DIVERSITY OF SPIDER FAUNA IN THE MANGROVE ECOSYSTEM FROM THE COASTAL REGIONS OF KERALA

Thesis submitted in partial fulfilment of requirements for the degree of

DOCTOR OF PHILOSOPHY IN ZOOLOGY

Under the Faculty of Science

UNIVERSITY OF CALICUT

by

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DECLARATION

I, **VISHNU DAS E. H.**, hereby declare that the work presented in the thesis titled, **"DIVERSITY OF SPIDER FAUNA IN THE MANGROVE ECOSYSTEM FROM THE COASTAL REGIONS OF KERALA"** submitted to the University of Calicut in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Zoology is a bonafide record of the research work carried out by me under the supervision of **Dr. Sr. ANIS K. V.**, Assistant Professor (Retd.), Department of Zoology, St. Joseph's College (Autonomous), Irinjalakuda and **Dr. SUDHIKUMAR A. V.**, Associate Professor, Department of Zoology, 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 title 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.

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I dedicate this thesis to the cherished memory of my beloved father, **Mr. Haridas E. K.**, whose love, wisdom, and dreams for me continue to guide my path. Though he is no longer here to witness this moment, his spirit is present in every page of this work.

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Vishnu Das E H.

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ABBREVIATIONS

1-D	Simpson's Dominance Index
CWE	Corrected Weighted Endemism
d	Margalef's Richness Index
Df	Degrees of freedom
DI	Disturbance Index
GMW	Global Mangrove Watch
H′	Shannon–Wiener Diversity Index
ICUN	International Union for Conservation of Nature
IUCNMSG	IUCN Mangrove Specialist Group
J′	Pielou's Evenness Index
KOH	Potassium Hydroxide
mGLM	multivariate Generalized Linear Model
NMDS	Non-metric Multidimensional Scaling
PERMANOVA	Permutational Multivariate Analysis of Variance
PDD	Plastic Debris Density
q	order of diversity
S	Species richness
WE	Weighted Endemism
WSC	World Spider Catalog

The love for all living creatures is the most noble attribute of man

- Charles Darwin

സംഗ്രഹം

ജൈവവൈവിധ്യങ്ങളെ നിലനിർത്തുന്ന സങ്കീർണ്ണമായ ആവാസവ്യവസ്ഥകളിലൊന്നാണ് കണ്ടൽ കാടുകൾ. ഒരുപാട് ജീവിവർഗങ്ങളുടെ പഠനം ഇവിടെ നടന്നിട്ടുണ്ടെകിലും ചിലന്തി വൈവിധ്യത്തെക്കുറിച്ചുള്ളപഠനം ഇന്നുവരെ നടന്നിട്ടില്ല. ഈ പഠനം ചിലന്തി വിഭാഗത്തിന്റെ വൈവിധ്യം, പ്രവർത്തന ഘടന, പ്രാദേശിയത, സസ്യജാലങ്ങളും മറ്റ് അജൈവീക ഘടകങ്ങളുമായുള്ള സംസർഗം, മനുഷ്യ സൃഷ്ട്ടാ സമ്മർദ്ദങ്ങൾ എന്നിവയെ ക്രമബന്ധമായി പര്യവേഷണം ചെയ്യുന്നു. ലൈൻ ട്രാൻസെക്ട് രീതിയും നിരവധി ശേഖരണ രീതികളും ഉപയോഗിച്ച് 21 കുടുംബങ്ങളിലായി വരുന്ന 102 ജനുസ്സിൽ പെടുന്ന 191 സ്പീഷിസുകളെ കണ്ടെത്താനായി. 10 ജില്ലകളിലെ 20 കണ്ടൽ വനങ്ങളിൽ നിന്നും കണ്ടെത്തിയ ഇവ 8 വിവിധയിനം ഇരപിടിയൻ വിഭാഗങ്ങളിൽ ഉൾപ്പെടുന്നു. വട്ടവലച്ചിലന്തികൾ, ചാട്ടചിലന്തികൾഎന്നീ കുടുംബങ്ങളാണ് കണ്ടല്ക്കാടുകളിൽ കൂടുതലായും കണ്ടുവരുന്നവ. കൊല്ലം ജില്ലയിൽനിന്നാണ് ഏറ്റവുമധികം സ്പീഷിസുകൾ ലഭിച്ചത് തുടർന്ന് കണ്ണൂർ, കോഴിക്കോട് ജില്ലകളിൽ നിന്നും ലഭിച്ചു. എറണാകുളം, ആലപ്പുഴ എന്നിവിടങ്ങളിൽ നിന്നുമാണ് താരതമ്മ്യേന. കുറഞ്ഞ സ്പീഷിസുകളെ ലഭിച്ചത്. ജൈവവൈവിധ്യ സൂചികകളുടെ ശാസ്ത്രീയ പ്രയോഗം ചിലന്തികളുടെ ലഭ്യത സമ്മിശ്ര സസ്യ സമൂഹങ്ങളിലാണെന്നു കൂടുതൽ എന്ന് കണ്ടെത്താൻ സഹായിച്ചു. ഇരപിടിയൻ വിഭാഗത്തിൽ വരുന്നവയുടെവിശകലനം വട്ടവല ചിലന്തികളും മറ്റു ഇരപിടിയന്മാരുമാണ് ഭൂരിഭാഗവും എന്ന് കണ്ടെത്താൻ സഹായിച്ചു. കനോപ്പി കവർ, താപനില, ആർദ്രത എന്നിവ സ്പീഷിസുകളുടെ വൈവിധ്യത്തിൽ പ്രസക്തമായ പങ്കു വഹിക്കുന്നു. എന്നാൽ കാഴ്ച്ചയിൽ ശ്രദ്ധേയമായ പ്ലാസ്റ്റിക് മാലിന്യങ്ങളുടെ സാന്നിധ്യം ഇവയെ സ്റ്റാറ്റിസ്റ്റിക്സ് പ്രകാരം

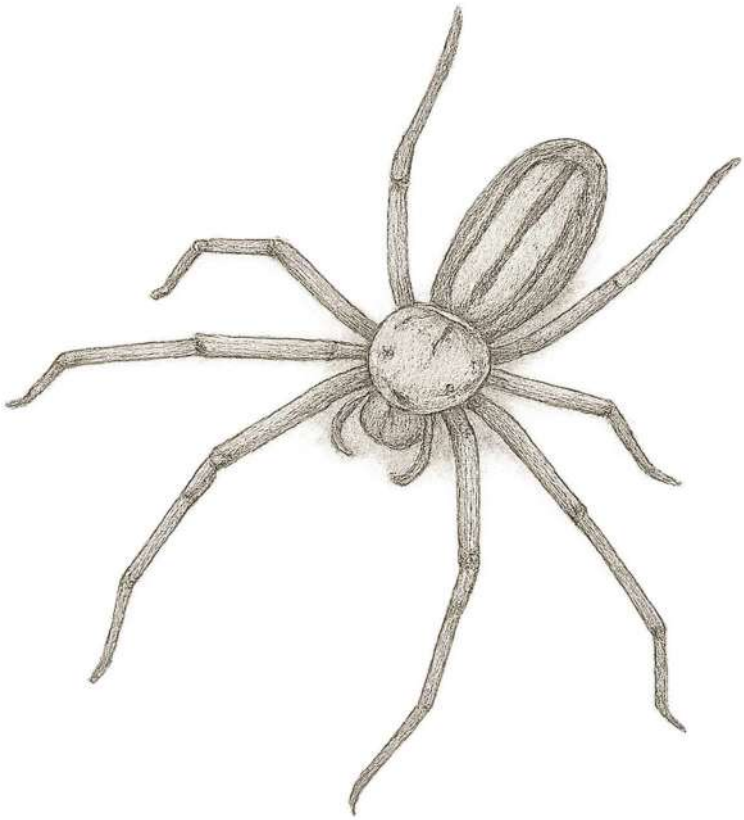
സ്വാധീനിക്കുന്നില്ല. വനനശീകരണവും തടി വെട്ടി മാറ്റലുമാണ് ചിലന്തിയുടെ നിലനിൽപ്പിനെ സാരമായി ബാധിക്കുന്നത്. കേരളത്തിലെ കണ്ടല്ക്കാടുകളിൽ മാത്രമായി കാണുന്ന ചിലന്തികളെ കണ്ടെത്താനായില്ലെങ്കിലും പ്രാദേശിയമായ സ്പീഷിസുകളുടെ സാന്നിധ്യം അതാത് കണ്ടൽ കാടുകളുടെ ഘടനാപരമായ പ്രാധാന്യത്തെ സൂചിപ്പിക്കുന്നു. ഈ പഠനം കണ്ടൽക്കാടുകളിലെ ചിലന്തിയുടെ വൈവിധ്യം, പാരിസ്ഥിതിക ഘടകങ്ങളോടുള്ള പ്രതികരണം, അവയുടെ ഇരപിടിയൻ രീതികൾ എന്നിവയുടെ അടിസ്ഥാന രൂപരേഖയാണ്. മോളിക്യൂലാർ സാങ്കേതികതയുടെയും, ആഴത്തിലുള്ള സ്വഭാവ പഠനങ്ങളുടെയും, ഉൾപ്പെടുത്തൽ ചിലന്തികളുടെ പഠനത്തിൽ ക്രമാതീതമായ അവബോധം ഉളവാക്കാൻ സഹായിച്ചേക്കാം.

പ്രധാനപദങ്ങൾ: ചിലന്തിവൈവിധ്യം, കണ്ടൽക്കാടുകൾ, ജൈവവൈവിധ്യം, വട്ടവലച്ചിലന്തികൾ, ചാട്ടചിലന്തികൾ.

ABSTRACT

Mangroves are one of the complex ecotones that support diverse faunal assemblages, and many diversity studies have been carried out in mangroves; yet, the diversity of the order Araneae remains critically overlooked. This study systematically explores the diversity, functional composition, regional endemism, and associations with vegetation and abiotic variables, as well as the responses to selected anthropogenic pressure factors. A combination of standardised line transect method with various collection techniques yielded 191 species under 102 genera and 21 families belonging to 8 foraging guilds from the 20 mangrove patches selected from 10 districts. Araneidae and Salticidae are the dominant families from mangrove ecosystems. Site 9 – Kollam reported as the species-rich sampling station, followed by Kannur (Site 2) and Kozhikode (Site 3). Species-poor sites were Ernakulam (Site 6) and Alappuzha (Site 7). Classic richness and diversity indices exposed significant spatial heterogeneity, with the highest diversity documented in florally complex mixed mangrove patches. Guild analysis identified orb web weavers and other hunters as dominant functional groups, reflecting substrate variability and canopy stratification. Canopy cover, temperature, and humidity played a significant role in the community composition of spiders. Even though plastic pollution is visibly significant, it hasn't contributed much to the community shifts of spiders in various mangrove patches. Deforestation and logging serve as the major drivers of spider assemblage in the habitat. True endemism was absent in mangroves, but the presence of site-specific endemics emphasises the importance of habitat complexity in maintaining the healthy spider community. The study lays a foundational framework in understanding the diversity, ecological response, and site specificity in Kerala's mangrove ecosystems. Incorporating molecular techniques for species inventory, genus-based behavioural and ecological studies to unveil detailed guild composition, and an in-depth understanding of some pollution variables could help to unlock the conservation potential of this overlooked group of invertebrates.

Keywords: Araneofauna, Mangroves, Biodiversity, Guild, Anthropisation



CHAPTER 1
INTRODUCTION

Biodiversity is our planet's fundamental cornerstone, defining the richness and variety of living things. Even though every biome varies in biotic and abiotic factors, some groups can survive in almost every habitat. Spiders are Arachnids, one of the most diverse groups of the animal kingdom. More than 52,000 spiders have been described worldwide, making them the world's seventh-largest group (Zhang, 2011; WSC, 2025) after major insect orders. They showcase remarkable variations in size, colour, and behaviour, moulding them into the toughest among terrestrial fauna. Regarding species diversity, spiders surpass many vertebrates, including mammals, birds, and reptiles.

Environmental changes at the global level caused unprecedented threats to biodiversity, which directly affected the dynamics of species abundance and occurrence. Climate change and loss of ecosystems are the most challenging problems of the modern era (Mosoh et al., 2024). An enormous rise in heat waves, droughts, unpredictable rainfall, floods, and wildfires are climatic phenomenon due to biodiversity loss. The changes include both increases and decreases, but the species extinction rate is still ahead, regardless of the conservation plans and strategies. The loss of biodiversity impairs carbon sequestration and may lead to increased carbon emissions and, eventually, greater climate change.

Recent decades have been marked by a rapid decrease in biodiversity. Anthropogenic disturbances and unprecedented increases in temperature and climate change are the leading causes of biodiversity loss. Biodiversity plays a critical role in keeping organisms alive on the planet, including humans. Serious policy-making and implementation have been cardinal parts of the conservation efforts. International organisations like IUCN and UN, as well as NGOs including WWF, The Nature Conservancy, and Natural Resources Defence Council, have a predominant role in conservation. Glitches like habitat destruction, invasive species, over-exploitation of natural resources, poaching, pollution, and climate change should be considered and prioritised for

conservation for a better tomorrow. The ecosystem services, including clean air and water that humans borrow from nature, are the byproduct of biodiversity.

The conservation conference led by IUCN in 2021 advised governments to protect at least 30 percent of the biodiversity by 2030 (Lind, 2024). Biodiversity makes life possible on Earth and provides essential ecosystem services. Even though the fact is known to the world, it faces alarming threats too, including habitat loss, climate change, and overexploitation and needs immediate need of conservation efforts (Joshi et al., 2025). A world without biodiversity may fail to achieve a successful existence and lead to a sixth mass extinction (Pimm et al., 2014). Biodiversity conservation is an ecological tactic meant to preserve, protect, restore, and manage the planet's most precious life forms at various levels. Conserving genetic, species, and ecosystem diversity integrates scientific research, policy-making, and practical interventions to reduce biodiversity loss caused by the overexploitation of resources. Taxonomy and diversity studies help to identify vulnerable species, protect critical habitats, maintain ecological connectivity, and implement sustainable development practices that maintain the harmonious coexistence of humans with nature.

1.1. Mangroves: The coastal cradles

Mangroves, the intertidal forests, are the paramount part of the seascape and an increasingly evaluated ecosystem for international conservation efforts. The vegetation includes halophytic unrelated woody plants that primarily inhabit the upper intertidal zones of saltwater within the tropical and subtropical regions. It usually occurs on soft sediments protected from wave action, although many taxa may establish themselves on protected rocky shores (Thom, 1982). Since mangroves are the central point of tropical and marine biotopes and the richest repository of biological diversity, this ecosystem hosts many animal species ranging from mammals to invertebrates. It plays a remarkable role in supporting the coastal water and protects the land side

by acting as a barrier, preventing forceful storms, heavy rain, and soil erosion, and immensely supports mankind's ideal functioning and well-being.

Confirmed fossil formulates the hypothesis regarding the evolution of mangroves, saying that they evolved independently from their terrestrial ancestors about 75 million years ago during the Cretaceous Palaeozoic Epoch (Srivastava & Prasad, 2019). Their evolution has an intricate relationship with sea level changes, and their geographical distribution also follows the pattern. Mangroves' most notable morphological specialisations, such as viviparity, salt secretion, and aerial roots, make them the most unique and tenacious biome. Transition regions are locations or ecosystems critical for understanding responses to changes in environmental and climatic conditions. Mangroves are an ecosystem extremely responsive to changes, and they are also distributed across the climatically sensitive range limits of tropical and subtropical shorelines, which makes them an interesting ecosystem to study (Ximenes et al., 2023).

Mangroves include highly specialised and unrelated taxa with impeccable morphological and physiological adaptations to survive in harsh environments. The existence of mangroves within their ranges is largely affected by temperature and moisture, and their geographical distribution is between latitudes 30^{o} North and 30^{o} South, circumtropically in 124 countries and territories, worldwide (Kathiresan & Bingham, 2001). According to the Global Mangrove Watch (2025), the area of mangroves was 147,358.99 km^{2} in 2020, representing a linear coverage of 14.93 % of the coastline, and the extent of mangroves in the world weakened by 5,245.24 km^{2} between 1996 and 2020. Mangroves are poorly comprehended, but there is an urgent demand to understand them better to prevent continuing degradation (Kathiresan & Bingham, 2001).

Large-scale land use change during the 1970s and 1980s was the predominant cause of mangrove loss. The accurate loss or regenerated mangrove areas cannot be measured due to the lack of technology and advancement in mapping. The past few centuries marked the peak dependency on mangrove resources, especially in the twentieth century. Potentially high usage of

land area and deforestation were said to be the leading causes. Since the portrait of the importance of the mangrove ecosystem is now more vivid, the loss has also become lower, but most of the degradation rates are largely unknown (Friess et al., 2019). If the deforestation rate reduces, the scenario can lead to a better world. A dynamic and productive ecosystem like a mangrove has always been a priority in international policymaking. A collective of international NGOs, "The Global Mangrove Alliance", has already set an ambitious target of a 20 % increase over the current extent by 2030 through rehabilitation and conservation (Global Mangrove Alliance, 2025).

1.2. Mangrove: The Flora and Fauna

Some distinctive features attributed to mangrove plants are crucial to their taxonomy. Low water potential and high intracellular salt concentration, viviparous water aid dispersal mechanism, exposed ground breathing roots, extra trunk supporting structure, and salt-excreting leaves are important features. According to the IUCN Mangrove Specialist Group (MSG), 82 species of mangrove plants from 32 genera and 18 families were described both from the Indo-West Pacific (IWP) and the Atlantic West Pacific (AWP). But there have always been challenges, according to IUCNMSG, the collective expertise in mangrove plant biogeography and taxonomy (Leal & Spalding, 2024). There are no clear criteria for defining a plant as a mangrove, no notable distinctions between some short-statured co-inhabiting marsh plants, incomplete phytogeographical knowledge, and the hybrid status of some species are some strong reasons for the taxonomic paradox. The Harvey Grove Watch is a live database of high-resolution global mangrove extent. It helps to monitor the mangrove loss around the world (Bunting et al., 2024).

Located between land and sea, mangroves are the ideal biome for many species, from some significant symbiotic bacteria to mammals like tigers and proboscis monkeys. The complexity of the flora of mangroves generates different niches like litter-dominated forest floors, mudflats, and minor water bodies, which allow many species to survive and promote endemism. More than 3000 trapped insects have also been reported from the mangrove spider webs of Singapore (Leal &

Spalding, 2024). Commercial fisheries are also highly dependent on the mangrove ecosystem. By keeping the biome species-rich, mangroves sustain a rich and complex food web.

1.3. Mangrove ecosystem of Kerala

Mangroves are well-explored tropical carbon sinks. Beyond mitigating global warming and climate change, it plays a pivotal role in maintaining a complicated niche system to support life. 124 tropical and subtropical countries have mangroves between 30° N and 30°S latitude, and India is one of them. According to the World Mangrove Watch, the area of mangrove habitat in India is 4,037.85 $km^{2,}$ representing 3 % of the world's area (GMW, 2024). Kerala is one of the important states of India, having a keystone coastal wetland. According to comprehensive satellite-constructed assessments and surveys of the forest department, Kerala spans around 590 km^2 of mangroves (George et al., 2019). This complex nexus of coastal forests represents a critical yet vulnerable component of the state's coastal infrastructure.

Mangroves are critically adapted for saline water and muddy soil, consistent tidal flooding and freshwater exchange from 41 perennial rivers produce a more appropriate environment on the fringes of the backwaters of Kerala. Kannur, Kasaragod, and Kozhikode are the three districts having a major portion of the mangroves of Kerala, with the other seven districts including Malappuram, Thrissur, Ernakulam, Alappuzha, Kottayam, Kollam, and Thiruvananthapuram (George et al., 2019). Despite the mangrove ecosystems occupying the coastal region of Kerala, their role in ecosystem servicing is disproportionate, including climate change mitigation, defending against coastal surges, maintaining water quality, carbon sequestration, and stabilising sedimentation. Anthropogenic pressure, such as coastal development, pollution, and habitat fragmentation, are the major threats facing the coastal area of Kerala.

1.4. Araneae: An evolutionary masterpiece

Spiders are arthropods from the subphylum Chelicerata, class Arachnida, and the order Araneae. There are 134 families and 4396 genera, of which 52,338 valid species have been discovered (WSC, 2025). Spiders are a distinctive group of animals that have numerous traits. Class Araneae covers many morphological forms ranging from hefty and hairy mygalomorphs to minute bald oonopids, from dull-looking lycosids to colourful salticids, and from having very long to short legs. The morphology typically reflects their ecosystem and behaviour, or the structural adaptation always reflects their ecological responses (Karr & James, 1975).

Fossils attributed to the Palaeozoic period are too incomplete to be identified as spiders. Fossils of *Attercopus fimbriunguius* from the mid-Devonian (380-374 mya) are the oldest, spinnerets of this species, showing similarities to recent mesotheles and have similarities with opisthotheles. Two species of orb weavers were also discovered from the early Cretaceous and can be placed under the modern families Tetragnathidae and Deinopidae. Araneae could have originated in the late Silurian or early Devonian with major radiation of araneomorphae in the late Paleozic or early Mesozoic time (Coddington & Levi, 1991). Subsequently, other families have also evolved and diversified. According to the key innovations in silk structure web construction patterns and the loss of foraging webs, the most accepted and discussed hypothesis is "codiversification" with insects (Dimitrov & Hormiga, 2021).

With more than 52,000 valid species, the order Araneae makes one of the most successfully established animal lineages on the planet. This successful occupancy is due to their unique body plan, generalist predatory habit, and other survival skills, including silk production, web construction ability, and venom-packed fangs to paralyse the prey and suffocate them to death.

The body of a spider is highly sophisticated. Unlike insects, their body can be divided into a cephalothorax and an abdomen, connected by a narrow, thread-like structure called a pedicel. Their exoskeleton is made up of hard chitin to which all inner muscles are connected, and it is the

factor that limits their growth and moulting. The cephalothorax is where all the appendages, eyes, and mouthparts are located. Opposite to insects, most spiders have eight simple eyes, of which the anterior median pair is the most efficient in visual detection. Spiders belong to the subphylum Chelicerata due to the presence of chelicerae, well equipped with a venom gland which ends in sharp, pointed fangs. Since they are included in the phylum Arthropoda, they have jointed appendages composed of seven segments and have four pairs of legs. Claws at the end of the legs provide them with adhesion. Many of the species have hair-like trichobothria or auditory hairs, which have a special sensory function. The sensory system of spiders is unique and sophisticated. Apart from the multiple sets of eyes, they have special sensors for thermo-hygro reception called the tarsal organ, and hair shafts at the sensory terminals, like claws, are tactile sensations that are crucial in mating, territorial and prey-capturing behaviour in spiders (Barth, 2002; Barth, 2004). Incredible use of chemical cues to communicate with their conspecifics, heterospecifics, and their environments is also observed in spiders. The evolution over the years shaped spiders to be one of the most successful classes of invertebrates, and their sensory system played a major role in it.

Even though the cephalothorax has major parts of the spider's body, the abdomen has a significant and iconic organ of spiders called the spinnerets. Spinnerets are small finger-like organs located at the rear end of the abdomen and are responsible for secreting silk from the silk glands in the abdomen.

Like hexapods, spiders also have an open circulatory system with a tubular heart and a pale blue-coloured circulatory fluid called the hemolymph. The clade Tetrapulmonata includes spiders, whip spiders, and vinegaroons. All of these have two pairs of book lungs for respiration, and also, spiders are the only arthropod lineage that has evolved tracheae independently, especially in modern world spiders. Most modern spiders have developed their second pair of book lungs into tracheae. Spiders are carnivorous in general and have external digestion. The powerful mixture of digestive enzymes delivered to the prey can liquify them, and is sucked up using mouthparts, and the nutrients are absorbed. To save water, spiders excrete guanine as their nitrogenous waste

product through a specialised excretory system, including the organ called the Malpighian tubules. This helps them to prevent maximum water loss.

Many characteristics make spiders unique among terrestrial arthropods, including eight legs, multiple eyes, silk glands, and venomous fangs. Like many insects, spiders reach adulthood through moulting and periodic shedding of exoskeletons during their lifetime. The process is controlled and regulated by a hormone called ecdysone, secreted by prothoracic glands, which helps the organism to shed its old skin and to help grow in size and mature sexually. The process is also called ecdysis. Spiders in general would have 5-10 moulting in their lifetime (Bonaric, 1987).

