ്ടിന്റെ തുടക്കത്തിൽ തുലാത്തുമ്പികളുടെ ദേശാടനത്തെപ്പറ്റിയുള്ള പുത്തൻ വിവരങ്ങൾ ലോകത്തിന് സമ്മാനിച്ചത്.

സമുദ്രജീവികളെയാണ് പ്രധാനമായും പഠിക്കുന്നതെങ്കിലും ഒരു നാച്ചുറലിസ്റ്റ് എന്ന നിലയ്ക്ക് എല്ലാ മൃഗങ്ങളെയും പഠിക്കുന്നതിന് ആൻഡേഴ്സൺ ജിജ്ഞാസുവായിരുന്നു. എല്ലാ വർഷവും ഒക്ടോബർ മാസത്തിൽ മാലിദ്വീപിന് മുകളിൽ വന്ന് നിറഞ്ഞിരുന്ന തുമ്പികളുടെ വലിയ കൂട്ടങ്ങൾ ആൻഡേഴ്സണെ അത്ഭുതപ്പെടുത്തി. ദ്വീപിലെവിടെയും ശുദ്ധജല സ്രോതസ്സുകളില്ല. ഈ തുമ്പികൾ അപ്പോൾ എന്തിനിവിടെ വരുന്നു? എവിടെ നിന്ന് വരുന്നു? എങ്ങോട്ട് പോകുന്നു? അങ്ങനെ അദ്ദേഹത്തിന്റെ മസ്തിഷ്കം ചോദ്യങ്ങൾ കൊണ്ട് നിറഞ്ഞു. ഈ തുമ്പികളെക്കുറിച്ച് പഠിക്കാൻ തന്നെ അദ്ദേഹം കച്ചകെട്ടിയിറങ്ങി. വർഷങ്ങളോളം തുലാത്തുമ്പികളുടെ കൂട്ടങ്ങൾ വരുന്നതും അപ്രത്യക്ഷമാകുന്നതും നിരീക്ഷിച്ച് തീയതികൾ രേഖപ്പെടുത്തിവെച്ചു. ആഫ്രിക്കയിലും ഇന്ത്യയിലുമുള്ള അദ്ദേഹത്തിന്റെ സുഹൃത്തുക്കളും ഈ പഠനത്തിൽ പങ്കാളികളായി. നേരിട്ടുള്ള നിരീക്ഷണങ്ങൾക്ക് പുറമെ തുമ്പികളുടെ ചിറകുകളിലെ കൈറ്റിൻ എന്ന രാസവസ്തുവിൽ അടങ്ങിയിട്ടുള്ള ഡ്യൂട്ടീരിയം ഐസോട്ടോപ്പിന്റെ അളവ് പഠിക്കുകയും ചെയ്തു. ഭൂമിയിൽ ഓരോ പ്രദേശത്തെ ശുദ്ധജല സ്രോതസ്സിലും ഹൈഡ്രജന്റെ മറ്റൊരു രൂപമായ (ഐസോട്ടോപ്പ്) ഡ്യൂട്ടീരിയത്തിന്റെ അനുപാതം വ്യത്യസ്തമായിരിക്കും. ഈ നൂതന സാങ്കേതികവിദ്യ ഉപയോഗിച്ച് തുമ്പികളുടെ ഉത്ഭവസ്ഥാനങ്ങൾ തിരിച്ചറിയാൻ സാധിച്ചു. ശാസ്ത്രലോകത്തെ ഞെട്ടിക്കുന്നതായിരുന്നു ഈ പഠനത്തിന്റെ കണ്ടെത്തലുകൾ. മാലിദ്വീപിൽ കണ്ടിരുന്ന തുലാത്തുമ്പികൾ ലാർവ്വയിൽ നിന്ന്

List of paper presentations in conferences

1. "Diversity of Odonates in the Kole Wetlands and Variations According to Aquatic Vegetation Types"- **Vivek Chandran A** and Subin K. Jose- Scientia 2: Second Multidisciplinary National Conference and Research Expo (2024), Christ College (Autonomous), Irinjalakuda, Kerala.

2. "Ecology of Odonata larvae in the Kole wetlands, Central Kerala, India"- **Vivek Chandran A** and Subin K. Jose- Biodiversity for a Sustainable Future: Under DBT Star College Scheme (2024), Department of Zoology, Alphonsa College, Pala, Kerala.

3. "Identification of Odonata larvae - bioindicators of water quality"- **Vivek Chandran A** and Subin K. Jose- Multidisciplinary National Conference and Research Expo (2024), Christ College (Autonomous), Irinjalakuda, Kerala.

4. "Dragonflies and Damselflies: Indicators of Wetland Health"- **Vivek Chandran A** and Subin K. Jose- Biodiversity of Kole Wetland and its Management: A Sustainable Approach (2024), St. Aloysius College, Elthuruth & Kerala State Biodiversity Board.

5. "Diversity and Seasonality of Odonates in Kole Wetlands"- **Vivek Chandran A** and Subin K. Jose- 34th Kerala Science Congress (2022), Kerala State Council for Science, Technology and Environment.

6. "Comparison of Odonata Diversity in Kole Wetlands and selected man-made ponds of Central Kerala"- **Vivek Chandran A** and Subin K. Jose- National Level Virtual Scientific Paper Presentation Competition (2021), Department of Zoology, Vimala College (Autonomous), Thrissur, Kerala.