Once spiders undergo the final moulting, they become sexually mature and ready to mate. The dimorphic male and female mates; the male spiders often engage in elaborate courtship behaviours to attract females. The courtship rituals can be as simple as leg-tapping or specific vibrations on the female's web, or can be byzantine and surprising, like some dance moves or carefully wrapped gifts on their silk strands. Unlike many other organisms, spiders aren't involved in direct copulation; instead, male spiders transfer their sperm through a special pair of organs called pedipalps. The pedipalps can be inserted into the female genital organ called the epigyne to transfer sperm. The female stores the sperm in the spermatheca, a storage chamber, until it is ready to fertilise the egg. Some female spider species have a notorious tendency to eat their male before, during, or after mating. This behaviour is called sexual cannibalism. Ecological conditions such as food availability, predator presence, sex ratio, and population density can play a major role in determining the dynamics of mating and cannibalism (Cornwallis & Uller, 2010; Perry & Rowe, 2018; Plesnar-Bielak & Łukasiewicz, 2021). Spiders are oviparous, and the number of eggs varies between species. The laid eggs are protected by many methods. For instance, wolf spiders keep and protect their eggs by attaching them to their bodies; some species are committed to guarding them until they hatch, and many orb weavers have a habit of abandoning their eggs left in a case on their web. The specially designed silken egg case offers protection from harsh environments

and some predators. The spiderling comes right after hatching, and they will have the ability to produce silk. There is an even chance of being caught up in the wind and travelling a very long distance. The phenomenon is called ballooning. The behaviour is usually shown by spiderlings, though rarely observed in adults too. This mode of dispersal offers them a wide geographical distribution and successful survival and colonisation. Many species from the order Araneae are known for their parental care, which is an evolutionarily streamlined behaviour where the maternal individual engages in dedicated offspring protection and ensures the survival of the next generation.

Most of the spider species are quite elusive, making them difficult to locate in their natural environments. Cryptic colouration and camouflage are the two evolutionary adaptations that make them challenging to locate in the natural environment (Oxford & Gillespie, 1998). Structural colouration via specialised setae, pigment-based alterations, and complex integumentary modifications facilitates the particular blending mechanism (Théry & Casas, 2002). The phenomenon of crypsis functions in many ways: blending the body into the background, disruptive colouration, and the practice of masquerade, where they modify their appearance to resemble a non-prey object. These evolutionary adaptations not only enhance their ability to capture prey but also provide essential defences against predators. In both ways, ensuring survival chances on this hostile planet.

Spiders can adapt to different ecosystems, making them one of the most diverse orders of invertebrates after some insect groups. They can adapt to both the physical and biotic factors. The community of spiders in an ecosystem can vary according to the flora and some critical factors, including salinity and water retention capacity of the soil and the insect prey species present. Based on the foraging pattern, spiders are classified into distinct guilds – a group of species that exploit a class of environmental resources similarly (Cardoso et al., 2011). The guild composition of spiders in mangrove environments is a hint of their adaptation to the floral complexity, salinity, tidal functions, etc. This functional categorisation of spiders within a community based on foraging

or prey-capturing tactics gives insights into a better understanding of their ecology and augments better conservation plans and biodiversity assessments.

1.5. Significance of the study

Understanding the diversity of spiders in the mangrove ecosystem is multifaceted. It provides a clearer understanding of both the spiders and the unique ecosystem. Studying the diversity in highly specialised ecosystems like mangroves can gain insights into broader biodiversity within the mangroves and between the primary producers to the top producers. Environmental changes affect the species distribution of spiders. This sensitivity makes them an excellent ecological indicator for ecosystem health. Proper taxonomy and diversity studies can help to identify species most responsive to changes and the ecosystem's overall biodiversity. Spiders play a massive role in maintaining ecological balance by controlling insect populations. Identifying their diversity in the mangrove ecosystem can provide insight into their ecological services, like their predatory potential. Regulating insect pests helps in the maintenance of a healthy floral community and a well-balanced biome. Mangroves are one of the most threatened ecosystems, and studying the diversity of spiders can emphasise the role of mangroves in keeping the spider population and maintaining a well-organised biome. Spiders exhibit variation in behaviour, especially in web building and hunting, and counting their abundance and richness can also be a good tool to understand their niches and intraspecific relationships.

1.6. Objectives of the study

1. Make a survey of spiders along with the mangrove ecosystems of Kerala.
2. Estimate and compare the diversity of spiders using different biodiversity indices in different mangrove ecosystems over Kerala.
3. Understand the guild composition of spiders in each mangrove ecosystem.
4. Analyse the endemic status of spiders in the mangroves of Kerala.

5. Study the habitat association of spiders.
6. Study the response of spider assemblages to selected anthropogenic proxies, thereby evaluating the health status of mangroves.

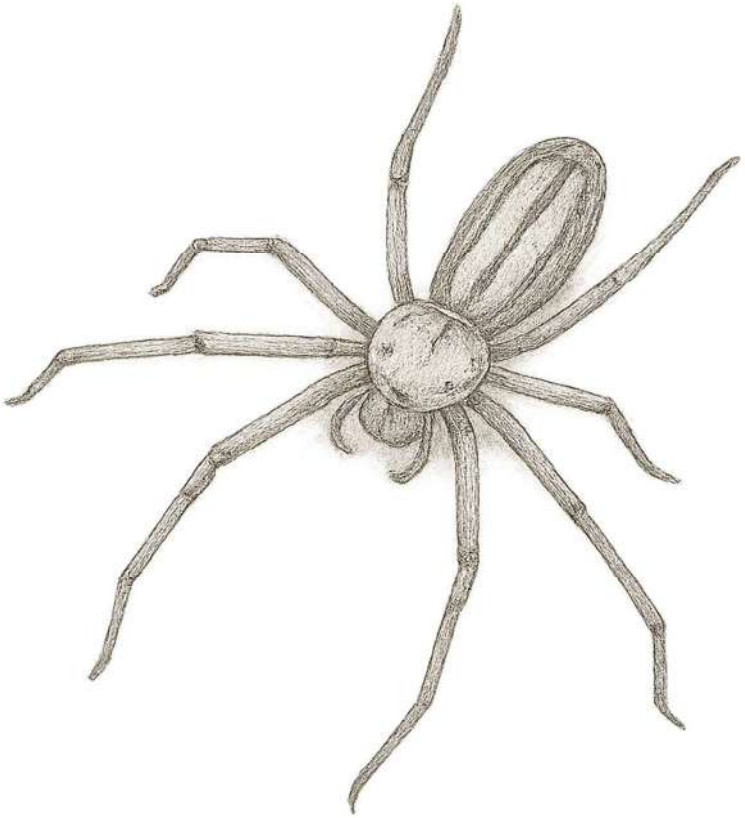
1.7. Scope and limitations

Species composition and community structure in such a unique habitat can be assessed and serve as the benchmark for future studies regarding population dynamics and their comprehensive ecology. Since they are bioindicators, their presence, abundance, and diversity can indicate environmental stress. Mangroves connect land and ocean, and studying the diversity of spiders in this hostile ecosystem can be crucial in understanding predator-prey relationships, niche partitioning, and how species adapt. The outcome can guide mangrove restoration and conservation efforts, offering baseline data for species-specific management and ecosystem recovery. To highlight their ecological role and adaptations, the spider diversity of mangroves can be compared to other biomes like rainforests, agroecosystems, and riparian ecosystems.

As with all research, this study has certain boundaries and constraints worth considering for the context. Mangroves find it challenging to conduct an extensive survey due to the waterlogged soil, tides, and saltwater exposure. Compared to other ecosystems, mangroves have limited baseline information on spider diversity, making it difficult to evaluate change or disturbances. Some traditionally followed sampling methods for spiders are unlikely to yield an expected result. The considerable knowledge gap in the taxonomy of spiders and the lack of a definitive taxonomic key, some species represented in the study cannot be identified up to the species level. Mangroves have always been close to human activities, given that human-induced pressure, like aquaculture, tourism, and industries, have an impact on the natural occurrence of spiders and potentially skews the study results.

However, there are challenges, the study contributes essential knowledge to understand spider diversity within the mangrove ecosystem, revealing these environments as key habitats for many

arachnid species and indicators of ecological health and serving as a groundwork for conservation management of mangroves. The study underlines the importance of further research to fully understand the ecological roles of spiders in this pristine ecosystem.



CHAPTER 2
REVIEW OF LITERATURE

2.1. Biodiversity: The cornerstone of survival

Biodiversity is the world's most expensive tapestry; each species represents a golden thread of limitless weaving. In 1986, Dasmann used the term 'biological diversity,' which later became 'biodiversity. 'Biodiversity' is a word used mostly in ecological and environmental sciences, but it does not have any particularly exclusive meaning; many conservationists and biologists normally implement a working definition that complements their interests and ideas. Tokas defined the term as the full variety of life on earth. Chao, on the other hand, gave a clearer definition for biodiversity: "the variety of all living organisms, including ecosystems, plants, animals, habitats, and genes (Adom et al., 2019). Maintaining biodiversity expands the ecosystem services, humans have relied on since the time of their evolution to survive and sustain their lineage. The term biodiversity was popularized in 1992 at the United Nations Conference on Environment and Development in Rio de Janeiro. Since then, biodiversity and its importance have been spoken worldwide. Biodiversity assessment studies are a vital part of scientific endeavors, promoting conservation efforts. Beginning from the groundbreaking work of Carl Linnaeus in the 18th century, this field has evolved into a multidisciplinary branch of science by incorporating statistics and mathematics to analyse and draw conclusions. Biodiversity studies enhance the understanding of ecosystem functioning, conservation planning, economic value assessment, more over the functioning of our planet.

The scientific discipline dealing with the classification, identification, and naming of living organisms is known as taxonomy. Carl Linnaeus laid its foundation in the 18th century by introducing the process of binomial nomenclature. Binomial nomenclature is the standardised framework for categorising the vast number of living organisms on the planet by giving a name that is accepted worldwide. The classical taxonomy plays a pivotal role in the identification and classification of the order Araneae. In arachnology, the classical taxonomy is basic in understanding the most diverse invertebrate group on earth (Platnick, 2000). The pioneering work

by Linnaeus himself on spiders was followed and refined by taxonomists like Eugène Simon and Embrik Strand in the late 19th and early 20th centuries, marking a remarkable period in the development of spider taxonomy. Traditional taxonomic methods in arachnology include detailed morphological evaluation, a thorough examination of critical diagnostic features, including the structure of genitals, and measurements of body length and legs (Sebastian & Peter, 2009). Even though the modern molecular approaches have given a clearer picture of the taxonomy, the foundational principle of morphological classification plays a substantial role.

2.2. Mangroves: Sanctums of Life

Mangroves are ecological assemblages of plants that have made extraordinary evolutionary adaptations and are specially adapted to the harsh intertidal areas of the tropical and subtropical belt. They are dispersed to a narrow, broken transitional line with a low topographic gradient between the marine and continental realms, above mean sea level, forming a discontinuous line along the steeper shores. The first mangroves appeared during the late Cretaceous, 100–65 Ma. Since then, their evolution and dispersion have been closely related to sea level changes during geological times. The oldest geological record of *Nypa* palm, with a broad ecological tolerance, is a good example of a mangrove with a pantropical distribution. High sea level and humid climate offered sufficient coastal regions and climate for developing 12 genera of mangroves in nine families and subsequent proliferation into newer areas during the early to middle Eocene (~50–40 Ma). Trees and shrubs belonging to different plant families growing on sheltered coastlines, mudflats, and riverbanks in many parts of the world are collectively called mangroves, and the literature on them is impressive (Field, 1999).

Even though mangroves are one of the extensively studied ecosystems, the history of their evolution remains chaotic. Mangroves are quite old; their age might be equal to that of the first angiosperm that evolved 114 million years ago (Duke, 1992). *Avicennia* and *Rhizophora* were probably the first genera to evolve during the late Cretaceous period (Chapman, 1976). Fossil

records of mangroves strongly suggest that these plants have a terrestrial evolutionary pathway. These plants became acquainted with the semi-aquatic salt and anaerobic environment and developed into the core mangrove flora that we see today (Srivastava & Binda, 1991). Fossil remnants of many mangrove plants have been discovered in various parts of the world where they no longer exist. Theories suggest that continental drift might have played a significant role in their current geographic distribution and gene mixing. Currently, they are more concentrated in the Indo-West Pacific region than the Western Atlantic and Caribbean (Kathiresan & Bingham, 2001).

The intertidal ecosystem of the rich green fringe of the tropical mangroves comprises 82 species of particularly adaptive plants that cover a total area of 147,358.99 km^2 globally across 123 countries and union territories including a significant forested area of Malaysia, India, Bangladesh, Brazil, Venezuela, Nigeria and Senegal (Spalding et al., 1997; Leal & Spalding, 2024). Duke (1992) suggests that the distribution of mangroves is greatly affected by temperature and moisture. According to World Mangrove Watch, the area of mangrove habitat in India was 4037.85 km^2 in 2020, which represents a linear coverage of 31.01 percent of the coastline (Global Mangrove Alliance, 2025).

The coastal region of India is a sacred place for the existence of the mangrove ecosystem. The world's largest mangrove, Sundarbans located in the delta region of the Ganges, Brahmaputra, and Meghna rivers and is shared by India and Bangladesh and spanning over 10,000 km^2. This is a UNESCO-recognised world heritage site known for its biodiversity. A comparative study of the spatiotemporal differences and the vegetation index during 1973 – 2023 revealed an alarming rate of deforestation and a rise in the surface temperature (Kanjin & Alam, 2024). In India, 43 species of mangrove plants have been identified, which is more than 50% of the total mangrove plants. More than 4,500 km^2 spanning 12 states and union territories, including Kerala, make India's mangrove area (Kathiresan & Dager, 2024). Mangrove - the keystone coastal forest plays a significant role in weather, carbon sequestration, and our nation's economy. Mangroves of Kerala along the west coast are an inevitable part of our country's biodiversity and economy. The

physiographic background of Kerala is unique; it is a narrow strip wedged between the Lakshadweep Sea and the Western Ghats, harbours chains of lagoons and estuaries with plenty of wetlands constituting 937. 3 km^2 (Sreelekshmi et al., 2021). The length of the coastline is approximately 590 km, with the limit at Manjeshwaram, Kasaragod, and Pozhiyur, Thiruvananthapuram, on the northern and southern sides, respectively. According to the estimates provided by Vidysagaran & Madhusoodanan (2014), the total area of mangroves in Kerala was 2,502 hectares; of this, the state owns 1,189 hectares, while 1,313 hectares are under private ownership. Once, the area of mangroves in Kerala was about 700 km^2; the patches we see today are relics of a glorious past (Vidysagaran & Madhusoodanan, 2014).

Unlike other forest ecosystems that are widespread across our planet, mangroves are limited geographically and are found only in the tropical and subtropical belts, and they support countless wildlife. The floral diversity within mangrove ecosystems is notably lower than that found in other natural biomes, mostly due to the challenging environmental conditions they endure. Therefore, mangroves have often been unrecognized and overlooked in faunal diversity research for decades. However, there has been an increased change in taxonomic and biodiversity research largely focused on mangrove ecosystems, including a diverse array of organisms, from benthic microinvertebrates to apex predatory mammals. This change in research attention reflects an increasing recognition of the ecological reputation of mangroves and associated faunal communities. A rich plant community is a good indication of a diverse population of insects, but mangroves are exceptions where a comparatively low number of phytophagous and frugivorous insects are found. In contrast, these habitats harbour an exceptionally high density of predatory insects. Meads et al. (2002) studied the diversity and abundance of terrestrial mangrove arthropods, especially insects, along the mangrove patches of South Wales, Australia, and documented 252 morphospecies of flying insects alone. This documentation highlights the rich biodiversity associated with mangrove ecosystems, which is often underappreciated. A study conducted by Yeo et al. (2021) emphasized the substantial prevalence of predatory insects in mangroves of Southeast

Asia, particularly within the Aranea, which in turn facilitates the attraction of a considerable number of avian species, making them a hub of biodiversity.

2.3. Arachnology through the ages

Arachnology - the scientific study of arachnids involves their behaviour, physiology, ecology, taxonomy, and evolution. Several exceptional personalities have contributed to make a solid foundation of arachnology. The meticulous work of many pioneering scientists made up the taxonomic framework of this field. In 1757, Carl Alexander Clerck published “Svenska Spindlar," the first comprehensive book on spiders of Sweden. This is the first monograph of an animal group ever published. This was followed and expanded by Carl Ludwig Koch (1871), whose work titled “Die Arachniden” established many genera that exist today. “Histoire Naturelle des Araignées”, published by Eugène Simon (1897a), describes more than 4000 species, making a significant advancement in the field of arachnology. Meanwhile, the study of Tamerlan Thorell (1877) on the spiders of Europe revolutionised the theoretical framework of arachnology during the early 18th century. The detailed documentation and descriptions of Cambridge (1879) on British spiders in the 19th century significantly inspired aspiring arachnologists.

Numerous prominent scientists have also shaped the field of arachnology in India. Their work has been influenced critically in enhancing knowledge and promoting conservation efforts of a greatly misread group of animals. Several European taxonomists initiated a taxonomic study on spiders in India later extended by Indian taxonomists. According to the literature, the earliest contribution was given by Blackwall (1864,1867), followed by Stolickza (1869). By describing many species of spiders mostly preserved specimens from India, Burma, and Sri Lanka Karsch (1873); Thorell (1877); Simon (1897a, b); Pocock (1895, 1899a, b, 1990) and Sheriffs (1919, 1927, 1928, 1929) were the pioneer taxonomic personalities of Asian particularly Indian spiders. A pioneering figure in the early twentieth century in Indian arachnology is B. K. Tikader, who revolutionised the idea of the taxonomy of Indian spiders. Tikader published extensive

documentation on spider fauna across different regions of India, including the Andaman and Nicobar Islands, in the 'Handbook on Indian spiders' in 1987. Tracing his journey, P. A. Sebastian, based at Sacred Heart College, Ernakulam, has appeared as a leading scientist in arachnology. Besides his taxonomic and diversity publications, he co-authored the 'Spiders of India' in 2009 with a more comprehensive description and field photos. Present-day researcher Manju Siliwal has also made significant contributions to the taxonomy of mygalomorph spiders in India. Current researchers like Mathew M.J. and Sunil Jose K have contributed to the taxonomy of spiders, especially in the Western Ghats, Kerala. A V. Sudhikumar has contributed substantially by publishing many articles in arachnology. 'Keralathile Chilanthikal', published in the regional language – Malayalam in 2021- is one of the notable works of Sudhikumar motivated many amateur nature enthusiasts.

Class Arachnida has been ignored for centuries, but currently, numerous studies are being conducted about spiders, especially in India. An updated checklist of Indian spiders published by Siliwal et al. in 2005 enumerated 1,442 species belonging to 59 families. This comprehensive checklist was prepared based on the World Spider Catalogue by Platnick, comparing the peer-reviewed publications of Tikader and Pocock, who have made significant contributions to the field of arachnology in India. After this, Siliwal & Molur (2007) released a checklist of spiders of South Asia, reporting 2299 species from 67 families from eight countries: Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, and Sri Lanka.

2.4. Spider diversity in India: An overview

Arachnology - the study of arachnids - gained significant attention in recent days, especially in India. Since they represent one of the most diverse groups of arachnids with over 52,000 species described worldwide (WSC, 2025), their distribution, diversity, and abundance are influenced by many ecological factors. Presently, India has 1974 species belonging to 512 genera in 63 families (Caleb & Sankaran, 2025). Changing environmental conditions and climate also reflect in their diversity. Investigating and documenting spider diversity is essential for

understanding their ecosystem services and how they contribute to the sustainability of an ecosystem. As global diversity encounters serious anthropogenic threats, the documentation and analysis of spiders are important to manage a sustainable ecosystem.

India is witnessing great development in the field of arachnology. The diversity of spiders in many states has been explored to some extent. Singh et al. (2023) explored the Union Territories of Jammu and Kashmir and Ladakh, located in northwest India. These regions host significant species diversity, with 284 spider species from 160 genera and 34 families. Jammu and Kashmir exhibits higher spider biodiversity - 252 species belonging to 148 genera from 31 families when compared to Ladakh. Only 42 species, 34 genera, and 14 families were recorded from Ladakh. However, many areas remain unexplored, necessitating extensive faunal surveys. Jammu and Kashmir has been a little more explored than Ladakh. Khan (2009) studied the biodiversity of spiders in the horticultural ecosystem of Jammu and Kashmir, highlighting the diversity and ecological significance of spiders in that region. Additionally, Khan (2011) explored spider fauna associated with temperate rice fields in Kashmir, providing valuable insights into species composition and their potential for pest management. In another study, Khan & Rather (2012) examined the diversity and foraging behaviour of spiders in the temperate maize ecosystem of Kashmir, emphasizing their role as biological control agents.

Singh & Singh (2021) updated the list of spiders in three northern and northwestern states and two union territories, Himachal Pradesh, Punjab, Haryana, Chandigarh, and Delhi, based on some museum collections and literature. In total, 242 species under 127 genera and 31 families were described. 59 species, 39 genera, and 16 families from Haryana. 109 species, 58 genera, and 19 families from Punjab and Himachal Pradesh. 90 species belong to 58 genera, and 22 families were listed. Meanwhile, they also stated that Delhi has 53 species from 18 families, and Chandigarh has 7 species from 7 genera and 5 families. This study significantly excluded many habitats, including wildlife sanctuaries, agricultural lands, human dwellings, and protected areas. So, wide explorations will help to find a better checklist of these states and union territories. In 2017, Kumari

et al. reported 46 species of spiders from the arid and semi-arid areas of Rajasthan. They found that spider abundance and richness were greater in woodlands than in caves, crevices, and rocky areas. Likewise, an updated checklist of the spider fauna of Rajasthan has been compiled by Singh (2022) and reports 173 morphospecies from 90 genera and 25 families. The study included 20 districts out of 33 districts of Rajasthan. Jodhpur was the district with the maximum diversity.

The first attempt to make a checklist of spiders from Gujarat was made by Yadav et al. (2017). 415 species of spiders from 169 genera and 40 families were listed. 29 genera and 17 families were endemic to Gujarat. They divided the entire state into 8 convenient agro-climatic zones. The upper southern zone has 278 species, which is the most diverse zone, and the northern zone is claimed to be the least diverse area with 70 species. Singh & Sharma (2022c) compiled the list of spiders of Andhra Pradesh. The list included 192 species, 104 genera, and 33 families from different districts. Araneidae, with 29 species, was the largest family, followed by Lycosidae (22 species) and Salticidae (23 species). The study needs to explore some core areas and habitats, including national parks, wildlife sanctuaries, forest areas, and human dwellings. A comprehensive checklist of spiders from the northeastern states of India was prepared by Singh & Singh (2021) based on the literature. 956 species from 225 genera and 43 families were compiled from 8 different states of India, including Assam, Meghalaya, Manipur, Arunachal Pradesh, Sikkim, Tripura, Mizoram, and Nagaland. Assam was the species-rich state with 266 species belonging to 136 genera and 27 families, followed by Meghalaya with 225 species. Manipur state has 142 species from 88 genera and 25 families. 108 species belonging to 56 genera and 20 families in Arunachal Pradesh. 89 species enlisted from Sikkim. Tripura has 79 species from 53 genera and 16 families. Mizoram with 70 species, 48 genera, and 18 families. Nagaland has the least number of species: 7 species, 6 genera, and 5 families. Singh & Sharma (2022b) updated the list of spiders in Madhya Pradesh with 336 species, 136 genera, and 30 families. Only 36 out of 52 districts were explored. Jabalpur, Mandla, and Balaghat are the districts with maximum diversity.

Significant studies on the spider fauna of Maharashtra have been carried out by many experts. Deshmukh & Raut (2014) explored the Salbardi forest in Maharashtra and listed 104 species of spiders from 18 families. They concluded that the winter season supports more species than the monsoon and summer. Maheshwari et al. (2018) reported 71 species from 15 families in North Maharashtra. Vairale & Wagh (2021) studied the diversity of spiders and their microhabitat in the tropical rainforest of Amaravati. The study compiled a list of 120 species, 37 genera, and 14 families. Choudhuri et al. (2019) attempted to compile a list of spiders from Odisha with a special emphasis on endemism. 248 species belonging to 138 genera and 39 families were recorded. 23 species were endemic to South Asia, 49 species were endemic to India, and 19 species were endemic to Odisha. The diversity explorations in two northern states of India were carried out by Singh (2022), resulting in 520 species, 236 genera, and 50 families. The list was a compilation of Uttar Pradesh and Uttarakhand. 373 species belonging to 202 genera and 45 families were recorded from Uttarakhand, and 284 species, 146 genera, and 36 families from Uttar Pradesh. They also stated that many of the ecosystems still need an extensive survey program. An updated checklist of spiders of West Bengal by Singh (2023a) documented 567 species, 245 genera, and 39 families in total. Darjeeling was the state with the maximum number of species, and Salticidae was the dominant family, followed by Araneidae and Lycosidae.

Bihar is one of the states with high-yielding rice varieties. Goswami et al. (2015) studied the diversity of spiders in rice cultivation during three growth phases: vegetative, flowering, and maturity. They collected 489 individuals belonging to 6 families, 10 genera, and 11 species. Ekka & Kujur (2015) explored 2 districts of Chhattisgarh and reported 118 species, 52 genera, and 23 families. Araneidae, Thomisidae, and Gnaphosidae were the predominant families. They also enlisted the 120 species belonging to 16 families from the Gomarda Wildlife Sanctuary in 2016, which is a dry deciduous forest. Thomisidae, Araneidae, and Gnaphosidae were the dominant families. Spider diversity of Goa from 5 different ecosystems resulted in a list of 126 species from 16 families (Singh & Singh, 2023). The study emphasises the importance of floral architecture in

maintaining diversity. The study reveals that forest areas and wetlands have greater diversity, whereas dunes have the lowest number of species.

Different districts of Telangana, except national parks, wildlife sanctuaries, agricultural areas, and human dwellings, have undergone spider diversity surveys. According to Singh & Sharma (2022a), Telangana is home to 121 species, 71 genera, and 21 families. Out of 19 districts explored, Hyderabad is the species-rich district, followed by Nalgonda. Araneidae, Lycosidae, and Salticidae were the three most dominant families. Attempts to explore the spider fauna of Karnataka have been made by many experts. Kuva et al. (2018) studied the diversity and composition of spiders in the Thungabadra irrigation canal, Bellari, and reported 50 species from 19 families. A list including 65 species belonging to 15 families from Mysore city was made by Mubeen & Basavarajappa (2018). A coffee plantation in the region of Western Ghats supported 30 species from 12 families (Somashekar et al., 2020). An updated checklist of spiders in Tamil Nadu included 547 species under 257 genera and 46 families. Out of the 33 explored districts, the maximum number of species was found in the Nilgiris, followed by Selam. Salticidae was found to be the dominant family, followed by Araneidae and Thomisidae (Dharmaraj et al., 2018).

2.5. Arachnology in Kerala

Situated on the southwestern coast of India, Kerala is home to many diverse ecosystems. From coastal plains to mountain ranges, the topography becomes a more complex network when it comes to rivers and backwaters. These topographic peculiarities make Kerala one of the wealthiest states in India, in terms of diversity. The advancement in taxonomic and diversity studies of spiders in Kerala marked the twentieth century. Different varieties of habitats and microhabitats make perfect niches for various animals, especially insects and spiders. Arachnology has leaped in this modern era. Several diversity and taxonomic studies took place in Kerala.

Many ecosystems in Kerala have been subjected to diversity explorations. A preliminary study on the diversity of spiders in the Mannavan Shola forest conducted by Sudhikumar et al. (2005c) resulted in 72 species, 52 genera, and 20 families, which is 5 % of the total families

represented from India. The study gave a clear picture of how a forest ecosystem can support a variety of spider species. Exploratory work on the order Araneae in the irrigated rice ecosystem in central Kerala across different elevations resulted in an even greater number of species. The team led by Sebastian in 2005 identified 92 species belonging to 47 genera and 16 families, coming under 7 feeding guilds. They have also found that lowlands have maximum diversity. Rice is one of the major crop plants cultivated across Kerala. The maximum yield of this cultivation is inversely proportional to the pest infestation. Spiders help manage the pest population. A study of the seasonal diversity of spiders conducted by Sudhikumar et al. (2005b) identified 94 species of spiders from 20 families in the Kuttandu rice field. During the two seasons, Kharif supported slightly more species than the Rabi season. A diversity study in a cashew plantation in Kerala reported 63 species of spiders belonging to 52 genera and 14 families. The study observed maximum diversity during the monsoon season (Smitha & Sudhikumar, 2020). A checklist of spiders from the sacred groves of Northern Kerala prepared by Sumesh & Sudhikumar in 2020 has reported 257 species belonging to 130 genera and 28 families. In the study, Araneidae was the dominant family, followed by Salticidae, Theridiidae, and Thomisidae. The study emphasizes that less disturbed ecosystems, like sacred groves, can support a diverse fauna of spiders. They also conducted a study and created a checklist of spiders from 15 sacred groves of two districts, Kannur and Kasaragod, in 2021. The checklist has reported 220 species from Kannur and 257 species from Kasaragod.

Parambikulam Wildlife Sanctuary is situated between the Anamalai ranges of Tamil Nadu and the Nelliyampathy ranges of Kerala. Sunil et al. (2008) updated the checklist of spiders in this protected area from 91 species to 147, belonging to 82 genera and 22 families. Likewise, Aswathy et al. (2022) conducted a faunistic survey of spiders at the Peechi-Vazhani Wildlife Sanctuary they identified 106 species from 24 families. A checklist of spiders from Shendurney Wildlife Sanctuary has been made according to the collection records and published records by Sudhin & Sen (2023). They enlisted 79 species from 53 genera and 16 families of spiders. Araneidae were the dominant family, followed by salticidae.

Jose et al. (2018) investigated the diversity of spiders in the Kavvayi river basin, which is primarily a lateritic biotope including many ecosystems such as lateritic vegetation, agroecosystem, seasonal pools, grasslands, sacred groves, mangrove marshes, and riparian areas. They identified 112 species, 81 genera, and 21 families. Araneae were the most dominant family, followed by salticidae. They concluded that the richness of spider fauna is due to the presence of various microhabitats in the river basin. Rajeevan et al. (2019) identified and compared the spider diversity in different ecosystems of the Western Ghats, Wayanad region, Kerala. 150 species belonging to 73 genera and 20 families were documented. They found that the high-altitude forest area has more diversity than Manathavady, a human-disturbed area. They concluded that the prey species, like leaf-mining insects, caterpillars, etc, could greatly influence the diversity and species richness of spiders. Jayasree et al. (2023) studied the diversity in 10 mixed agroecosystems in Palakkad. 98 species belonging to 71 genera and 14 families were recorded in the study. They categorised the spiders into 6 feeding guilds, and Salticidae, Araneidae, and Theridiidae were dominant in the study. Singh (2023b) updated the list of spiders in different districts of Kerala. 598 species belonging to 260 genera and 44 families were recorded. Idukki was the species-rich district, followed by Wayanad, Thrissur, Palakkad, Ernakulam, Kannur, Kasaragod, Alappuzha, and Thiruvananthapuram. The rest of the districts were recorded with fewer than 100 species. Salticidae were the dominant family with 97 species, followed by Araneidae with 86 species and Theridiidae with 55 species.

2.6. Araneofauna of Mangroves

Mangroves have always been an unnoticed biome for biodiversity exploration of land invertebrates. The mangrove ecosystems of India have gathered only slight attention in the study of spider diversity, revealing a complex landscape of species distribution. A preliminary investigation by Muthukumaravel (2013) in Muthupet, Tamil Nadu, documented a modest array of 9 species across 6 genera and 5 families, predominantly from the Araneidae. This limited diversity raised

concerns about potential ecological health issues or the effectiveness of observational and collection techniques in the region. In the latest study, Raja et al. (2023) expanded upon this foundation by identifying 47 species across 29 genera and 14 families; again, the family Araneidae was found to be the dominant family. Their findings highlighted seasonal population dynamics, with peak densities observed during post-monsoon and summer periods, associating these findings with favourable environmental conditions. In Maharashtra, Sheetal et al. (2022) recorded 38 species from 12 families and 6 feeding guilds in the Godrej mangroves, with the Salticidae family as the most prominent. Meanwhile, Parmar et al. (2015) conducted a comprehensive assessment in the Gulf of Kutch, identifying an impressive 123 spider species across 81 genera and 25 families, underscoring the ecological richness of the region. Collectively, these studies illustrate the intricate and significant role of mangrove ecosystems in supporting diverse arachnid populations, highlighting areas for potential ecological research and conservation efforts.

In Kerala, the studies on the araneofauna in mangroves are limited. Sebastian et al. (2005) explored the diversity of spiders in the Mangalavanam mangrove ecosystem, Cochin. It is an urban mangrove forest in the middle of the city facing incredible destruction due to urbanisation. They identified 51 species from 40 genera and 16 families. Araneidae was the dominant family represented by 12 species. 7 feeding guilds were assigned to the total species identified in the study. In 2021, Vishnudas et al. studied the diversity of spiders in the mangrove ecosystem of Poovar, Thiruvananthapuram, a tourist destination in the capital city of Kerala. The study revealed 70 species of spiders from 45 genera and 16 families. Salticidae, represented by 17 species, became the most dominant family, followed by Araneidae with 14 species. Both studies represent 27 % of the total families recognised from India, which proves that mangroves are the perfect habitat for spiders to survive and successfully establish.

2.7. The Concept of Guild

The concept of niche is one of the most intricate and fundamental ideas in ecology. A niche is defined as an organism's functional role within its habitat, including its interactions with other

species, the particular environment it inhabits, and the way by which it utilises resources for survival. Root (1967) introduced the term "guild" to describe a group of species that exploit the same category of environmental resources in similar ways, irrespective of their taxonomic classifications. By the guild concept described by Root, Cardoso et al. (2011) identified eight distinct categories of spiders based on their feeding strategies and prey-capturing methods. This classification includes careful analysis of various spider families, both web-building and non-web-building, which fall into these eight feeding guilds. The eight feeding guilds identified are: sensing web weavers, sheet web weavers, space web weavers, orb web weavers, specialists, ambush hunters, ground hunters, and other hunters. The composition of species coming under these guilds may fluctuate depending on habitat complexity and the architectural arrangement of vegetation. Structural features of the vegetation create diverse opportunities for web attachment and yield significant hunting grounds (Uetz et al., 1999; Cardoso et al., 2011). Furthermore, research by Gibson et al. (1992) and Downie et al. (1995) has emphasised that vegetation density plays a vital role as a determining factor that directly or indirectly influences both prey populations and their nesting sites. The concepts of guilds and functional groups are often misunderstood, leading to inappropriate interchangeability. Even though these two approaches are related in ecology, there are definite distinctions between these two ideas. A guild is how a group of species share resources in a competitive environment, whereas a functional group focuses on how species process resources to deliver an ecosystem service. Both concepts include mostly species independent of evolutionary relationships, and sometimes overlap could occur (Wilson, 1999).

Learning spider guilds offers valuable insights into ecological dynamics, biodiversity, and ecosystem health. By categorising spiders based on their hunting strategies, researchers can assess their roles in controlling prey populations, mostly insects, which is critical for pest management in agricultural and natural ecosystems (Uetz et al., 1999). Moreover, spider guilds serve as bioindicators, showing habitat quality and environmental changes due to their sensitivity to disturbances (Marc et al., 1999). Understanding guild structures also aids in conservation efforts,

as spiders contribute to nutrient cycling and serve as prey for higher trophic levels (Wise, 1993). Overall, studying spider guilds helps to monitor ecosystems, predict ecological responses, and promote sustainable biodiversity conservation.

2.8. The vegetation structure and spider diversity

Despite being categorised as the topmost invertebrate predators, spiders are, in fact, dependent on plants for their survival. This relationship highlights the communion of spiders with the ecosystems, as even predatory organisms rely mostly on herbivorous prey species for sustenance. Spiders utilise vegetation not only as a habitat for hunting but also as a critical environment for nesting and caring for their young.

The study of Rodrigues et al. (2014) on spider diversity in riparian forests of Southern Brazil revealed the influence of edge effect and vegetation characteristics. They focused on three microhabitats: grassland edge, forest interior, and river–forest edge. Sampling across four rivers resulted in 28 families and 440 species. The forest interior exhibited a higher abundance, possibly due to the lower abiotic stress. At the same time, the grassland edge showed higher overall species richness, potentially from faunal overlap and the transition between forest and grassland. Canopy cover positively correlated with spider diversity, suggesting a preference for low-light environments. Although spider composition varied among rivers, it was consistent across microhabitats. Vegetation structure may influence specific spider subgroups or guilds rather than the entire assemblage (Rodrigues et al., 2014).

Vasconcellos-Neto et al. (2017) took an ecological approach to study the interaction of spiders with plants after careful observation and experimentation. They found that structures like rosette-shaped leaves or glandular trichomes attract spiders, providing them shelter and easy access to prey species. They offer the plants protection from herbivory, but this could not be considered a mutualism because they often consume the pollinators too. They also state that specific associations, adaptations, or mutualistic relationships are not yet observed or known. Spider

families that are actively hunting through the foliage are simply wandering rather than associating with it.

2.9. Araneofauna under Anthropogenic Stressors

Harvey & Dong (2023) studied how high temperature affects spiders' reproductive and nesting behaviour. With the sudden and unpredictable temperature changes due to climate change, spiders face unique challenges. They compared the lifestyles of both male and female spiders. The study found that female spiders are potentially exposed to heat waves due to their fixed web-making skills and sedentary lifestyles, whereas the males get an advantage due to their nomadic behaviour and prefer cooler microhabitats. The study highlights that exposure to heat waves could potentially reduce egg viability and the spiders' endurance.

Ecological researchers, including Shochat et al. (2004, 2008), investigated the impact of land-use modification on spider and harvestman diversity across six different habitats. They emphasised that productivity has a significant role in determining the community structure of an ecosystem. The selected habitats for the study include productive ecosystems like agricultural land and less productive xeric habitats. The productive environments demonstrated increased spider abundance but reduced taxonomic diversity. While in the desert ecosystem, more families were found, even though the abundance was comparatively low. In productive habitats, the dominant family, like lycosidae, exhibited a positive correlation with habitat productivity and a negative correlation with predatory arthropod assemblages, including other spider families. The study exposed that anthropogenic landscape modifications can modulate ecological responses to seasonal fluctuations, potentially favouring previously adapted taxa and altering the whole community composition.

Żmudzki & Laskowski (2012) studied the impact of long-term exposure to metal pollution on epigeal spider diversity the Southern Poland. They found an increased concentration of Zinc in the soil and surveyed the diversity of spiders. Biodiversity assessment on different levels like

family, genus and species, was calculated. A comparison of more metal-polluted areas and unpolluted areas in the same locality revealed a decline in the hierarchical diversity index in polluted areas. The study concluded that metal pollution decreases overall diversity and favours the survival of certain groups.

Sharma et al. (2023) studied how urbanisation alters spider community structure in Guwahati, Assam. They studied the taxonomic and functional diversity of spiders in an urban park and forest area. The species composition significantly differed among habitat types. Urban park showed a lower diversity of spiders and observed a dominance of a few species of synanthropic spiders. Functional richness was highest in forests and lowest in urban parks, while functional divergence was highest in urban areas. Functional richness indicates an ecosystem's resilience and stability; lower functional richness indicates how vulnerable the ecosystem is. The study concludes that urban land-use variations can significantly alter both the structure and ecological functioning of spider communities. Jung et al. (2008) investigated how soil contamination by cadmium and lead affects the diversity and population dynamics of ground-dwelling spiders. They observed a negative trend in heavy metal pollution, especially pollution by lead, and the diversity of spiders.

Khnyckin & Ivantsova (2021) examined the transformation of spider communities under anthropogenic influence in the dry steppe ecosystem of Volgograd, Russia. Spiders were collected from three pollution sources: an unauthorised landfill, a highway, and a thermal power plant. Sample sites were established at the pollution source, midway to the legal exclusion zone boundary, and beyond this boundary. Community structural changes were analysed using different diversity indices to assess qualitative species composition and quantitative population metrics. Results demonstrated a significant anthropogenic impact on spider assemblages near pollution sources, with pronounced recovery gradients as distance increased. Beyond exclusion zone boundaries, spider community composition reverted to levels considered ecologically acceptable, suggesting that current regulatory spatial parameters effectively protect arthropod biodiversity in this ecosystem.

Even though spiders are invertebrates, they have a crucial role in the ecosystem's functioning and its sustainability. Like all other species on earth, spiders also face multiple threats and difficulties to their existence. A comprehensive global survey of arachnological experts identified five primary threats to spider biodiversity: agriculture, livestock farming & forestry, climate change, urbanisation, and pollution, particularly pesticides (Branco & Cardoso, 2020). Two foremost conservation strategies that can be used to limit the threats are: land protection and education or awareness initiatives. However, there are significant localised conservation challenges. This pioneering global assessment is a groundbreaking initiative for spider conservation, emphasising the need for protected habitat designation, sustainable agroforestry practices, mitigation of climate change, and enriching public awareness regarding the importance of spiders. There could be other serious threats which are undetectable, making spiders vulnerable, including anthropogenic pressure. They conclude by addressing this as the knowledge gap, as spiders remain underrepresented in conservation efforts.

The taxonomic studies in India, especially Kerala, contribute a significant understanding of arachnid biodiversity. Research across various Indian regions has documented impressive species richness, with particularly notable works from the Western Ghats, a biodiversity hotspot. Exploratory studies on the diversity of spiders in ecosystems, including forests, deserts, sacred groves, agricultural ecosystems, river banks, wetlands, floodplains, and urban gardens, have been done by many researchers lately. Despite mangroves being recognised as ecologically crucial habitats with unique environmental conditions, spider communities within these ecosystems remain severely understudied compared to other terrestrial habitats.

Studies in Kerala have significantly contributed not only to taxonomic diversity but also to ecological relationships and habitat preferences across diverse ecosystems. However, substantial knowledge gaps persist, with many regions remaining sampled and numerous taxonomic groups requiring further investigation. Future research directions should prioritise standardised sampling methodologies, integration of molecular techniques with traditional morphological identification,

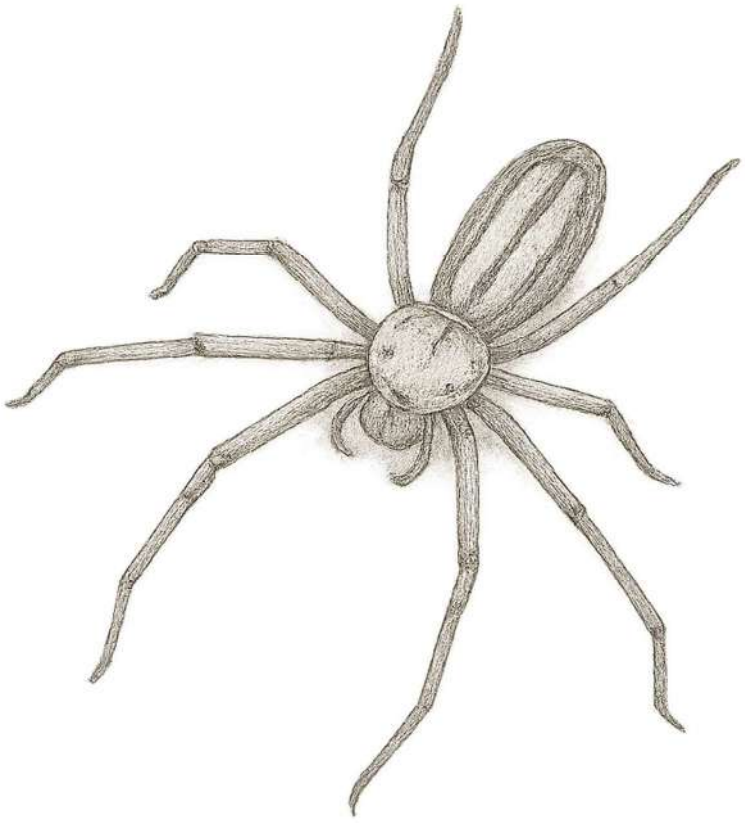
and increased attention to microhabitat utilisation patterns. Additionally, conservation-oriented research is urgently needed given the increasing anthropogenic pressures on spider habitats throughout India. These efforts will contribute significantly to both regional conservation planning and our global understanding of arachnid biodiversity patterns.

2.10. Spiders as bioindicators

Many scientists suggested that the spider web is an excellent bioindicator of atmospheric pollution (Mansour & Cohen, 1993; Samu et al., 1996). The atmospheric pollution caused largely by vehicles causes significant risks to human health and ecosystems. Spider webs have emerged as effective bio-indicators for monitoring environmental pollution. The ability to accumulate both organic and inorganic pollutants makes the spider web an effective and better bioindicator of pollution, offering advantages over traditional indicators like lichens and mosses. Spider webs demonstrate unique strengths, though limitations exist. Overall, spider webs are a promising method for detecting and evaluating air pollution changes. Kochi a metro city in Kerala, is known for its industries. A study carried out by Anil & Joseph (2024) monitored air quality in Kochi using spider webs. They chose two web-building spiders, *Pholcus phalangioides* and *Cyrtophora spp,* as bioindicators. The collected sample underwent spectroscopic analysis and was found the presence of 13 heavy metals. They found that iron (Fe) was the predominant metal that accumulated, followed by mercury (Hg). The findings highlight spider webs as effective tools for assessing pollution from vehicular and industrial emissions. Egyptian scientists Ossamy et al. (2016) investigated the usefulness of araneofauna as bioindicators for anthropogenic disturbance assessment. Statistical analyses showed significant variation in the values between natural and disturbed habitats due to the mining of petroleum. The disturbed area exhibited markedly diminished species richness and abundance. The undisturbed habitats with healthy edaphic parameters and floristic composition supported richer spider fauna. These findings substantiate the incomparable utility of arachnid assemblage as a sensitive metric for biodiversity disturbance

assessment, thereby providing quantitative constraints for conservation management protocols. These studies suggest that spiders can be used as potential bioindicator tools.

Despite the ecological importance of mangroves and their role in supporting diverse animal communities, studies on spider diversity within these habitats remain limited, particularly in Kerala. Mangroves provide unique microhabitats that support many spider species, contributing to maintaining the balance of the ecosystem through their roles as predators and bioindicators. However, most biodiversity assessment studies in Kerala's mangroves have largely ignored spiders, creating a substantial knowledge gap. Understanding spider diversity patterns and their ecological functions is essential for developing effective conservation strategies, especially for mangrove ecosystems. Addressing this gap is crucial for ensuring the resilience and sustainability of the pristine coastal ecosystems of Kerala -Mangrove.



CHAPTER 3
MATERIALS AND METHODS

The araneofauna allied with the mangroves in Kerala remains underexplored and incompetently documented. In this chapter, we describe the materials, sampling areas, sampling protocols, data processing, workflow, and the statistical procedures used to study spiders in the mangroves of Kerala.

3.1. Study Area and Survey Technique

Mangroves are the sole plant species from unrelated families of trees and shrubs, where the frequent exchange of tidal water takes place. These ecotones connect marine and terrestrial habitats and protect the coastal community from tidal actions, ensuring shoreline stability. According to Ramachandran et al. (1985), Kerala was once spread around 700 sq. km of mangroves, but the area has been reduced to 20 sq. km today. From Pozhiyoor to Kumbala, the mangrove zones are spread across 10 districts out of 14 in Kerala. There are 15 true mangroves and 33 mangrove-associated species existing across Kerala's coastal belt.

Table 3.1. Site selection matrix of mangrove with coordinates across Kerala

District	Location	Site	Coordinates
KASARAGOD (1.228160 km²)	Kumbla	Site 1	12° 35' 57.41" N
			74° 56' 11.02" E
	Uppala		12° 40' 28.55" N
			74° 54' 09.04" E
KANNUR (9.10894 km²)	Dharmadom	Site 2	11° 46' 55.33" N
			75° 27' 45.79" E
	Valapattanam		11° 55' 48.29" N
			75° 20' 52.19" E
KOZHIKODE (1.125627 km²)	Kadalundi	Site 3	11° 07' 51.32" N
			75° 49' 44.58" E

	Beypore		11° 10' 58.99" N 75° 49' 03.19" E
MALAPPURAM (0.640991 km²)	Tirur	Site 4	10° 54' 51.36" N 75° 54' 29.69" E
	Ponnani		10° 45' 30.65" N 75° 56' 26.07" E
THRUSSUR (1.315048 km²)	Chettuva	Site 5	10° 32' 12.94" N 76° 03' 00.56" E
	Poyya		10° 12' 40.04" N 76° 14' 0.26" E
ERNAKULAM (5.531498 km²)	Puthuvype	Site 6	9° 59' 36.65" N 76° 13' 42.18" E
	Mangalavanam		9° 59' 19.57" N 76° 16' 21.13" E
ALAPPUZHA (1.28942 km²)	Azheekkal	Site 7	9° 8' 25.87" N 76° 27' 51.70" E
	Ezhupunna		9° 49' 56.63" N 76° 19' 7.63" E
KOTTAYAM (0.008873 km²)	Vechoor	Site 8	9° 40' 57.778"N 76° 24' 47.617" E
	Kumarakom		9° 37' 45.90" N 76° 25' 24.94" E
KOLLAM (0.883697 km²)	Ayiramthengu	Site 9	9° 7' 13.809"N 76° 28' 41.912" E
	Asramam		8° 53' 42.81" N

			76° 35' 09.58" E
THIRUVANANTHAPURAM (0.011213 km²)	Poovar	Site 10	8° 19' 15.46" N
			77° 04' 37.58" E
	Veli		8° 30' 48.14" N
			76° 53' 19.73" E

We established the study sites following a stratified random design across the mangrove ecozones of Kerala. Two plots of mangroves from each district. Each district is considered a stratum, and two independent plots were randomly selected. Selected paired plots were aggregated into 10 composite sites, one per district, to streamline the statistical analysis. We used GeoTracker (Android) to lock in the coordinates with high precision. We chose a line transect method for finding the morphospecies of spiders. We established three 50-meter transects with a 4-meter-wide belt (2 m on both sides) and searched across this systematically, examining every microhabitat.

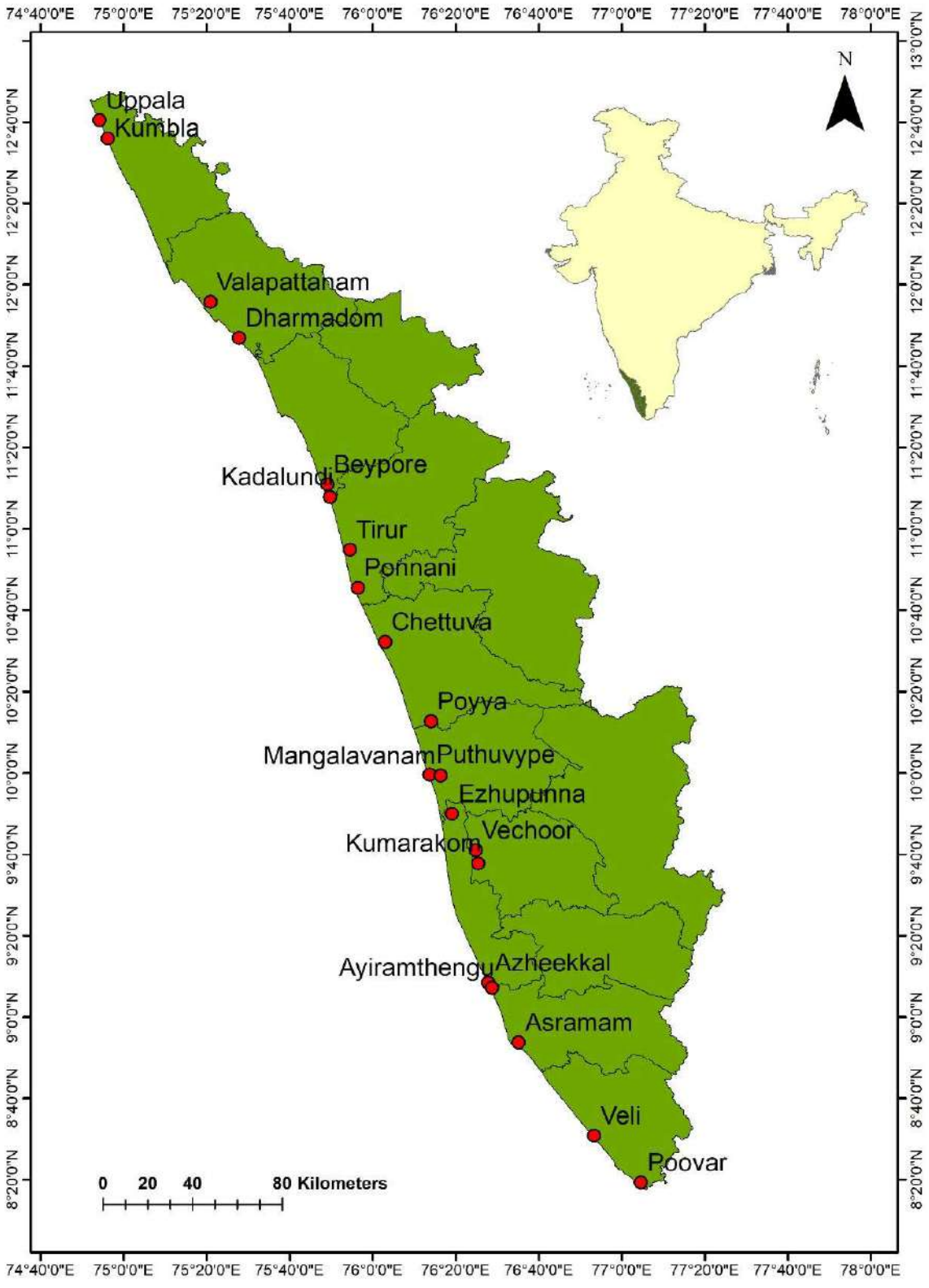


Figure 3.1. Map showing the study sites in different districts of Kerala

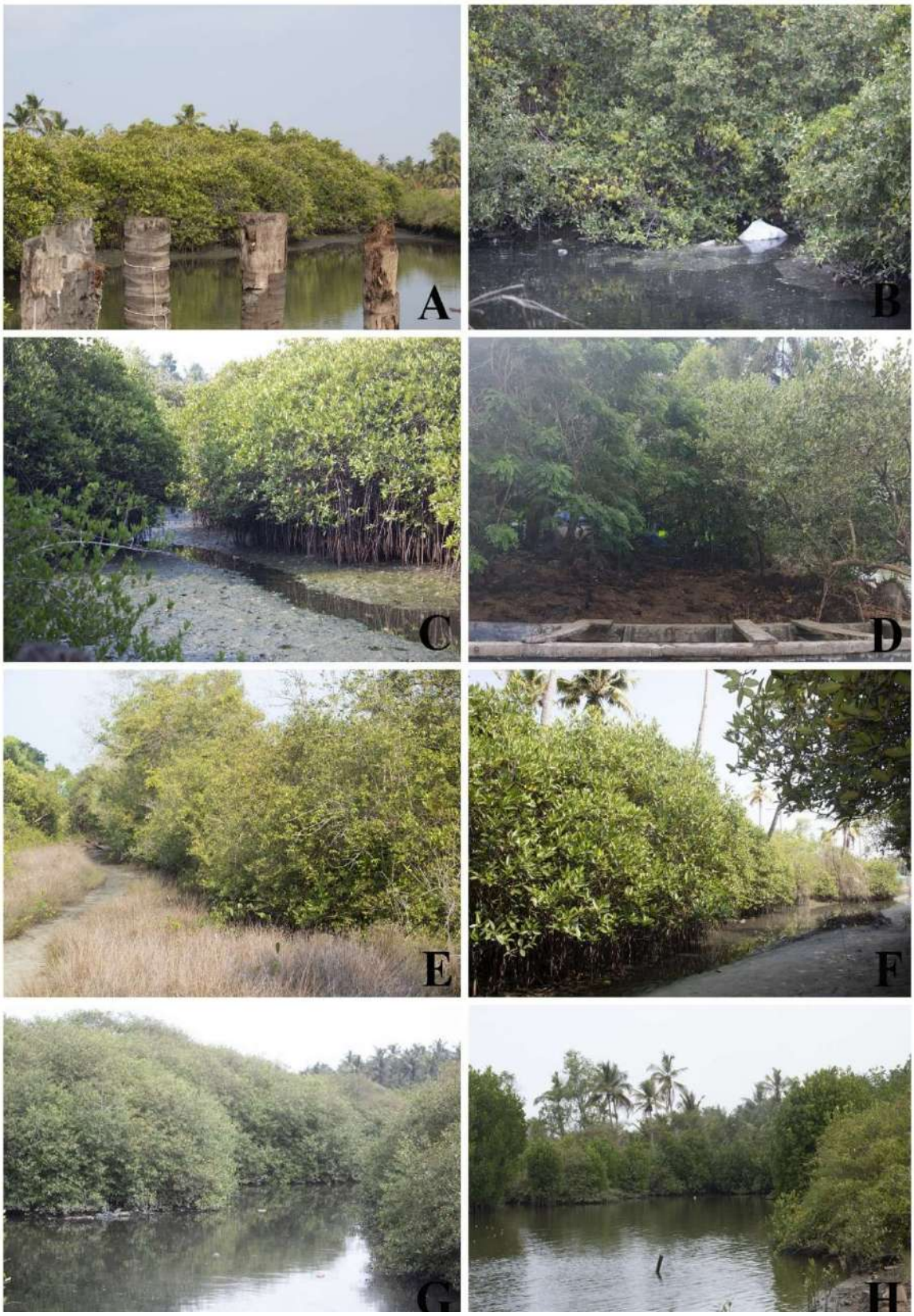


Figure 3.2a. Different collection sites: A-Alappuzha, B-Ernakulam, C-Kannur, D-Kasaragod, E-Kollam, F-Kottayam, G-Kozhikode, H-Malappuram

Figure 3.2b. Different collection sites: I-Thrissur, J-Thiruvananthapuram

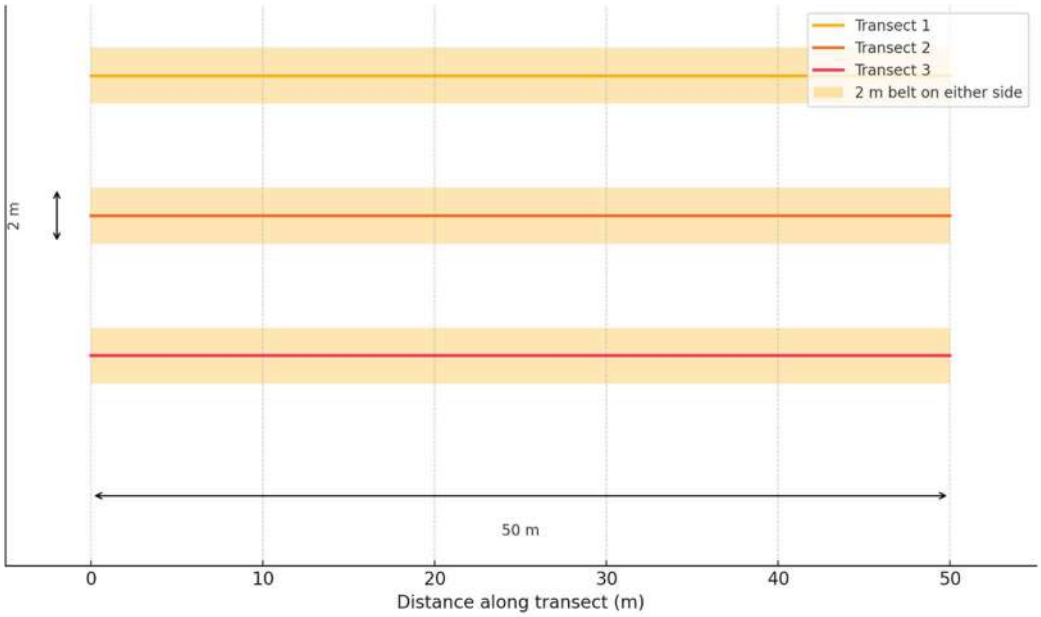


Figure 3.3. Schematic representation of the line transect method

3.2. Collection Methods

Since the study sites are mainly mangroves, certain collection methods cannot be performed, like pitfall trapping. Most of the spiders are UV sensitive and show negative phototaxis (Suter, 1999); therefore, collection was done during defined times. We chose morning from 7 to 10 and evening from 4 to 7, which is the peak time of optimal light and temperature with maximum spider activity.

3.2.1. Visual searching and Hand picking

Visual searching and hand picking are the most commonly used methods to collect spiders regardless of the ecosystem. We searched for spiders along the predefined transects carefully on all the substrates (Sudhikumar et al., 2005a; Foelix, 2010). Ground spiders were collected primarily by directly by hand or by putting plastic vials to trap them. Carefully inspected the upper and lower sides of the foliage. Folded leaves, leaves, and bark with retreats were carefully inspected for spiders (Southwood & Henderson, 2000). The hardy wood barks with crevices were inspected with a needle and a small, pointed painting brush dipped in alcohol (Millar et al., 2000).

3.2.2. Beating and shaking

Spiders have unique adhesive strength to the surface of any substrate. Beating and shaking is a classic method used to dislodge arboreal and shrub-dwelling spider species into a collection surface, usually a white cotton cloth. From there, specimens are transferred to vials filled with alcohol (McCaffrey et al., 1984; Southwood & Henderson, 2000). The vigorous agitation of the foliage is highly effective for medium to large-sized canopy-dwelling spiders.

3.2.3. Litter sampling

Leaf litter sampling helps to isolate cryptic, detritus-dwelling minute spiders. Litter is collected and placed in a white cloth and extracted with a paint brush dipped in alcohol, then transferred into the collection vials (Southwood & Henderson, 2000). Since pitfall traps are less commonly used to collect mangrove spiders, litter sampling serves as an important technique used to collect ground and litter-dwelling spiders.

Figure 3.4. Different collection methods: A-Visual searching and handpicking, B-Beating and shaking, C-Litter sampling

3.3. Identification

To identify the collected spiders, specimens were examined under a stereo zoom microscope (Leica-M205C). Identification was primarily based on morphological features like size, colour, shape, distribution of eyes, type of tapetum, morphology of chelicerae, articulation of fangs, leg morphology, and spination.

For a precise species-level identification, microscopic examination of the male and female genitalia is necessary. Palp is the male and epigyne is the female genitalia that is to be examined. These structures were carefully dissected out of the spider using sharp and pointed needles and forceps. Most of the male palp can be viewed directly under a microscope without any post-dissection treatments. But the female epigyne should be treated with 10% KOH to wash off the excess tissues since the epigyne is embedded in the fleshy abdomen (Ubick et al., 2005; WSC, 2025).

3.4. Guild structure analysis

The ecological guild concept was first put forward by Richard B Roots in 1967. A guild is a group of related species exploiting a resource in similar ways. In the case of spiders, they are categorized according to their prey hunting strategy. There are 8 feeding guilds according to the

latest publication of Cardoso et al., in 2011. They compiled the ecological traits, foraging strategy, prey range, strata-based assemblage, and circadian rhythm of over 100 families and created a dendrogram easy to identify and compare the subject families. We compared the spider assemblage of our study following Cardoso et al. (2011) and compiled the results.

3.5. Data Analysis and Visualizations

The analytical and visualization part of our workflow is carried out using Microsoft Excel and R statistical software. Excel is used for primary data entry, filtration, tabulation, and rapid visualization. For more extensive data analysis, we used R software. It gives a comprehensive platform to import, transform, and validate the data, integration of both Microsoft Excel with R software ensures efficient and transparent representation and visualization of data.

3.5.1. Species accumulation curve and Diversity indices by Community ecology package - Vegan

A species accumulation curve shows the cumulative sampling efforts. It helps in understanding both species richness and the adequacy of the survey. The curve plots the number of units, that is number of sites, against the cumulative species richness. The asymptotic nature of the graphs says the sampling has been almost completed. The vegan package on the R software is used to plot the curve.

In diversity and ecological practices, the diversity indices are computed to transform complex abundance matrices into quantitative metrics that reliably capture both species richness, the mode of their distribution. Calculating the indices according to the abundance matrix is helpful to standardize the sampling and diversity by reducing the sensitivity of sampling efforts to the presence of rare taxa, unprecedented dominance of a few taxa, etc.

Species richness (S): Species richness is the raw count of individual species at each site across the predetermined transects. By knowing how many, we can predict the habitat complexity and understand the basis of community dynamics.

Shannon Weiner Index (H′): It is the one metric that counts both species richness and evenness in a single frame to capture the entropy of the assemblage. Mathematically, $H' = -\sum_i (p_i \cdot \ln p_i)$, where $p_i = n_i / N$, n_i is the count of species i, and N is the total number of species at the site. This index is sensitive to both rare and common species, and higher values indicate high diversity (Shannon, 1948; Oksanen et al., 2013).

Simpson's Diversity Index (1–D): This metric tells the probability that two randomly drawn individuals from a site belong to different species. $1 - D = 1 - \sum_i (n_i/N)^2$ is the mathematical backbone of this index, where $p_i = n_i/N$, n_i is the number of species *i*, and *N* is the total count at the site. This index focuses on how evenly individuals are dispersed in the study site (Simpson, 1949).

Chao1 Richness Estimator: This estimator gives more weight to rare species- singletons and doubletons, and provides a bias-free lower bound on true species richness. It is calculated by following $Chao1 = S\_obs + (f_1^2) / (2f_2)$, where S_obs is the number of observed species, f1 is the number of singletons, and f2 is the number of doubletons (Chao, 1984).

Margalef's Richness Index (d): It is the measure of species richness that accounts for sample size and sampling effort. The index is calculated by d (S-1) / ln(N). S is the species richness, N=total number of individuals. A higher value obtained from the calculation indicates a higher richness (Margalef, 1956).

Pielou's Evenness Index (J′): This measure shows how spiders are dispersed among species in the community. $J' = H' / \ln(S)$ is the mathematical equation that gives the value. H′ is the Shannon diversity index, and S is the species richness. The values always fall between 0 and 1. A value close to one indicates a perfectly even community (Pielou, 1966).

Fisher's Alpha Diversity Index (α): It describes the connection between species richness and abundance in a community. $S = \alpha \cdot \ln (1 + N/\alpha)$, where S is the species richness, and N is the total number of individuals. The α does not depend on the sample size, but is highly sensitive to the number of rare species in the site (Fisher et al., 1943).

Shapiro-Wilk Normality Test: Before proceeding with the parametric test, the data should undergo normality testing. The Shapiro-Wilk test will measure the W statistic and the p-value with a significance threshold of 0.05.

Kruskal-Wallis Test: This test is applied when there are three or more independent groups present. The test is fundamentally rank-based and finds whether the median of diversity metrics differs across the study sites according to the significant threshold (0.05).

Dunn's Post hoc test: This test helps to find which pair of sites differ significantly in spider diversity metrics. This is also a rank-based non-parametric test that calculates the Z score from the mean rank sums, and finally, an adjusted p-value is obtained.

3.5.2. Diversity profile, Rarefaction, and Coverage-based completeness Curves by Hill numbers framework package – iNEXT

Diversity profiles are based on the Hill numbers, which are a unified group of diversity metrics as the effective number of species in the study sites as a function of the 'q'- parameter. For a community with 'S' number of species and relative abundance 'pi'. The q=0 indicates the species richness, q=1 is the exponential of Shannon entropy, and q=2 is the inverse Simpson. The diversity profile curves show how the community responds to the shifting of rare and common species (Hsieh et al., 2016).

The rarefaction curve is an ecological insight into sampling efforts, focusing on how the observed species richness piles up as the sampling proceeds. This curve neutralizes the uneven sampling errors. A plateau in the plot indicates a good effort in the collection of species in the study sites (Chao et al., 2014; Hsieh et al., 2016).

Coverage-based completeness curve shows the fraction of the total community captured or sampled. As the sampling proceeds. The sampling coverage (*C*^) calculates the proportion of observed species. The steep rise of the plot indicates the relatively common species captured, and

the shallow slope indicates how much further effort is needed for a good sampling (Chao et al., 2014; Hsieh et al., 2016).

3.5.3. Beta diversity indices by the Community dissimilarity package – ecodist

The site-species matrix of the study was imported to the R console and analysed with the ecodist package for the community dissimilarity.

The Bray-Curtis is a continuous gradient of the total turnover and is sensitive to both the relative abundance and species list of presence-absence. This beta diversity index is ideal if the abundance differs between at least two of the study sites, and to understand the shift of the total assemblage driven by dominant taxa (Bray & Curtis, 1957).

Jaccard index, on the other hand, is a simple and robust method that measures the pure absence and turnover, as well as the number of species not shared between two sites. The dominant taxa have no sensitivity towards this index (Jaccard, 1901).

3.5.4. NMDS by Vegan

The geometry of dissimilarity between sites is shown by the NMDS ordination plot using the vegan package. Loading the package towards the site-species matrix gives corrected data by following Hellinger's transformation and calculates the dissimilarity, and an NMDS ordination was generated (Oksanen et al., 2013). Since NMDS works on the rank of dissimilarity rather than row abundance data, it gives negligible inflation and shows the true ranking of community differences.

3.5.5. PERMANOVA by Vegan

To study the difference in community composition among selected grouping factors, we chose PERMANOVA using the vegan package. The test assesses the level of difference of the selected groups from the centroid, i.e., the multivariate mean in multivariate space, primarily based on the Bray-Curtis dissimilarity matrix (Anderson, 2001; Oksanen et al., 2013). The pseudo-F

value and the p-value with a threshold can give a robust idea about the influence of any grouping factors on the community shifts.

3.5.6. Weighted Endemism (WE) and Corrected Weighted Endemism (CWE) by phyloregion

By loading the abundance data into the R console and running the phyloregion, the picture of endemism can be calculated. The abundance data helps to find the unique species in any study site. WE spotlight on the rare species or species that barely appear in the study site during the study. The weighting of each species is 1/ (species range); this amplifies the species with a very low distribution range. Meanwhile, the CWE makes the richness hype less forceful by dividing the WE by the number of species observed at that particular site, thereby normalizing the richness.

3.5.7. IndVal by Indicspecies

Indicator species value can be found by the package IndVal. This measures and blends how a species is restricted to a particular site with the consistency of that species in that site into a numerical value using permutation. The value usually ranges from 0 to 100. The test gives the signature species of an ecosystem (Dufene & Legendre, 1997).

3.5.8. Multivariate GLM (mGLM) by Mvabund

Loading the abundance matrix with environmental factors in the R console and against the Mvabund package helped to fund the community-environment link through numerical values. This joins the responses of species to environmental predictors based on diversity metrics, interspecies covariance, and overdispersion (Wang et al., 2012).

3.5.9. Mangrove floral identification

Mangrove plants were photographed using a Canon Rebel T7 (2000D). Plant branches with almost all features, including healthy leaves, flowers, and fruits, were selected, and the in-situ pictures were taken against a neutral background. The identification was done by following a bracketed dichotomous key by Anupama & Sivadasan (2004), which covers all the mangrove

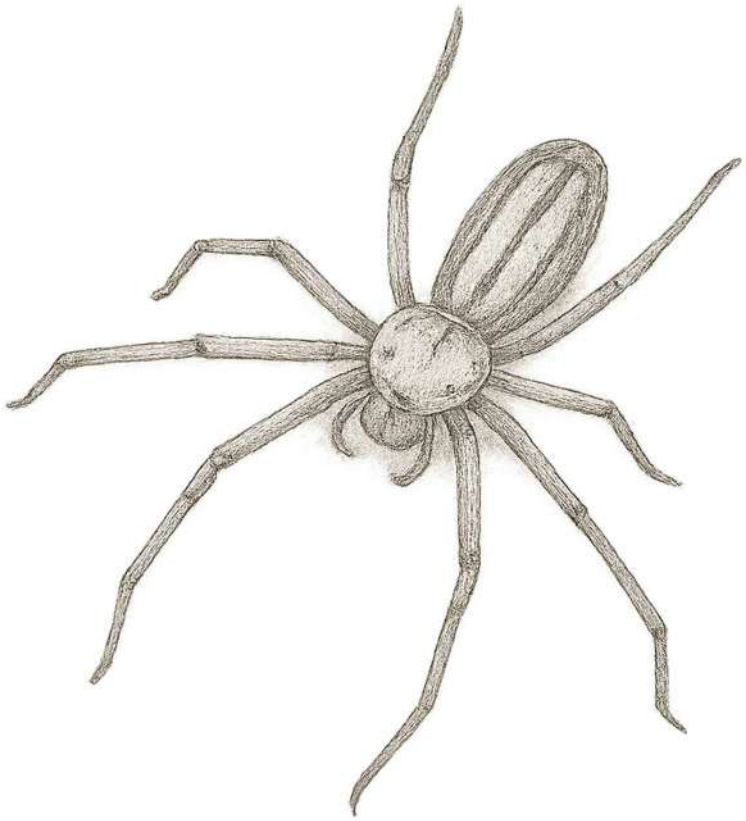
plants of the coastal belt of Kerala. The mangrove-associated plants were identified by comparing the photographs taken from the field with Sujanapal & Sasidharan (2014). The obtained botanical names and accepted synonyms were compared with the master checklist of The Plant List V 1.1 (2013).

3.5.10. Plastic Debris Count and the Disturbance Index (DI)

We counted every plastic debris, which is any anthropogenic polymer item found across the transects in the study site. Density was calculated, and a Z-score was given to each site by following a $Zi=Di-\mu/\sigma$ where Di= count of plastic in site-i, μ is the mean, and σ is the standard deviation (Opfer et al., 2012). The disturbance index was calculated by compiling the canopy openness and the stump density. The canopy openness is measured by taking a photograph of the vegetation through a mobile App – Canopy Cover. It converts the green pixels in the photographs into two percentages. We counted all the stumps across the transect under investigation to measure and standardize the stump density following the same mathematical equation for plastic debris density conversion (Mueller & Ellenberg, 1974).

3.5.11. Retrieval of Temperature and Humidity Data – ERA5

We drew the monthly temperature and humidity of the study period for the 10 mangrove sites from Copernicus Climate Data Store (CDS)-ERA5 land monthly means. We generated a request for the selected parameters (temperature and humidity). We specified the spatial domain- the coordinates and the period with the year and months for each parameter. NetCDF files were obtained as a result. The files were then converted into a Word file with proper units and incorporated into the data analysis.



CHAPTER 4
RESULTS

4.1. Survey and Checklist of spiders along with the mangrove ecosystems of Kerala

Mangrove ecosystems are the classic ecotones tightly bridging land and ocean, and host species from both realms, providing vital ecosystem services. The study of mangrove-associated araneofauna in 10 sites lining the coastal side threading the western coast from Kasaragod down to Thiruvananthapuram resulted in 9950 individuals, 191 species, 102 genera from 21 families. Across the 10 sites from where spiders are collected, the mean richness pulses with 101.5 ± 19.0 species, with the abundance pattern of 995 ± 195.7.

Table 4.1.1. Checklist of Spiders from Mangroves of Kerala

Sl. No	Family	Sl. No.	Species
I	Araneidae	1	*Acusilas coccineus* Simon, 1895
	Araneidae	2	*Anepsion maritatum* (O. Pickard-Cambridge, 1877)
	Araneidae	3	*Arachnura angura* Tikader, 1970
	Araneidae	4	*Araneus* sp.1
	Araneidae	5	*Argiope aemula* (Walckenaer, 1841)
	Araneidae	6	*Argiope anasuja* Thorell, 1887
	Araneidae	7	*Argiope pulchella* Thorell, 1881
	Araneidae	8	*Bijoaraneus mitificus* (Simon, 1886
	Araneidae	9	*Cyclosa bifida* (Doleschall, 1859)
	Araneidae	10	*Cyclosa confraga* (Thorell, 1893)
	Araneidae	11	*Cyclosa hexatuberculata* Tikader, 1982
	Araneidae	12	*Cyclosa neilensis* Tikader, 1977
	Araneidae	13	*Cyclosa quinqueguttata* (Thorell, 1881)
	Araneidae	14	*Cyclosa* sp.1
	Araneidae	15	*Cyclosa* sp.2
	Araneidae	16	*Cyclosa* sp.3
	Araneidae	17	*Cyclosa* sp.4
	Araneidae	18	*Cyrtarachne* sp.1
	Araneidae	19	*Cyrtophora cicatrosa* (Stoliczka, 1869)
	Araneidae	20	*Cyrtophora citricola* (Forskål, 1775)
	Araneidae	21	*Cyrtophora moluccensis* (Doleschall, 1857)
	Araneidae	22	*Cyrtophora unicolor* (Doleschall, 1857)
	Araneidae	23	*Eriovixia excelsa* (Simon, 1889)
	Araneidae	24	*Eriovixia poonaensis* (Tikader & Bal, 1981)
	Araneidae	25	*Eriovixia* sp.1
	Araneidae	26	*Eriovixia* sp.2
	Araneidae	27	*Gasteracantha geminata* (Fabricius, 1798)
	Araneidae	28	*Herennia multipuncta* (Doleschall, 1859)
	Araneidae	29	*Macracantha* sp.1

	Araneidae	30	*Neoscona bengalensis* Tikader & Bal, 1981
	Araneidae	31	*Neoscona elliptica* Tikader & Bal, 1981
	Araneidae	32	*Neoscona mukerjei* Tikader, 1980
	Araneidae	33	*Neoscona nautica* (L. Koch, 1875)
	Araneidae	34	*Neoscona* sp.1
	Araneidae	35	*Neoscona* sp.2
	Araneidae	36	*Neoscona* sp.3
	Araneidae	37	*Parawixia dehaani* (Doleschall, 1859)
	Araneidae	38	*Thelacantha brevispina* (Doleschall, 1857)
	Araneidae	39	*Thelacantha* sp.1
II	Cheiracanthiidae	40	*Cheiracanthium aizwalense* B. Biswas & K. Biswas, 2007
	Cheiracanthiidae	41	*Cheiracanthium danieli* Tikader, 1975
	Cheiracanthiidae	42	*Cheiracanthium indicum* O. Pickard-Cambridge, 1874
	Cheiracanthiidae	43	*Cheiracanthium melanostomum* (Thorell, 1895)
	Cheiracanthiidae	44	*Cheiracanthium poonaense* Majumder & Tikader, 1991
	Cheiracanthiidae	45	*Cheiracanthium* sp.1
	Cheiracanthiidae	46	*Cheiracanthium* sp.2
	Cheiracanthiidae	47	*Cheiracanthium* sp.3
III	Clubionidae	48	*Clubiona bengalensis* Biswas, 1984
	Clubionidae	49	*Clubiona drassodes* O. Pickard-Cambridge, 1874
	Clubionidae	50	*Clubiona* sp.1
	Clubionidae	51	*Clubiona* sp.2
	Clubionidae	52	*Simalio* sp.1
IV	Corinnidae	53	*Castianeira furva* Sankaran et al., 2015
	Corinnidae	54	*Castianeira zetes* Simon, 1897
	Corinnidae	55	*Castianeria* sp.1
	Corinnidae	56	*Corinnomma severum* (Thorell, 1877)
	Corinnidae	57	*Corinnomma* sp.1
V	Eresidae	58	*Stegodyphus sarasinorum* Karsch, 1892
VI	Filistatidae	59	*Filistata* sp.1
	Filistatidae	60	*Pritha insularis* (Thorell, 1891)
	Filistatidae	61	*Pritha nana* (Simon, 1868)
	Filistatidae	62	*Pritha* sp.1
VII	Gnaphosidae	63	*Drassodes* sp.1
	Gnaphosidae	64	*Drassodes* sp.2
	Gnaphosidae	65	*Zelotes jabalpurensis* Tikader & Gajbe, 1976
	Gnaphosidae	66	*Zelotes* sp.1
VIII	Hersiliidae	67	*Hersilia longivulva* Sen, Saha & Raychaudhuri, 2010
	Hersiliidae	68	*Hersilia savignyi* Lucas, 1836
	Hersiliidae	69	*Hersilia striata* Wang & Yin, 1985
	Hersiliidae	70	*Hersilia* sp.1
	Hersiliidae	71	*Hersilia* sp.2
	Hersiliidae	72	*Murricia* sp.1
IX	Lycosidae	73	*Draposa* sp.1
	Lycosidae	74	*Pardosa sumatrana* (Thorell, 1890)
	Lycosidae	75	*Pardosa* sp.1
	Lycosidae	76	*Pardosa* sp.2
	Lycosidae	77	*Lycosa tista* Tikader, 1970

	Lycosidae	78	*Lycosa mackenziei* Gravely, 1924
	Lycosidae	79	*Hippasa agelenoides* (Simon, 1884)
	Lycosidae	80	*Lycosa* sp.1
	Lycosidae	81	*Lycosa* sp.2
	Lycosidae	82	*Lycosa* sp.3
X	Mimetidae	83	*Mimetus indicus* Simon, 1906
	Mimetidae	84	*Mimetus* sp.1
XI	Oxyopidae	85	*Hamadruas sikkimensis* (Tikader, 1970)
	Oxyopidae	86	*Hamadruas* sp.1
	Oxyopidae	87	*Hamadruas* sp.2
	Oxyopidae	88	*Hamataliwa* sp.1
	Oxyopidae	89	*Hamataliwa* sp.2
	Oxyopidae	90	*Oxyopes birmanicus* Thorell, 1887
	Oxyopidae	91	*Oxyopes hindostanicus* Pocock, 1901
	Oxyopidae	92	*Oxyopes javanus* Thorell, 1887
	Oxyopidae	93	*Oxyopes shweta* Tikader, 1970
	Oxyopidae	94	*Oxyopes* sp.1
	Oxyopidae	95	*Oxyopes* sp.2
	Oxyopidae	96	*Peucetia viridana* (Stoliczka, 1869)
XII	Philodromidae	97	*Psellonus planus* Simon, 1897
	Philodromidae	98	*Psellonus* sp.1
	Philodromidae	99	*Philodromus* sp.1
	Philodromidae	100	*Thanatus elongatus* (Tikader, 1960)
XIII	Pholcidae	101	*Crossopriza lyoni* (Blackwall, 1867)
	Pholcidae	102	*Pholcus phalangioides* (Fuesslin, 1775)
	Pholcidae	103	*Pholcus* sp.1
	Pholcidae	104	*Smeringopus pallidus* (Blackwall, 1858)
XIV	Pisauridae	105	*Dendrolycosa gitae* (Tikader, 1970)
XV	Salticidae	106	*Afraflacilla* sp.1
	Salticidae	107	*Asemonea tenuipes* (O. Pickard-Cambridge, 1869)
	Salticidae	108	*Bianor angulosus* (Karsch, 1879)
	Salticidae	109	*Bianor* sp.1
	Salticidae	110	*Brettus cingulatus* Thorell, 1895
	Salticidae	111	*Carrhotus viduus* (C. L. Koch, 1846)
	Salticidae	112	*Chrysilla volupe* (Karsch, 1879)
	Salticidae	113	*Cocalus* sp.1
	Salticidae	114	*Colyttus* sp.1
	Salticidae	115	*Curubis tetrica* Simon, 1902
	Salticidae	116	*Curubis* sp.1
	Salticidae	117	*Curubis* sp.2
	Salticidae	118	*Epeus indicus* Prószynski, 1992
	Salticidae	119	*Epeus* sp.1
	Salticidae	120	*Habrosestum* sp.1
	Salticidae	121	*Hyllus semicupreus* (Simon, 1885)
	Salticidae	122	*Hyllus* sp.1
	Salticidae	123	*Indopadilla insularis* (Malamel, Sankaran & Sebastian, 2015)
	Salticidae	124	*Marengo crassipes* G. W. Peckham & E. G. Peckham, 1892
	Salticidae	125	*Menemerus bivittatus* (Dufour, 1831)

	Salticidae	126	*Myrmaplata plataleoides* (O. Pickard-Cambridge, 1869)
	Salticidae	127	*Myrmarachne* sp.1
	Salticidae	128	*Phaeacius fimbriatus* Simon, 1900
	Salticidae	129	*Phintella vittata* (C. L. Koch, 1846)
	Salticidae	130	*Chalcotropis pennata* Simon, 1902
	Salticidae	131	*Plexippus paykulli* (Audouin, 1826)
	Salticidae	132	*Plexippus petersi* (Karsch, 1878)
	Salticidae	133	*Plexippus* sp.1
	Salticidae	134	*Portia fimbriata* (Doleschall, 1859)
	Salticidae	135	*Portia* sp.1
	Salticidae	136	*Portia* sp.2
	Salticidae	137	*Rhene flavicomans* Simon, 1902
	Salticidae	138	*Rhene flavigera* (C. L. Koch, 1846)
	Salticidae	139	*Siler semiglaucus* (Simon, 1901)
	Salticidae	140	*Stenaelurillus lesserti* Reimoser, 1934
	Salticidae	141	*Myrmarachne melanocephala* MacLeay, 1839
	Salticidae	142	*Telamonia dimidiata* (Simon, 1899)
	Salticidae	143	*Thiania bhamoensis* Thorell, 1887
	Salticidae	144	*Toxeus* sp.1
	Salticidae	145	*Vailimia* sp.1
XVI	Scytodidae	146	*Scytodes fusca* Walckenaer, 1837
	Scytodidae	147	*Scytodes pallida* Doleschall, 1859
	Scytodidae	148	*Scytodes thoracica* (Latreille, 1802)
	Scytodidae	149	*Scytodes* sp.1
XVII	Sparassidae	150	*Gnathopalystes flavidus* (Simon, 1897)
	Sparassidae	151	*Heteropoda venatoria* (Linnaeus, 1767)
	Sparassidae	152	*Heteropoda* sp.1
	Sparassidae	153	*Olios milleti* (Pocock, 1901)
	Sparassidae	154	*Olios* sp.1
	Sparassidae	155	*Thelcticopis moolampilliensis* Jose & Sebastian, 2007
XVIII	Tetragnathidae	156	*Tetragnatha hasselti* Thorell, 1890
	Tetragnathidae	157	*Tetragnatha keyserlingi* Simon, 1890
	Tetragnathidae	158	*Tetragnatha mandibulata* Walckenaer, 1841
	Tetragnathidae	159	*Tetragnatha viridorufa* Gravely, 1921
	Tetragnathidae	160	*Tetragnatha* sp.1
	Tetragnathidae	161	*Tylorida striata* (Thorell, 1877)
	Tetragnathidae	162	*Tylorida ventralis* (Thorell, 1877)
XIX	Theridiidae	163	*Achaearanea durgae* Tikader, 1970
	Theridiidae	164	*Achaearanea* sp.1
	Theridiidae	165	*Argyrodes ambalikae* Tikader, 1970
	Theridiidae	166	*Argyrodes argentatus* O. Pickard-Cambridge, 1880
	Theridiidae	167	*Argyrodes flavescens* O. Pickard-Cambridge, 1880
	Theridiidae	168	*Argyrodes* sp.1
	Theridiidae	169	*Ariamnes flagellum* (Doleschall, 1857)
	Theridiidae	170	*Chikunia nigra* (O. Pickard-Cambridge, 1880)
	Theridiidae	171	*Chrysso angula* (Tikader, 1970)
	Theridiidae	172	*Meotipa* sp.1
	Theridiidae	173	*Nesticodes rufipes* (Lucas, 1846)

	Theridiidae	174	*Nihonhimea mundula* (L. Koch, 1872)
	Theridiidae	175	*Propostira quadrangulata* Simon, 1894
	Theridiidae	176	*Steatoda* sp.1
	Theridiidae	177	*Theridion* sp.1
XX	Thomisidae	178	*Amyciaea forticeps* (O. Pickard-Cambridge, 1873)
	Thomisidae	179	*Bomis* sp.1
	Thomisidae	180	*Camaricus formosus* Thorell, 1887
	Thomisidae	181	*Indoxysticus* sp.1
	Thomisidae	182	*Oxytate elongata* (Tikader, 1980)
	Thomisidae	183	*Runcinia* sp.1
	Thomisidae	184	*Thomisus andamanensis* Tikader, 1980
	Thomisidae	185	*Thomisus* sp.1
XXI	Uloboridae	186	*Hyptiotes indicus* Simon, 1905
	Uloboridae	187	*Hyptiotes* sp.1
	Uloboridae	188	*Miagrammopes extensus* Simon, 1889
	Uloboridae	189	*Uloborus plumipes* Lucas 1846
	Uloboridae	190	*Uloborus* sp.1
	Uloboridae	191	*Uloborus* sp.2

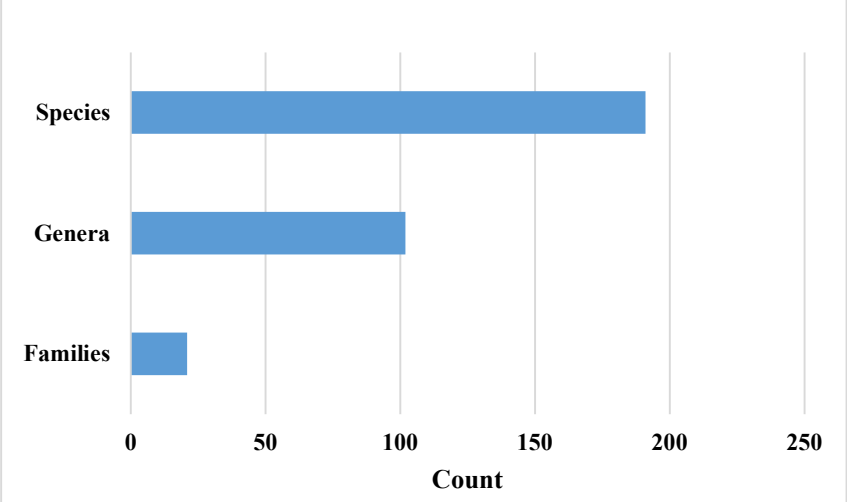


Figure 4.1.1. Horizontal bar chart showing the categorical count of spiders

Table 4.1.2. Summary of spider abundance and species richness across mangrove sites

Statistic	Abundance (individuals)	Richness (species)
Mean ± SD	995 ± 195.7	101.5 ± 19.0
Range	642–1287	79–127
Maximum	1287 (Site 3)	127 (Site 9)
Minimum	642 (Site 7)	79 (Site 6)

On average, each study site harbors about 995 individuals, fluctuating roughly ±196 from site to site, and 101 species per site ±19. 642 is the lowest number of individuals found in a site, and the highest is 1287. For species richness, the count is 79 to 127. Site 3 has the most individuals, and Site 9 is the species epicentre. Site 7 has the lowest individual count, and site 6 has the lowest richness.

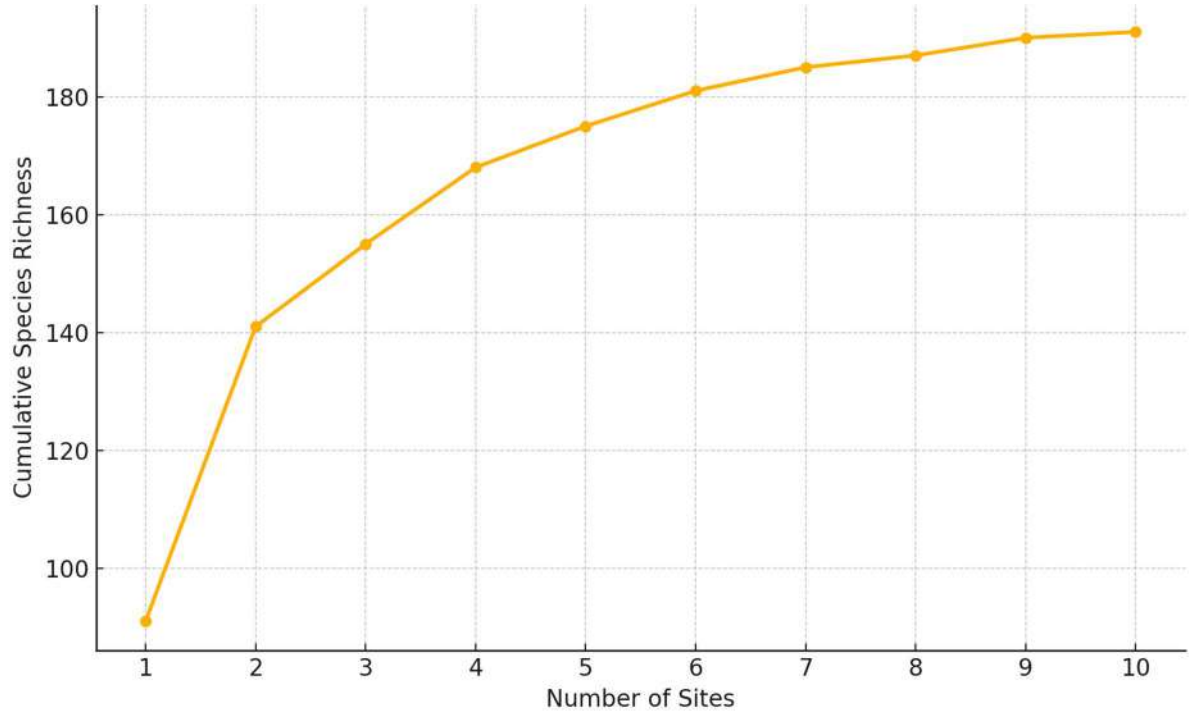


Figure 4.1.2. Species accumulation curve of spiders across the study sites

The species accumulation curve obtained by pooling spider species from 10 mangrove sites across Kerala exhibits an early, steep rise, indicating high species turnover. Beyond the sixth site, the species turnover became low, and only rare species were added. The curve visibly plateaus at eight sites, showing the sampling completeness.

4.1a. FAMILY LEVEL DESCRIPTIONS OF SPIDERS

1. **Family ARANEIDAE** Clerck, 1757
(Orb web spiders)

Small to large sized araneomorphs, ecribellate, carapace frequently flat; sternum triangular or heart-shaped; eight eyes in two rows with lateral eyes widely separated from median eyes;

abdomen various, overhanging the carapace; legs usually with numerous spines three tarsal claws, male palp highly complex with cymbium, median apophysis and radix in the embolic division; female epigyne mostly sclerotized with scapus or septum.

Lifestyle: Occupying a wide range of habitats. The web is orb-shaped and sticky, usually built vertically to the ground.

Distribution: Worldwide.

2. **Family CHEIRACANTHIIDAE** Wagner, 1887
(Long-legged sac spiders)

Small to medium-sized spiders; carapace smooth without foveae; covered with recumbent setae; sternum nearly oval, aligned with the rim of carapace; eight sub-equal eyes in two rows; legs long and slender; large first pair of legs; abdomen elongate, cylindrical; male palp with prominent retrolateral tibial apophysis; embolus slender and filiform; epigyne simple with plate.

Lifestyle: Free-living, cursorial, tree-dwelling, often found on tree trunks and occasionally epigeic.

Distribution: Worldwide.

3. **Family CLUBIONIDAE** Wagner, 1887
(Sac spiders)

Small to medium-sized araneomorph spiders; carapace ovoid, longer than wide, fovea regularly shallow or absent; eight eyes in two rows, small and uniform in size; posterior row slightly longer than anterior rows; abdomen oval; male abdomen sometimes has scutum; legs moderately long with two clawed; male palp with a retro lateral tibial apophysis; epigynal plate usually convex and sclerotised. They are generally free-living, typically nocturnal, and found inside a sac-like retreat in the foliage during the day.

Lifestyle: Free living, nocturnal hunters. During the day, they are found inside saclike retreats on foliage.

Distribution: Worldwide.

4. **Family CORINNIDAE** Karsch, 1880
(Dark sac spiders/Ant-like sac spiders)

Small to medium-sized araneomorph spiders; carapace ovoid or sometimes elongated ant-like; sternum ovoid, flat or slightly impressed with blunt end; eight eyes in two rows; widely spaced, closely grouped, or anteriorly bulging; posterior eye row procurved, recurved, or straight; abdomen ovoid, elongated, or ant-like with or without scuta or transverse bands. Legs sturdy with two claws; male palp with tapering tegulum; epigyne variable.

Lifestyle: Free living; epigeal spiders are sometimes found in leaf litter. Some species mimic ants and mutillid wasps.

Distribution: Worldwide.

5. **Family ERESIDAE** C. L. Koch, 1851
(Velvet spiders)

Small to large-sized araneomorph spiders; carapace rectangular, often high or flattened; sternum with distinct labiosternal groove. Eight eyes; two pairs of median eyes close together, and the lateral eyes wide apart. Short and stout legs with three claws. Abdomen often rounded and oval, clothed in plumose setae. Male palp short lacks tibial apophyses; epigyne is simple with a median septum.

Lifestyle: Live in a wide variety of habitats. Construct retreat webs, and some species are found on the ground in burrows or on plants. Three species of the genus *Stegodyphus* are social.

Distribution: Afrotropical and Palearctic regions.

6. **Family FILISTATIDAE** Ausserer, 1867
(Crevice weavers)

Small to medium-sized araneomorphs. Cephalic region distinctly narrowed, covered densely with setae; fovea absent. Sternum subcircular or oval, fused with labium. Eight eyes in compact rows on tubercles. Legs fairly long, especially in males, with numerous spines and three claws. Oval abdomen. Male palp simple with Cymbium varying in shape; epigyne simple without external plate but with internal structures.

Lifestyle: Found inside silk-lined tubular retreats made in cracks and crevices of rocks and walls.

Distribution: Tropical, subtropical, arid regions in southern parts of North America, South America, southern Europe, Australia, Afrotropical Region.

7. **Family GNAPHOSIDAE** Pocock, 1898
(Flat-bellied ground spiders)

Small to medium-sized araneomorph spider. Carapace convex, oval, and with distinct foveae. Sternum with pointed apex. Eight eyes in two rows usually small. Legs two-clawed; prograde; short and stout. Abdomen elongated to oval. Male palp variable; slender embolus with short pointed retrolateral tibial apophysis. Epigyne with conspicuous cuticular margins.

Lifestyle: Free living epigeal spiders. Eggs are protected by papery egg sacs and are deposited on firm ground.

Distribution: Worldwide.

8. **Family HERSILIIDAE** Thorell, 1870
(Two-tailed spiders/ Whirligig spiders)

Small to medium sized araneomorph spiders; carapace ovoid and flattened, covered with plumose setae; heart shaped sternum; eight eyes on tubercles in two strongly recurved rows; legs very long with tree claws; third leg very short; abdomen flat with plumose setae; male palp with filiform conductor, without tibial apophysis; epigyne with large central septum.

Lifestyle: Have a diverse lifestyle from wandering tree trunk dwellers to ground-dwelling orb web weavers. Producing a band of silk to enswathe the prey.

Distribution: Tropical and subtropical regions.

9. **Family LYCOSIDAE** Sundevall, 1833
(Wolf spiders)

Small to very large araneomorph spiders; carapace higher in cephalic region with elongated foveae; sternum scutiform and oval; eight eyes in three rows; size unequal; legs three-clawed with spines; abdomen oval and covered with setae; palp without tibial apophysis; embolus variable; epigyne heavily sclerotised with median septum.

Lifestyle: Free living, ground dwelling, hunting spiders live in burrows. They make sheet webs with a funnel-shaped opening. Eggs are attached to spinnerets. Newly hatched spiderlings spend their life on the abdomen of the mother for days or weeks.

Distribution: Worldwide.

10. **Family MIMETIDAE** Simon, 1881
(Pirate spiders)

Small to medium-sized spiders; carapace oval with sloping thoracic area; sternum scutiform; eyes eight; with large anterior median eyes; legs long and slender with strong spines; abdomen variable, often broad and angular; male palp long with paracymbial processes; embolus strongly curved; epigyne relatively simple but heavily sclerotised.

Lifestyle: Most members are araneophagous and do not make a web. Found mainly on low vegetation or in the webs of other spiders.

Distribution: Worldwide.

11. **Family OXYOPIDEA** Thorell, 1870
(Lynx spiders)

Small to large araneomorphs; carapace anteriorly convex, longer than wide; sternum scutiform; eight eyes arranged in a hexagonal shape; legs three-clawed with prominent spines; abdomen posteriorly tapering; male palp variable with tibial apophysis and paracymbium; epigyne varies between genera; presence of a semicircular or U-shaped dark rim.

Lifestyle: Free-living, plant-dwellers; may jump toward flying prey; rarely, some species spin small webs.

Distribution: Worldwide.

12. **Family PHILODROMIDAE** Thorell, 1870
(Small huntsman spiders)

Small to medium-sized spiders; carapace flattened, foveae absent; covered with recumbent setae; sternum correlated with carapace; eight eyes in two rows equal in size; legs equal except second, second leg larger than others; abdomen covered with recumbent setae, oval, elongate or heart-shaped; male palp with small tibial apophysis; embolus variable, usually short.

Lifestyle: Free-living, agile spiders commonly found on plants or rarely epigeic.

Distribution: Worldwide.

13. **Family PHOLCIDAE** C. L. Koch, 1851
(Daddy long-leg spiders)

Very small to medium-sized spiders; carapace short, circular, sometimes reniform; fovea deep and longitudinal; sternum flat, convex and rarely truncated; six to eight eyes located the entire width of the carapace; anterior median eyes small or absent other eyes on two triads or tubercles; legs extremely long and slender; abdomen globose or cylindrical; male with very complex palp, large paracymbium, bulbus divided in to two parts; epigyne simple covered by thin sclerotized plate.

Lifestyle: Found in a variety of habitats, including caves under stone and fallen logs. Some species are synanthropic.

Distribution: Worldwide.

17. Family PISAURIDAE Sundevall, 1833
(Fishing / Nursery-web spiders)

Small to medium-sized spiders; mostly convex carapace with a deep longitudinal fovea and a nearly flat sternum. Eyes 6-8; eyes are distributed the full length of the carapace; anterior median eyes are reduced; the rest of the eyes are located as triads on relatively small stalks. Legs are long and slender; numerous spines are present on the legs. The abdomen is mostly cylindrical or globose. Male with very complicated palp; the paracymbium is relatively large with a bilobed bulb. The female epigyne is simple, located just beneath the thinly sclerotized epigynal plate.

Lifestyle: Found mostly near water bodies, females exhibit parental care. Egg sacs are carried by females by attaching to their chelicerae and will weave nursery web for the young.

Distribution: Worldwide.

14. **Family SALTICIDAE** Blackwall, 1841
(Jumping spiders)

Small to large araneomorph spiders; carapace mostly square; eye area frequently clothed with long setae; sternum variable; eyes eight in two or three rows; legs longer or stronger with two

claws with claw tufts; abdomen short to oblong or elongated in some genera; epigyne variable; male pal with tibial apophysis and femoral protuberance; embolus variable in shape and size.

Lifestyle: Diurnal, cursorial hunting spider with well-developed vision. They occupy a wide range of habitats.

Distribution: Worldwide.

15. **Family SCYTODIDAE** Blackwall, 1864
(Spitting spiders)

Small to medium-sized spiders; carapace domed towards the thoracic region; foveae absent; sternum oval with sclerotized rim with blunt apex; six eyes arranged in three widely spaced diads; abdomen broad, oval, covered with dark setae; male palp with tarsi variable; small to large bulbus; embolus with slender base; epigyne simple with two clasping holes just behind epigastric fold.

Lifestyle: Wandering spiders, found in diverse habitats. Spitting glue to capture prey. Egg sac carried in chelicerae.

Distribution: Pantropical with three cosmopolitan species.

16. **Family SPARASSIDAE** Bertkau, 1872
(Huntsman spiders)

Medium to very large sized spiders; carapace broad and oval; narrower in the eye region; foveae covered with dense layer of setae; sternum circular; longer than wide; eyes eight in two rows; posterior eyes equal in size; legs long; laterigrade with two claws; abdomen round to oval rarely elongated; palp with tibial apophysis; tegulum with embolus; epigyne conspicuous and prominently sclerotized.

Lifestyle: Nocturnal wandering spiders are found on plants, the soil surface, or in caves. Desert species burrow in sand, and some of them are synanthropic.

Distribution: Worldwide.

17. **Family TETRAGNATHIDAE** Menge, 1866
(Water Orb weavers)

Small to very large araneomorph spiders; carapace longer than wide; sternum pointed posteriorly; eight eyes in two rows: rarely on tubercle; tapetum absent in some genera; legs long and

slender; spines absent; abdomen elongated and cylindrical or round to ovoid; palp simple with movable paracymbium; tegulum spherical with coiled embolus; epigyne with epigynal plate, sometimes unsclerotized.

Lifestyle: Orb weavers with an open hub. They occupy a wide range of habitats. Webs of some genera are often horizontal above waterbodies.

Distribution: Worldwide.

18. **Family THERIDIIDAE** Sundevall, 1833
(Cob web spiders/Gum foot web spiders)

Small to medium-sized spiders; carapace variable from flat to high, broad to narrow; sternum scutiform to triangular; eight eyes in two rows encircled by a brown ring; moderately long, three-clawed legs with serrated bristles forming a comb. Abdomen variable extending beyond spinnerets; male palp without apophysis and paracymbium; embolus often filiform; Epigyne complex and variable.

Lifestyle: Construct an irregular cobweb. Found in a wide range of habitats. Most species prefer foliage-free dry twigs. They overpower the prey by biting and wrapping it in sticky silk.

Distribution: Worldwide.

19. **Family THOMISIDAE** Sundevall, 1833
(Crab spider)

Small to large sized spiders; abdomen varies from ovoid, semicircular, or elongated; sternum heart shaped; eight eyes in two rows; lateral eyes sometimes on tubercles; legs two clawed; I and II longer than III and IV; abdomen round, ovoid or elongated; male palp with ventral and retrolateral apophysis; embolus variable; epigyne sclerotized usually with hook and atrium.

Lifestyle: Wandering ambush hunters. Found predominantly on foliage and flowers. Very rarely as epigeal.

Distribution: Worldwide.

20. **Family ULOBORIDAE** Thorell, 1869
(Hackled orb web spiders/triangle web spiders)

Small to medium sized araneomorphs; carapace variable with a posterior or median swellings; sternum long, oval or triangular; eight eyes in two rows; legs three clawed with rows of trichobothria; abdomen slender with one or two humps; sometimes extending beyond spinnerets; male palp with modified palpal tibia; embolus circular, coiled, filiform, or spiny; cymbium with two apical setae; epigyne with paired or unpaired caudal projections.

Lifestyle: Constructs mostly incomplete orb webs, ranging from a section of an orb web to a single line. Overpower the prey by wrapping it in silk as a packet.

Distribution: Worldwide.

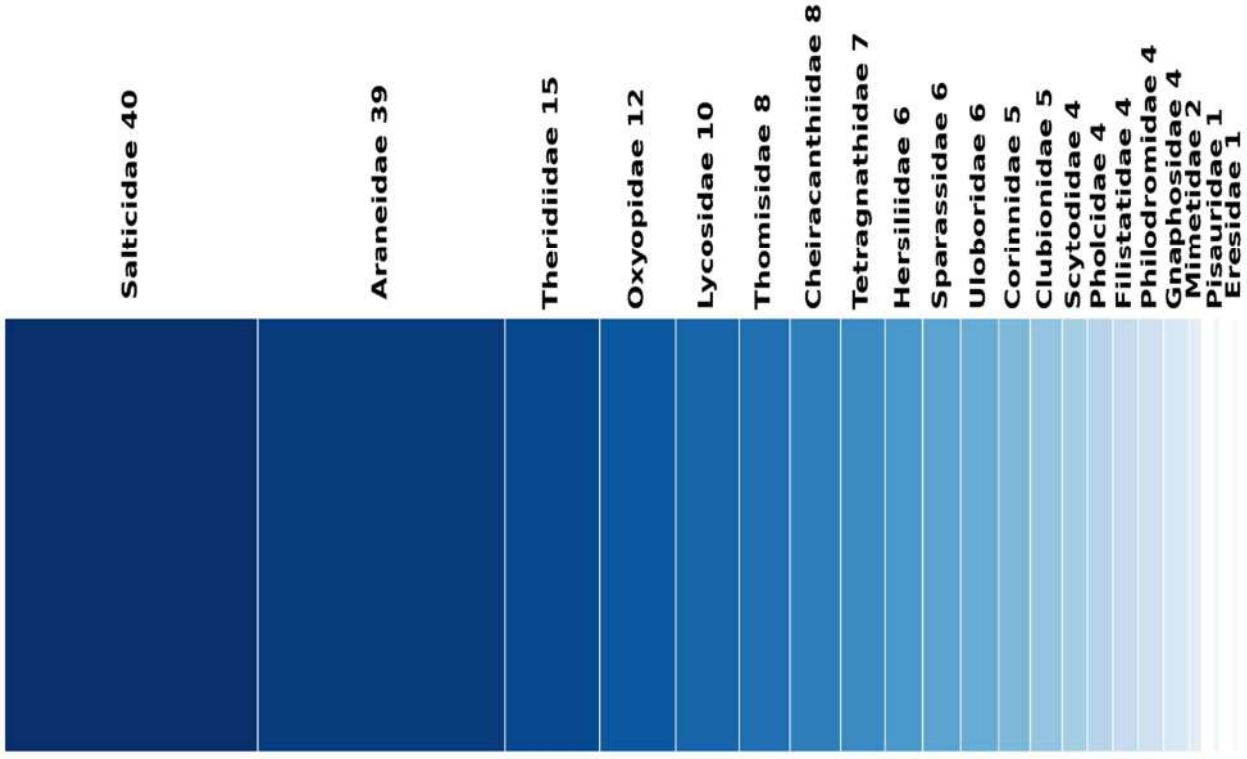


Figure 4.1.3. Species composition matrix of spiders from each family

The Species composition matrix showed Salticidae as the most dominant family with 40 species, followed by Araneidae with 39 species. Families including Theridiidae (15 species), Oxyopidae (12 species), Lycosidae (10 species), Thomisidae, Cheiracanthiidae (each with 8 species), and Tetragnathidae with 7 species exhibited moderate species composition. 6 species were identified from Hersiliidae, Sparassidae, and Uloboridae. 5 species each from Corinnidae and

Clubionidae. 4 species represent families including Pholcidae, Filistatidae, Philodromidae, and Gnaphosidae. Family Mimetidae is represented by 2 species. Pisauridae and Eresidae are the families with a single species and can be considered rare families.

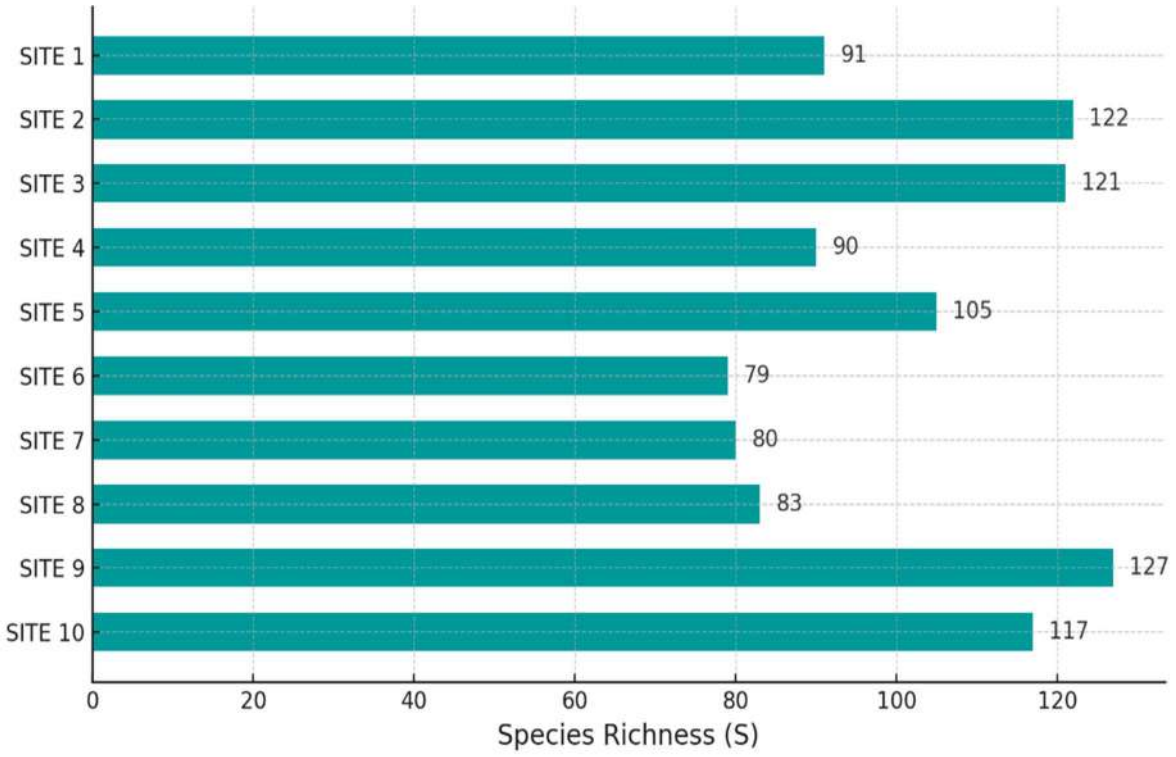


Figure 4.1.4. Horizontal bar chart showing the species richness across study sites

The horizontal bar chart shows species richness across 10 mangrove sites. From a low number of 79 species at site 6 to a peak of 127 at site 9. Sites 2 and 3 are also exhibiting a high diversity with species richness of 122 and 121, respectively. A mid-range of species richness is exhibited in sites 10 (117) and 5 (105). A lower diversity cohort is exhibited in sites 1 (91), 4 (90), 8 (83), and 7 (80).

4.2. Estimation and comparison of spiders using different biodiversity indices in different mangrove ecosystems across Kerala

The diversity patterns of spiders across 10 mangroves were measured in all dimensions, including richness, evenness, dominance, and abundance. Species richness, both observed and estimated, Shannon, Simpson, Margalef's, and Fisher's alpha were tabulated (Table 4.2.1).

Table 4.2.1. Comparative diversity indices for the spider fauna of mangroves

Site	S	H'	1-D	Chao1	Margalef's d	Evenness J'	Fisher alpha
SITE 1	91	4.108089	0.973841	91.33333	13.13439	0.910711	24.81914
SITE 2	122	4.510584	0.985718	123	16.95891	0.938918	33.40117
SITE 3	121	4.408982	0.983798	123.5455	16.75961	0.919344	32.73029
SITE 4	90	4.082644	0.975827	92.625	12.76252	0.907293	23.43002
SITE 5	105	4.218146	0.977659	105.1765	15.11318	0.906356	29.87551
SITE 6	79	4.005343	0.972876	79.125	11.48732	0.91667	20.94724
SITE 7	80	4.118171	0.97962	82	12.22042	0.939787	24.1028
SITE 8	83	4.04924	0.974062	83.125	12.28778	0.916358	23.37544
SITE 9	127	4.485792	0.98487	131.4	18.1399	0.926015	37.96418
SITE 10	117	4.47701	0.984586	117.8571	16.65451	0.940119	33.60473

Observed species richness and Chao1 estimator

Observed species richness (S) varies from 79 (site 6) to the highest value of 127 (site 9), and every other site value clusters between 90 and 122 species. The Chao1 estimator shows the estimated richness. The values of Chao1 show close values to the observed richness (S), indicating the sampling completeness. Sites 1, 5, 6, 8, and 10 showed approximately the same value. Sites 2, 3, 4, 7, and 9 showed slightly different values (Figure 4.2.1); among them, site 9 showed a considerable difference between observed and estimated richness (Table 4.2.1).

Figure 4.2.1. Combined bar chart of Observed species richness and Chao1 estimator across study sites

Diversity and Evenness metrics

A consistently high value of Shannon-Wiener diversity (H') was observed from the lowest value of site 6 (4.005) to the highest value (4.511) of site 2 (Figure 4.2.2). While Simpson's diversity index ranges from 0.973 to 0.986, it reflects the species richness and equitable abundance distribution. Pielou's evenness (J′) index emphasized this picture with values from 0.907 to 0.940 (Table 4.2.1). The result says that sites 10 and 2 are the most balanced communities regarding abundance and evenness (Figure 4.2.3).

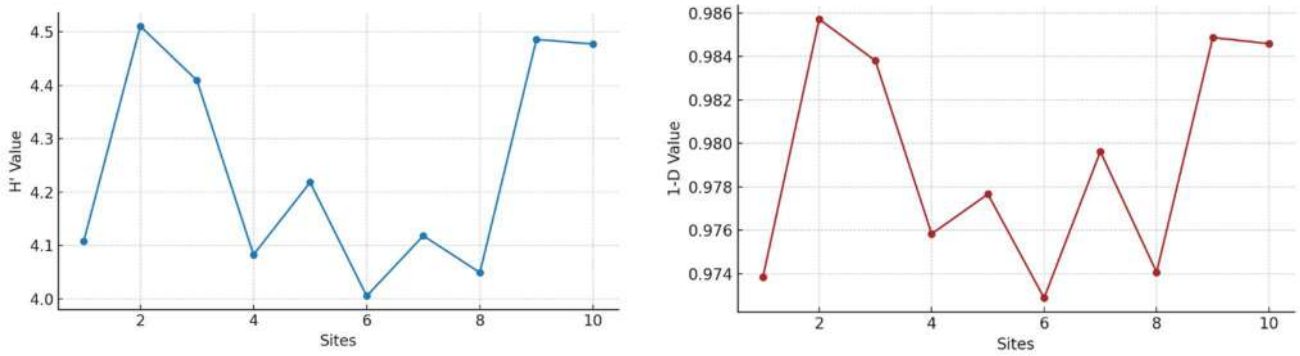


Figure 4.2.2. Variation in the Shannon diversity index and Simpson's diversity index across the study sites

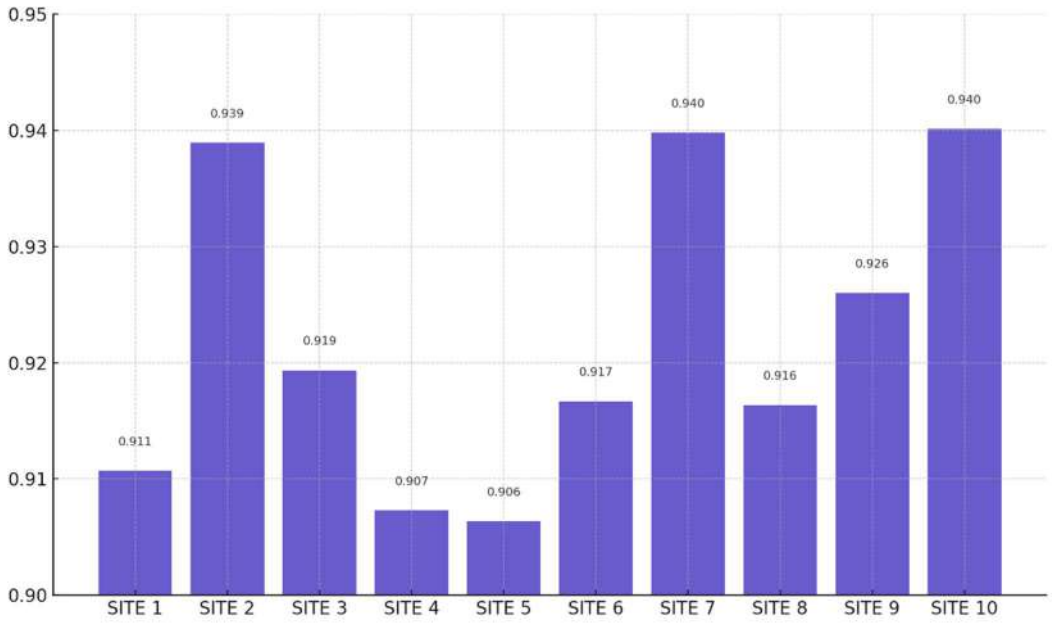


Figure 4.2.3. Bar chart showing Pielou's index across study sites

Margalef's Richness and Fisher's α

Margalef's richness (d) underscores that site 9 has the richest community (d=18.14) and site 6 has the poorest community (d=11.49). Fisher's α reinforced this pattern by showing the highest values at site 9, 37.96, and the lowest value at site 6, which is 20.95 (Figure 4.2.4). These metrics emphasize that Site 9 has the greatest number of species, but also sustains an evenly distributed community.

Figure 4.2.4. Combined bar chart showing Margalef's Richness and Fisher's α across study sites

Table 4.2.2. Shapiro-Wilk Test results for abundance distribution across study sites

Site	W	p-value
SITE 1	0.5073	0.000739
SITE 2	0.7372	0.000405
SITE 3	0.7131	0.000725
SITE 4	0.5694	0.000149
SITE 5	0.5746	0.000195
SITE 6	0.5207	0.000138
SITE 7	0.6495	0.000122
SITE 8	0.5384	0.000363
SITE 9	0.7198	0.000115
SITE 10	0.6932	0.000189

All the study sites showed strong non-normal distribution. The Shapiro-Wilk W statistic value ranged from the lowest 0.073 of site 1 to 0.7372 of site 2, associated with a very small p-value (all $p < 0.001$). The values deviated significantly from the normal distribution. All P values

show a below-threshold value deviating from the Gaussian distribution, resulting in the rejection of the null hypothesis of normality. The highest value of site 2 (W=0.7372) yielded a p-value of 0.000405. The spider assemblage at all sites is greatly skewed, suggesting non-parametric approaches to understanding the diversity dynamics.

Table 4.2.3. Statistical comparison of abundance between sites by the Kruskal-Wallis test

Comparison	H	df	p-value
Abundance across 10 sites	53.87	9	0.00000319

Kruskal-Wallis H test showed a striking difference in spider abundance among the 10 study sites (H = 52.8, df = 9, p = 0.00000319). The median number of spiders is demonstrably unequal from one site to another ($p < 0.001$). Some mangrove sites have greater abundance, and some have lower abundance, and the variation is significantly high. The p-value makes the suggestion of heterogeneity, confirming that the spider abundance varies across sites.

Table 4.2.4. Pairwise comparison by Dunn's post hoc test with the Bonferroni error control method

Pair of sites	Z-statistic	p-value
site 2 vs site 6	3.857	0.005
site 2 vs site 7	4.448	0.0004
site 2 vs site 8	3.978	0.003
site 7 vs site 9	–3.752	0.008
site 7 vs site 10	–3.572	0.016
site 8 vs site 9	–3.282	0.046

Dunn's post hoc pairwise comparison with a Bonferroni adjustment test was performed for all 45 possible pairs. The major differences are given between the following pair of sites. After Bonferroni's correction, those sites significantly differed in the species abundance distribution. Site 2 shows more spider species and sites 6, site7, and 8 (Z=3.857, p=0.005; Z=4.448, p=0.0004; Z=3.978, p=0.003, respectively). Site 7 shows a lower number of spiders than sites 9 and 10 (Z=–

3.752, p=0.008; Z=–3.572, p=0.016). Likewise, site 8 has a less abundant community of spiders than site 9, where Z=–3.282, and the p=0.046.

The alpha diversity metrics (Richness [0D], Shannon [1D], and Simpson [2D]) for each site, estimated using both Chao1/Jost and Observed methods, are summarized in Table 4.2.5.

Table 4.2.5. Comparison of observed and estimated diversity by Hill Numbers (Chao1/Jost vs Observed) for study sites

Site	Estimator	0D (Richness)	1D (Shannon)	2D (Simpson)
SITE 1	Chao1/Jost	91.56	60.83	38.23
	Observed	91	60.83	38.23
SITE 2	Chao1/Jost	123.39	90.97	70.02
	Observed	122	90.97	70.02
SITE 3	Chao1/Jost	124.2	82.19	61.72
	Observed	121	82.19	61.72
SITE 4	Chao1/Jost	93.5	59.3	41.37
	Observed	90	59.3	41.37
SITE 5	Chao1/Jost	105.28	67.91	44.76
	Observed	105	67.91	44.76
SITE 6	Chao1/Jost	79.29	54.89	36.87
	Observed	79	54.89	36.87
SITE 7	Chao1/Jost	83.12	61.45	49.07
	Observed	80	61.45	49.07
SITE 8	Chao1/Jost	83.29	57.35	38.55
	Observed	83	57.35	38.55
SITE 9	Chao1/Jost	132.14	88.75	66.09
	Observed	127	88.75	66.09
SITE 10	Chao1/Jost	118.33	87.97	64.87
	Observed	117	87.97	64.87

The estimated (Chao1/Jost) and observed values closely matched all over the sites. It ranges from 79.29 (site 6) to 132.14 (site 9). The values of Chao1/Jost observed were almost the same slight variation in estimated and observed values seen in site 3 (124.2 -121), site 7 (83.12-80), and site 9 (132.14 – 127), respectively. The effective Shannon diversity (1D) varies from 54.89 (site 6) to 90.97 (site 2). The effective number of dominant species by the reciprocal Simpson's index (2D) shows the highest value for site 2, 70.02, whereas site 6 has the lowest value of -36.87.

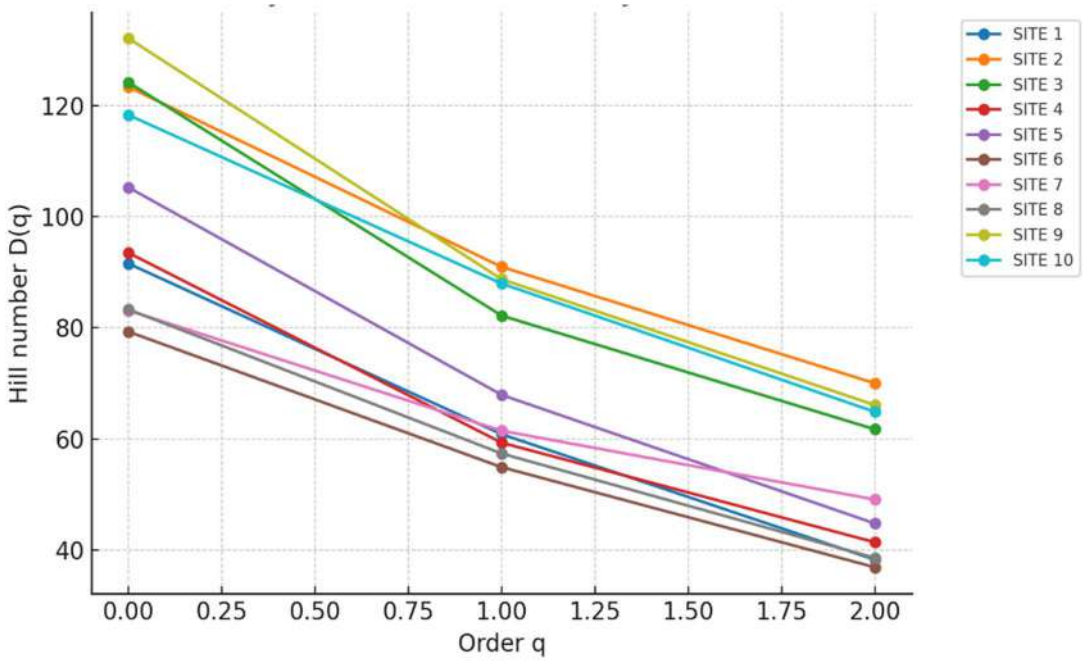


Figure 4.2.5. Diversity profile curves in different study sites based on Chao1/Jost estimators

The figure – diversity profile curve (Hill numbers D_0, D_1, D_2) suggests that site 9 has the highest estimated richness (D=132.14) yet shows a 50 % decline by q = 2 (D_2 = 66.09), indicating considerable dominance. But, site 2 indicates great richness (D_0 = 123.39), with significant evenness (D_1 = 90.97; D_2 = 70.02), suggesting a healthy community in terms of structure. Site 6 shows the lowest diversity at all orders (D_0 = 79.29; D_2 = 36.87) and the poorest species richness and evenness.

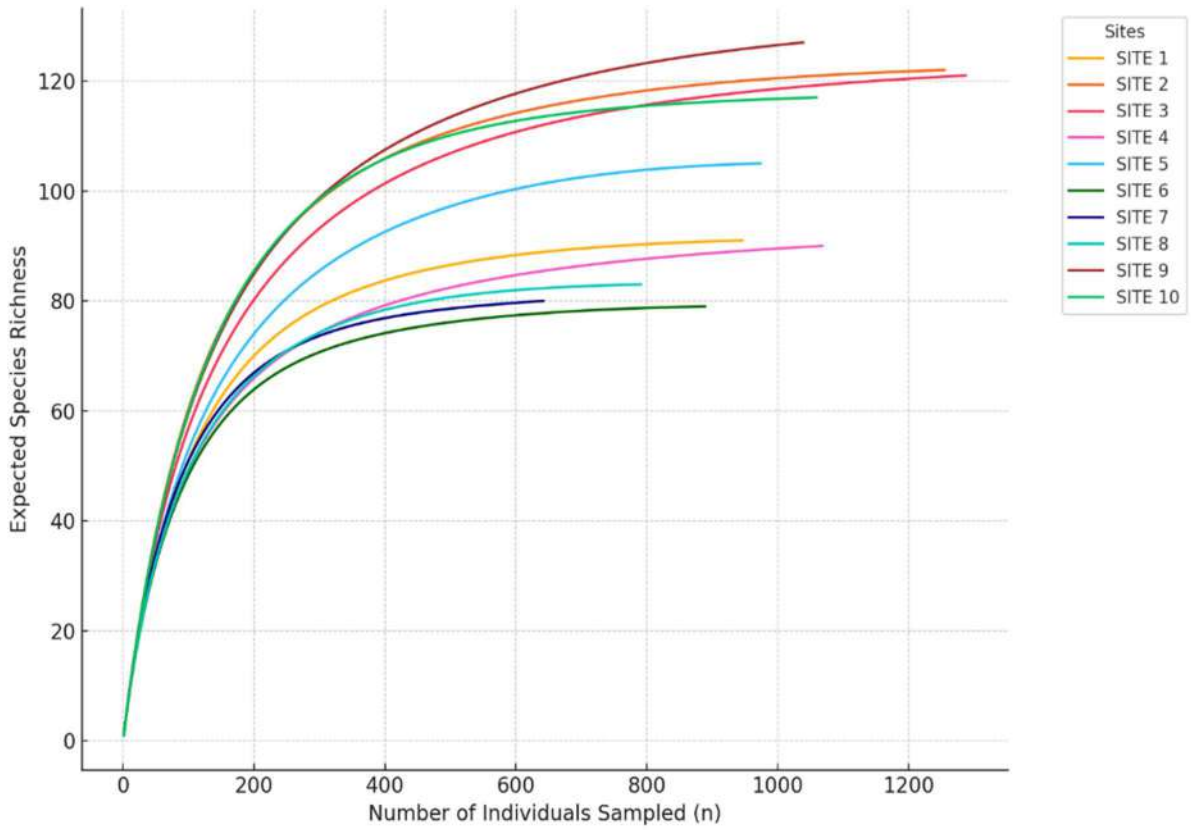


Figure 4.2.6. Combined Rarefaction curve of 10 study sites

The rarefaction reveals distinct richness and sampling efficiency trajectories. Site 9 exhibits the steepest and highest curve, plateauing at ≈ 130 species, showing the high species richness and sampling completeness. Sites 2 and 3 also follow this pattern of high richness and sampling efficiency levelling off around 120-12 species. Site 10 also shows high species richness, but a gentler slope, indicating further sampling. Sites 5,8, and 4 reach plateaus between 90-105 species with clear asymptotes indicating sufficient sampling. Site 1 asymptote near 90 species. Sites 6 and 7 reach the plateau at 75 -80 species, showing a low species richness and adequate sampling.

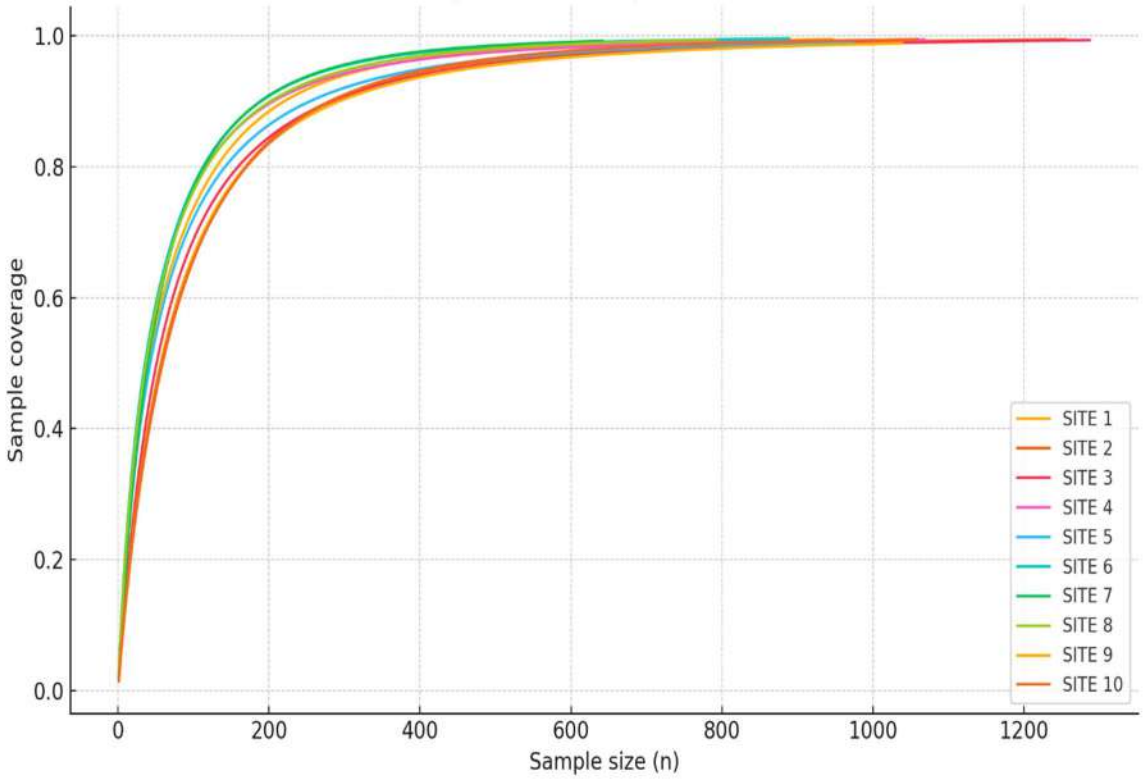


Figure 4.2.7. Coverage-Standardized Completeness Profile curves of the 10 study sites

The Coverage-based completeness curve is used in ecology to estimate how completely a community has been sampled based on the coverage of the sample rather than the sample size. The goods coverage estimate for the sampling sites ranges from 0.9885 (site 9) to 0.9978 (site 6), indicating that the individual collected from 98.85 % to 99.78 %. Sites 6 and 7 hit 95% coverage by approximately 200 individuals. These communities are skewed due to some abundant species, therefore quickly reaching the asymptote. While sites 2 and 9 took more than 500 species to reach the threshold, this indicates the presence of some undiscovered cryptic singletons. In general, all the curves reached asymptotes, representing a good sampling effort.

Table 4.2.6. Pairwise Bray-Curtis dissimilarity analysis of the most and least similar pairs of sites

Statistic	Site pairs	Values
Highest dissimilarity	Site 1 & 4	0.557
Lowest dissimilarity	Site 7 & 8	0.189

Calculated the Bray-Curtis dissimilarity index to measure the differences in the community structure driven by the dominant species. Site 1 and site 4 showed the highest dissimilarity with the minimum number of shared species where whereas site 7 and site 8 shared the most species and showed high compositional similarity.

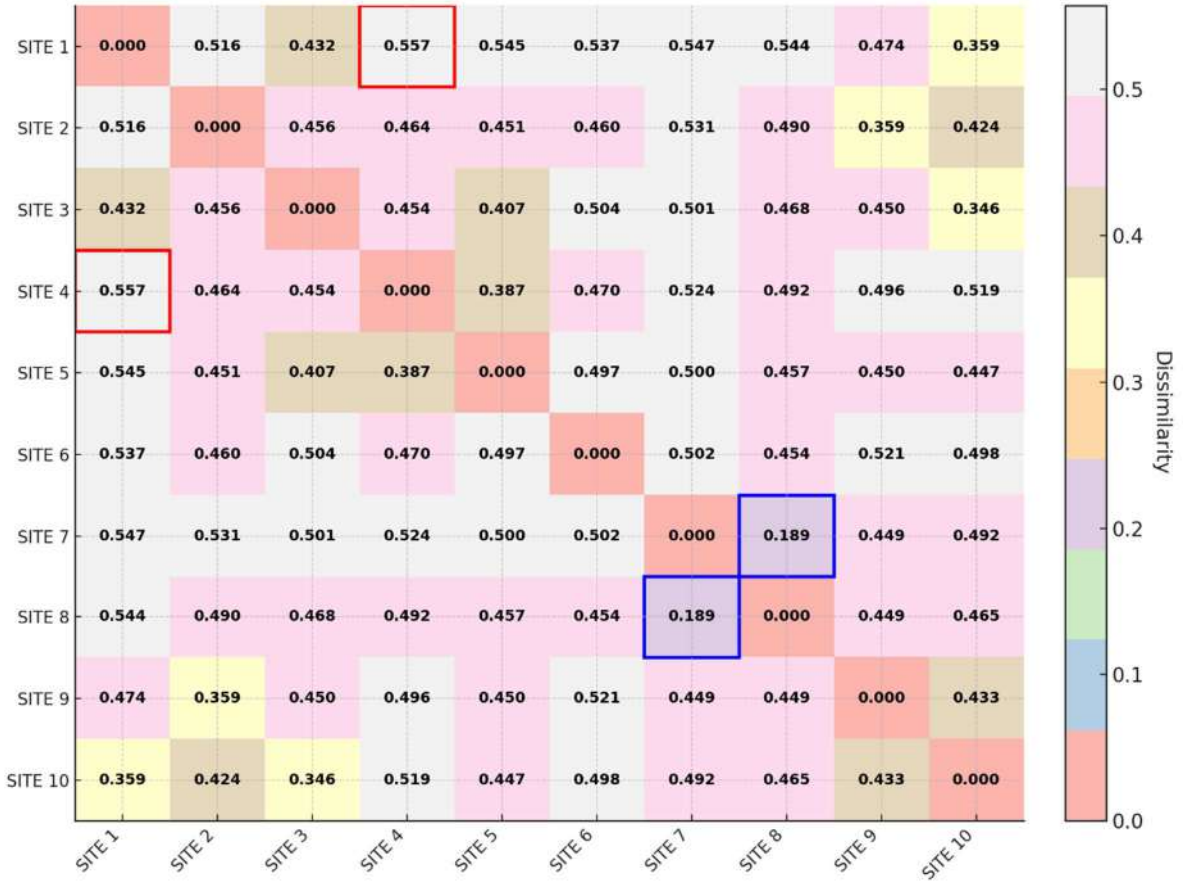


Figure 4.2.8. Bray-Curtis dissimilarity heatmap of every pair of study sites

Calculating the Bray-Curtis dissimilarity index of the study sites resulted in a higher value between sites 1 and 4. The value 0.0557 indicates that approximately 56 % of the total abundance would not overlap. Suggesting sites 1 and 4 support more than half of the dominant taxa. In contrast

lowest dissimilarity is shown by sites 7 and 8 (0.0189), indicating roughly 19 % of their abundance distribution differs, and 81 % of the community overlaps.

Table 4.2.7. Pairwise Jaccard dissimilarity index of the most and least similar pairs of sites

Statistic	Site pairs	Values
Highest dissimilarity	Site 2 & 6	0.585
Lowest dissimilarity	Site 7 & 8	0.060

Sites 2 and 6 share only 41.5% of their spider species turnover, making them the most compositionally divergent pair. Conversely, sites 7 and 8 exhibit a Jaccard similarity of 94, % near identical assemblage.

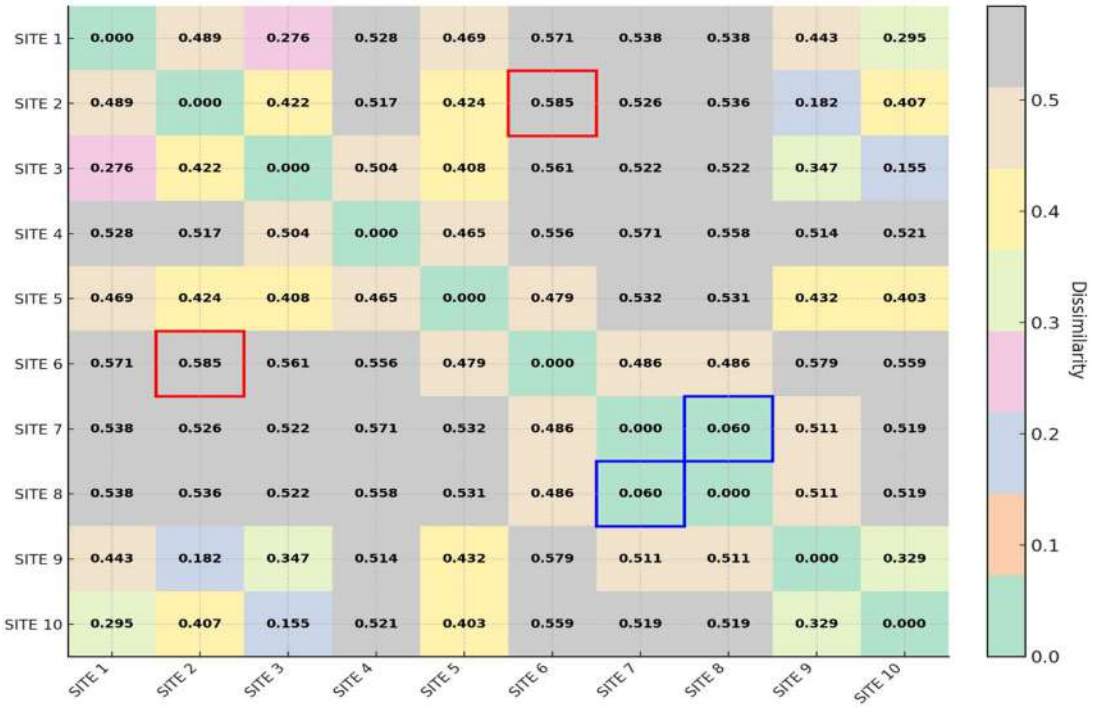


Figure 4.2.9. Jaccard dissimilarity heatmap of every pair of study sites

The Jaccard dissimilarity index of 0.585 between sites 2 and 6 shows nearly 59 % of the species do not overlap, with only 41.5 % of the species being the same in both study sites. By contrast, the lowest value of 0.060 between sites 7 and 8 shows that they share about 94% of the

same species in both habitats. Only 6% of the taxa differ in both sites, indicating maximum overlapping and minimum composition turnover.

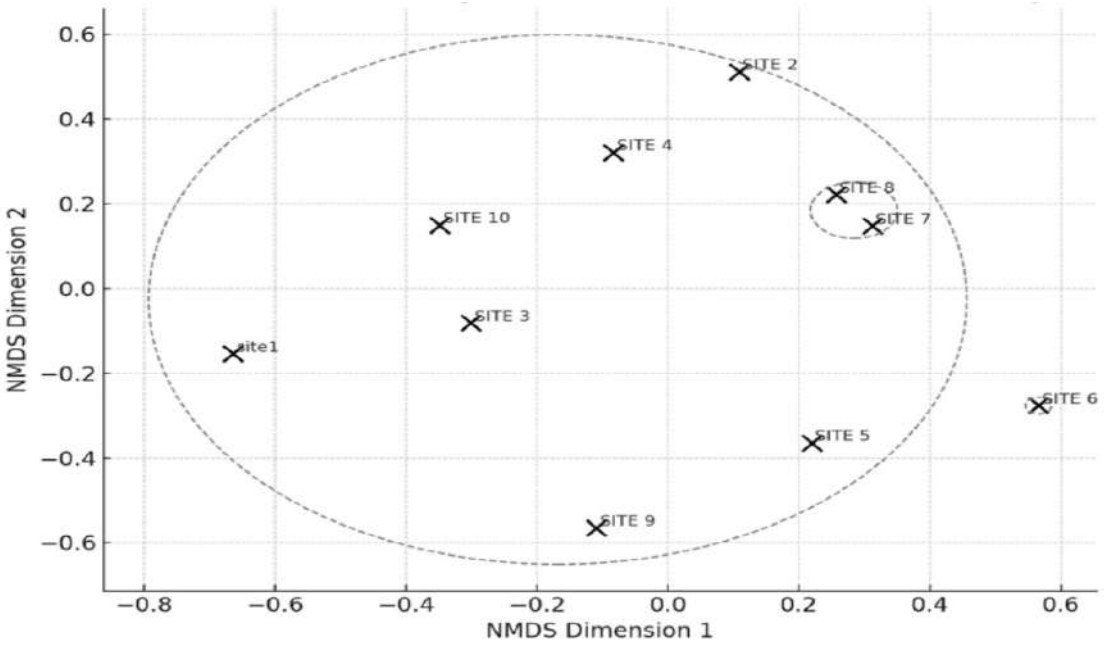


Figure 4.2.10. NMDS plot of spider assemblage across study sites with 95 % confidence ellipse

NMDS ordination of spider community across the 10 study sites based on Bray-Curtis dissimilarity shows a clear compositional difference. Most of the sites, which are inside the ellipse, show an overall similarity, but the distance between each point indicates that each site has a community shift. Sites 7 and 8 are included in a smaller, distinct cluster showing a similar assemblage of spiders. Site 6 is distinctly placed, indicating uniqueness in the community assemblage.

Table 4.2.8a. PERMANOVA of spider assemblage regarding Leaf Area Index of High Vegetation

Source	df	SS	MS	pseudo-F	R^2	p-value
LAI_HV	1	0.1188	0.1188	2.426	0.1188	0.011
Residual	18	0.8812	0.04896	—	0.8812	—
Total	19	1.0000	—	—	1.0000	—

PERMANOVA was conducted to find the statistical significance of the Leaf Area Index of High Vegetation on the spider assemblage. The significant $p = 0.011 < 0.05$ value indicates that the Leaf Area Index of High Vegetation contributes to the spider assemblage. However, the relatively modest value of $R^2 = 0.1188$ suggests that the High vegetation leaf area index has influenced 11.88 % of the spider assemblage, remaining 88.12 % not influenced by that variable. The pseudo-F statistics (2.426) echo a moderate distinction in spider community composition across the mangrove floral complexity. PERMANOVA test results the spider assemblages across the study sites are sufficiently different to be statistically significant.

Table 4.2.8b. PERMANOVA of spider assemblage regarding Leaf Area Index of Low Vegetation

Source	df	SS	MS	pseudo-F	R^2	p-value
LAI_LV	1	0.1112	0.1112	2.251	0.1112	0.011
Residual	18	0.8888	0.04938	—	0.8888	—
Total	19	1.0000	—	—	1.0000	—

The PERMANOVA analysis resulted in a p-value of 0.011, demonstrating the statistically significant effect of low vegetation – Leaf Area Index on spider community in the mangroves. The R^2 (0.1112) value indicates there is only a subtle variation by 11.12 % of the total spider assemblage. The pseudo-F statistics value suggests that the variation between groups is 2.25 times greater than within groups, indicating a moderate community difference along the lower vegetation complexity.

Table 4.2.8c. PERMANOVA of the spider assemblage regarding Canopy cover

Source	df	SS	MS	pseudo-F	R^2	p-value
Canopy Cover	1	0.1256	0.1256	2.584	0.1256	0.009
Residual	18	0.8744	0.04858	—	0.8744	—
Total	19	1.0000	—	—	1.0000	—

PERMANOVA analysis with the canopy cover on spider diversity across the study sites ended up with a statistically significant p-value of 0.009. The value of $R^2 = 0.1256$ indicates that canopy cover is the most influential vegetation variable examined. The pseudo-F statistics value, 2.584, indicates that variation between groups exceeds within-group variation by 2.58, demonstrating a strong community distinction with the canopy cover percentage.

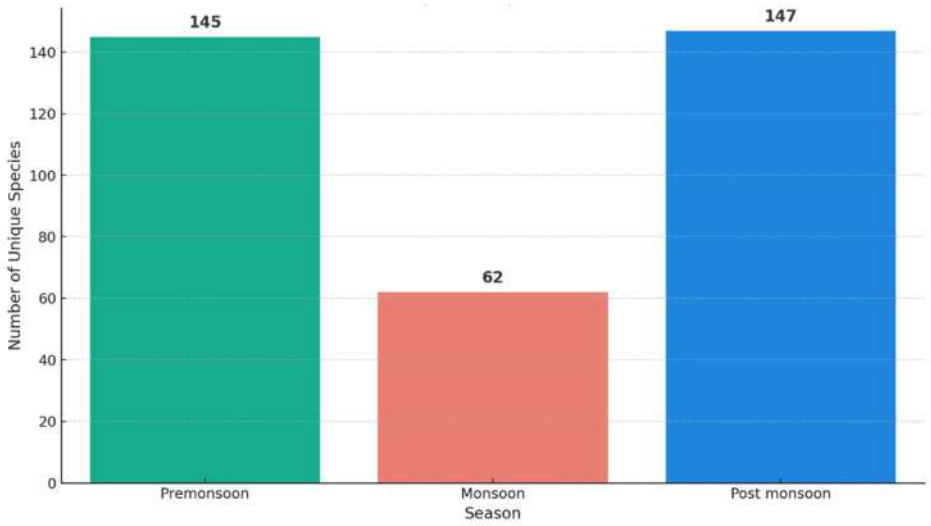


Figure 4.2.11. Bar chat showing seasonal composition of spiders across three seasons

Of all the 191 species identified during the major seasonal windows, pre-monsoon, monsoon, and post-monsoon. 32 species were found in all seasons, which is about 16.8% of the total species composition. Season-wise species composition visibly varies across the three seasons. The post-monsoon period is the richest, with 147 species, immediately followed by the pre-monsoon period with 145 species, but a significant drop in the species number was observed during the monsoon. Only 62 species, which is 32.46 % of the total collection.

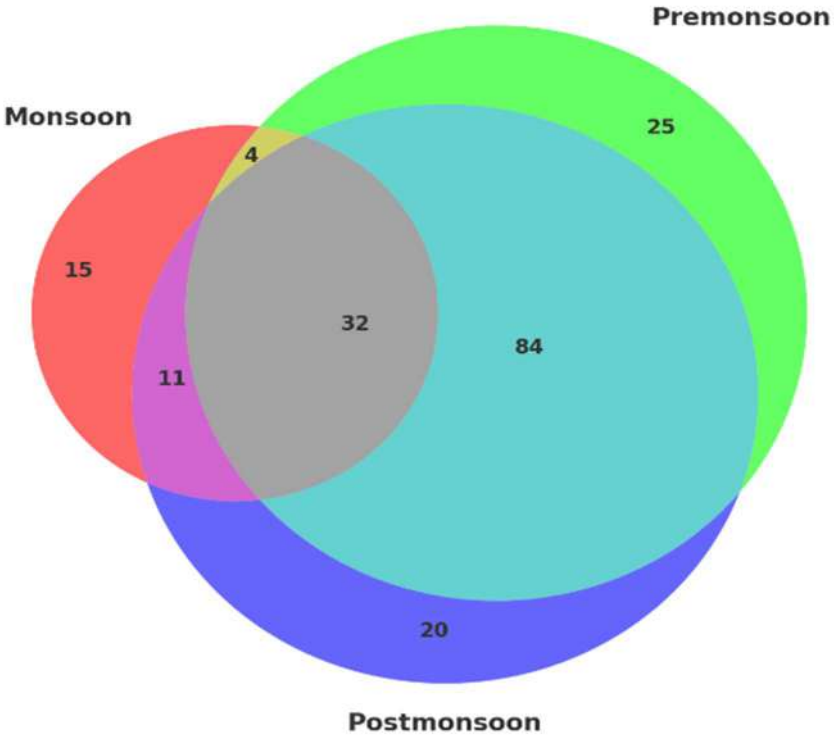


Figure 4.2.12. Venn diagram showing seasonal overlap of spiders across the three seasons

The seasonal overlap of spider species is depicted by a Venn diagram. 32 species form the core species assemblage found in all three seasons. The richest number of species is shared by the pre-monsoon and post-monsoon seasons, which is 84. Species found exclusively during pre-monsoon is 25, monsoon is 15, and the post-monsoon is 20. Pre-monsoon and monsoon share only 4 species. monsoon and post-monsoon by 11 species.

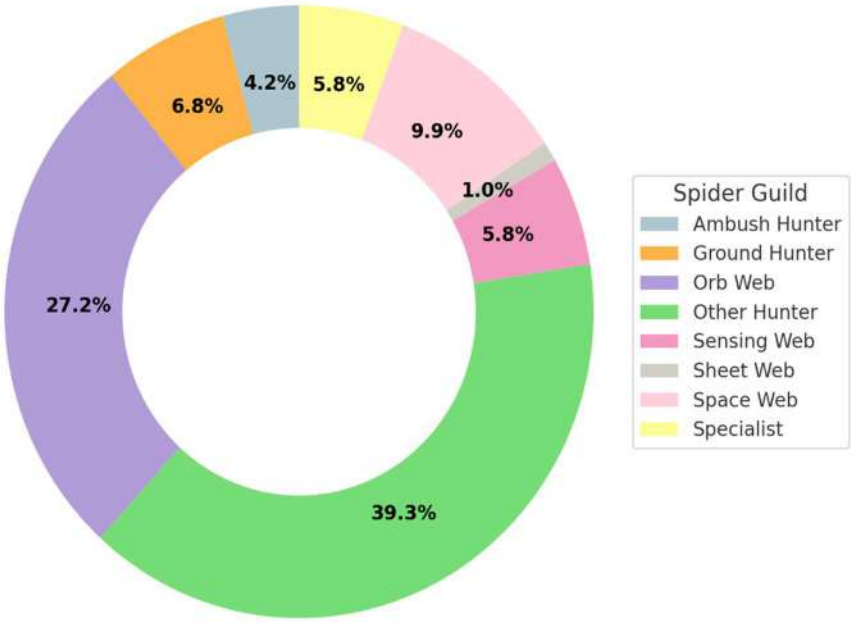
4.3. Guild composition of spiders in mangroves

The guild family table shows a clear picture of the hunting strategies among the spider assemblage in the study sites. Orb weavers are represented by three families- Araneidae, Tetragnathidae, and Uloboridae. Ground hunters by Gnaphosidae and Lycosidae. Hersiliidae and Filistatidae are the families in the sensing web guild. The sheet web guild includes three families, Pholcidae, Pisauridae, and Eresidae. Specialists include Corinnidae, Mimetidae, and Philodromidae. Other hunters consist of 6 families and are the largest guild in the study. Oxyopidae, Clubionidae, Cheiracanthiidae, Sparassidae, Scytodidae, and Salticidae are the

families that make up the guild of other hunters. Space web and ambush hunters are the two guilds represented exclusively by Theridiidae and Thomisidae, respectively (Table 4.3.1).

Table 4.3.1. Guild composition of spiders in the study sites

SL. No	Guild	Families
1	Orb web	Araneidae, Tetragnathidae, Uloboridae
2	Ambush hunters	Thomisidae
3	Ground hunters	Lycosidae, Gnaphosidae
4	Sensing web	Hersiliidae, Filistatidae
5	Other hunters	Oxyopidae, Clubionidae, Cheiracanthidae, Sparassidae, Scytodidae, Salticidae
6	Sheet web	Eresidae, Pisauridae
7	Space web	Pholcidae, Theridiidae
8	Specialist	Corinnidae, Mimetidae, Philodromidae



4.3.1. Percentage guild composition in mangroves of Kerala

The percentage guild composition shows that the dominant guild is other hunters, constituting about 39.3 % of the total guilds in the study area. 27.2 % are orb web builders. Space web builders (7.9 %), ground hunters (6.8 %), specialists (5.8 %), and sensing web builders (5.8 %) are the modest guilds found during the study. Two rare guilds in the study sites are mabush hunters (4.2 %) and sheet web builders (3.1 %). Orbweb builders and other hunters together contribute 66.5 % in the entire study. Web builders together contributes 43.9 % and 50.3 % of them were hunters and 5.8 % were specialists.

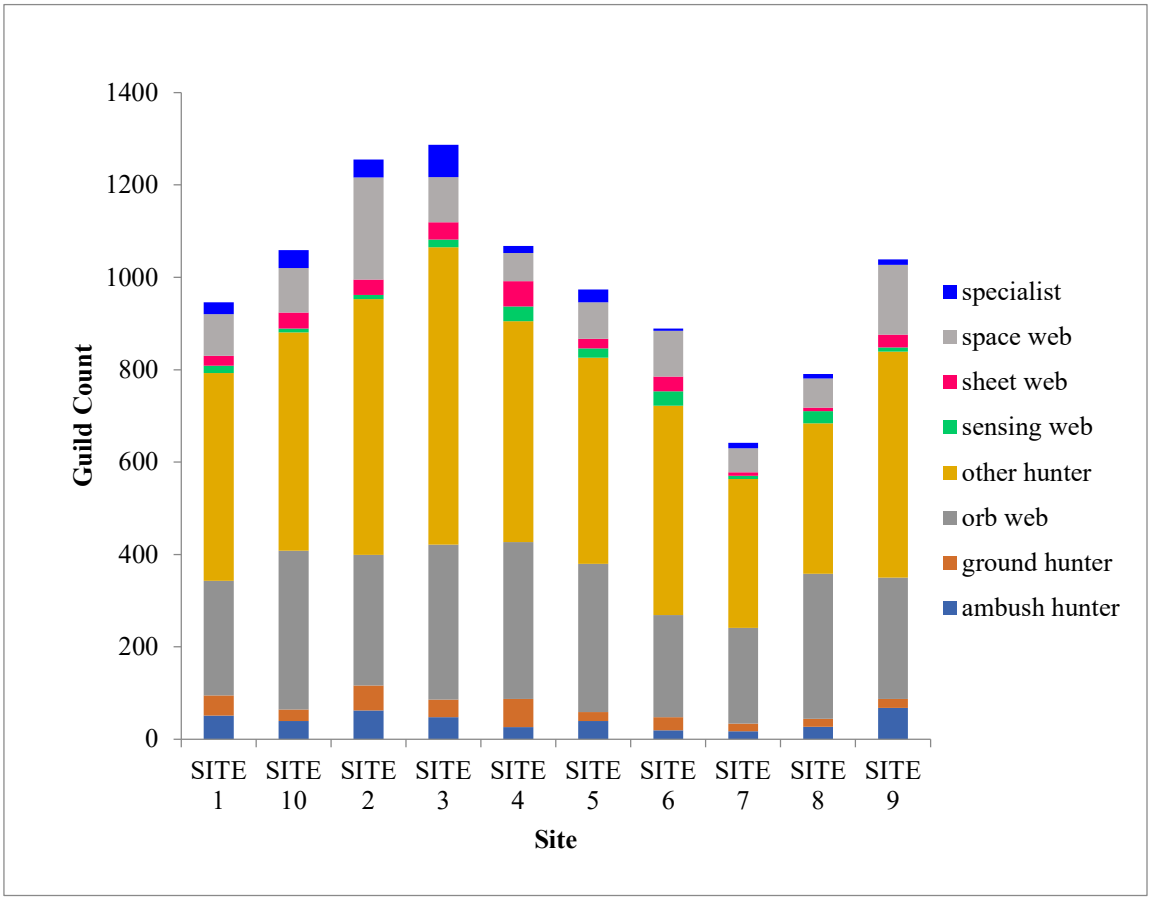


Figure 4.3.2. Stacked bar chart of guilds across 10 study sites

The stacked bar chart of guilds across 10 study sites shows the site-level contrast in functional diversity. The true guild hotspot is site 3 with approximately 1300 individuals. A high number of other hunters, space web builders, orb weavers, and specialists make site 3 as functionally diverse. Sites 2 and 9 also follow closely as site 3. Each site has a robust number of

other hunters (≈550 and ≈490, respectively) and orb weavers (≈280 and ≈330). In contrast to this site, 7 and 8 have the lowest guild counts. The two minor guilds with negligible counts are specialist and sheet web builders across all sites.

4.4. Endemism in mangrove ecosystems

Site-specific endemism in the selected study sites is striking. The confinement of taxa to individual habitat patches ranged from 1 species to 6, underscoring the heterogeneity of spider assemblages across the study sites. The list of site-specific endemic species is given in Table 4.4.1.

Table 4.4.1. Site-specific endemic species from each study site

Site	Site-specific endemics
SITE 1	None
SITE 2	*Cheiracanthium* sp. 3 *Castianeria* sp. 2 *Curubis* sp. 2 *Cyrtarachne* sp. 1 *Cyrtophora citricola* *Scytodes thoracica*
SITE 3	*Cheiracanthium aizwalense* *Lycosa* sp. 3 *Mimetus* sp. 1 *Psellonus* sp. 1
SITE 4	*Acusilas coccineus* *Cheiracanthium poonaense* *Pritha insularis*
SITE 5	*Thelacantha* sp. 1 *Cheiracanthium indicum* *Hyptiotes indicus*
SITE 6	*Lycosa mackenziei* *Scytodes pallida*
SITE 7	*Hamataliwa* sp. 1
SITE 8	*Filistata* sp. 1 *Pritha nana*
SITE 9	*Drassodes* sp. 2
SITE 10	*Lycosa* sp. 2

A site-specific, endemic species inventory is generated. Species exclusive to a single site are tabulated. Site 2, with 6 species, was the hotspot of site-specific endemism. *Cyrtophora citricola,*

Scytodes thoracica, Cheiracanthium sp. 3.3, *Castianeria* sp. 2, *Curubis* sp. 2, *Cyrtarachne* sp. 1 were exclusive to site 2. Site 3 has 4 exclusive species: *Cheiracanthium aizwalense, Lycosa* sp. 3, *Mimetus* sp. 1, *Psellonus* sp1.1. *Acusilas coccineus*, *Cheiracanthium poonaense,* and *Pritha insularis* are the three species from site 4. Site 5 also has three regional endemic species: *Thelacantha* sp.1, *Cheiracanthium indicum,* and *Hyptiotes indicus*. Study sites 6 and 8 each host two distinct species: *Lycosa mackenziei* and *Scytodes pallida* at Site 6, and *Filistata* sp. 1 and *Pritha nana* at Site 8. Three sites, only one species earned the status of site-specific endemism: *Hamataliwa* sp. 1 from site 7, *Drassodes* sp. 2 from site 9, and *Lycosa* sp. 2 from site 10.

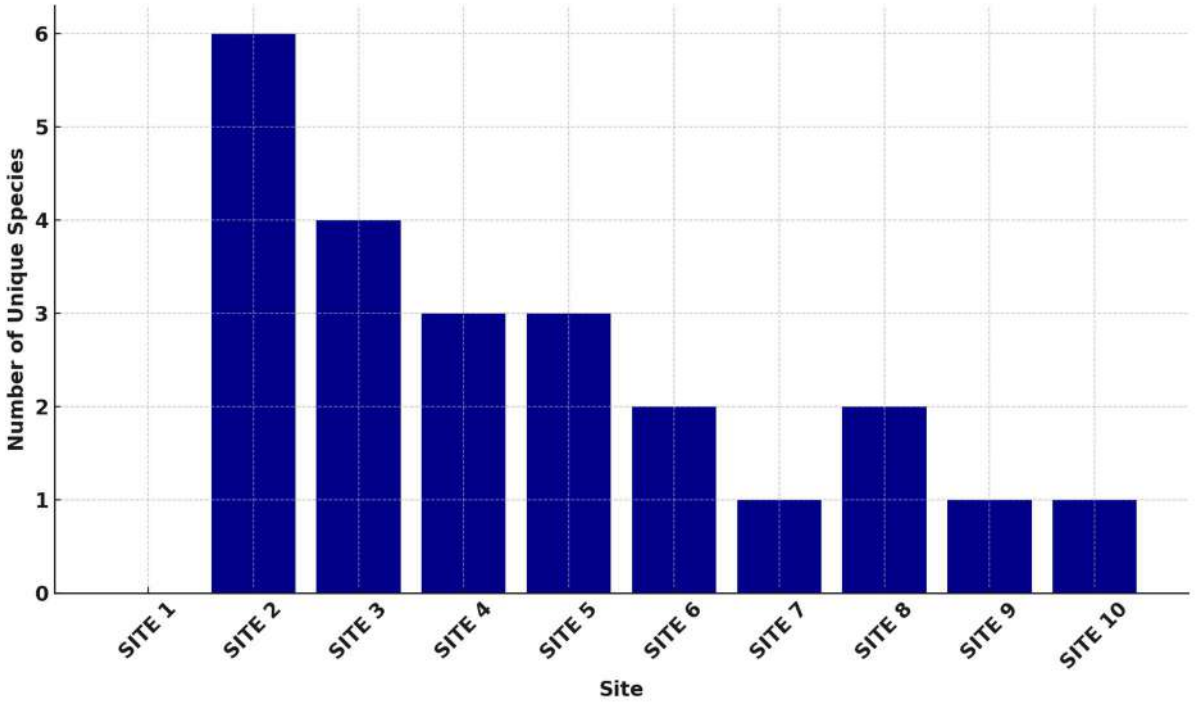


Figure 4.4.1. Bar chart showing site-specific endemism

The bar chart shows a mosaic pattern of the number of site-specific endemic species across 10 study sites. Site 2 is observed as the epicenter of micro-endemic richness (n=6). Site 3 also hosts 4 unique species. Sites 4 and 5(n=3) moderate count of site-specific-endemic species. 1 to 2 local endemic species counted at sites 6,7,8,9, and 10. Meanwhile, no site-specific endemic species were observed at site 1.

Table 4.4.2. Site-wise Weighted Endemism (WE) and Corrected Weighted Endemism (CWE) in the study sites

Site	Richness (S)	WE	CWE	WE p-value	CWE p-value
SITE 1	91	13.628	0.150	1.000	0.999
SITE 2	122	26.078	0.214	0.002	0.039
SITE 3	121	23.793	0.197	0.019	0.243
SITE 4	90	18.882	0.210	0.559	0.070
SITE 5	105	20.360	0.194	0.264	0.331
SITE 6	79	16.307	0.206	0.910	0.104
SITE 7	80	12.298	0.154	1.000	0.995
SITE 8	83	13.774	0.166	0.991	0.952
SITE 9	127	25.199	0.198	0.007	0.243
SITE 10	117	20.682	0.177	0.226	0.756

The Weighted Endemism (WE) and Corrected Weighted Endemism (CWE) are calculated via a range size constrained randomization test. The result reveals a scattered pattern of single-site endemic species across the study sites. Site 2 is recorded as the undeniable endemism hotspot with the highest number of WE (26.078) and CWE (0.214), both satisfying a significant p-value, 0.002 and 0.039, respectively. Sites 9 and 3 also show the occurrence of site-specific endemic species, where the p-values of WE are 0.007 and 0.019. But the CWEp of sites 9 and 3 has no significance, showing that the endemism is driven by species richness rather than range restriction. The rest of the study sites have no significant p-values; hence, no claim of endemism.

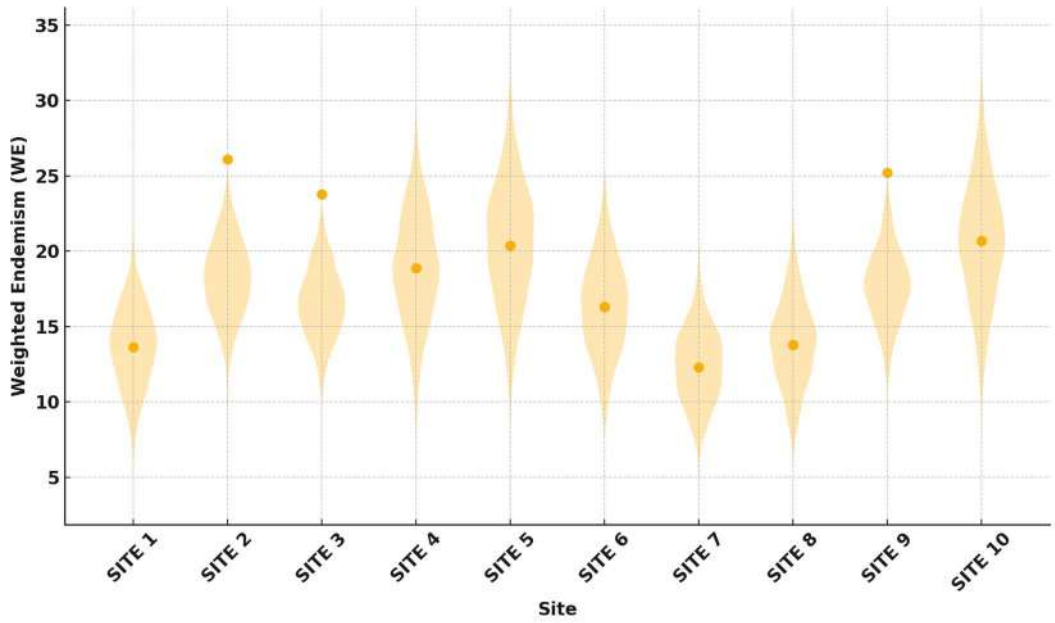


Figure 4.4.2. Violin plot of the Weighted Endemism (WE) across the study sites

The plot indicates a strong heterogeneity in WE across the study sites. Site 2 was highest with a high WE of ≈ 26.1 and potential site endemism. Elevated WE of sites 3 and 9, but a slimmer violin indicating more concentrated rarity credits than other sites. All other sites with WE value ranging from 12.298 to 20.682 indicate a scope of rarity but with species range restriction.

4.5. Habitat association of spiders in mangroves

15 true mangrove species falling under 9 genera and 6 families, along with 33 mangrove associates found across the 10 study sites. Although multiple mangrove species occur at the study sites, some genera dominate. The study sites are divided according to the presence of dominant mangrove taxa. These species

Table 4.5.1. Mangroves and mangrove associates found across the study sites

TRUE MANGROVES	MANGROVE ASSOCIATES
Aegiceras corniculatum	*Acanthus ilicifolius*
	Acrostichum aureum
Avicennia marina	*Annona glabra*
	Ardisia elliptica
Avicennia officinalis	*Ardisia solanacea*
	Barringtonia racemosa

	Caesalpinia nuga
Bruguiera cylindrica	*Calamus rotang*
	Calophyllum calaba
Bruguiera gymnorrhiza	*Calophyllum inophyllum*
	Cerbera odollam
Bruguiera sexangular	*Clerodendron inerme*
	Crinum defixum
Ceriops tagal	*Derris scandens*
	Derris trifoliata
Excoecaria agallocha	*Dolichandrone spathacea*
	Entada sp.
Excoecaria indica	*Flagellaria indica*
	Hibiscus tiliaceus
Kandelia candal	*Holigarna arnottiana*
	Ipomoea pes-caprae
Lumnitzera racemosa	*Lannea coromandelica*
	Melastoma malabathricum
Rhizophora apiculate	*Morinda citrifolia*
	Pandanus tectorius
Rhizophora mucronate	*Pongamia pinnata*
Rhizophora mucronata *Sonneratia alba*	*Premna latifolia*
	Premna serratifolia
	Scaevola sericea
Sonneratia alba *Sonneratia caseolaris*	*Stenochlaena palustris*
	Syzygium travencoricum
Sonneratia caseolaris	*Terminalia catappa*
	Thespesia populnea

Figure 4.5.1a. Major mangrove plants found across the study sites: A- *Aegiceras corniculatum*, B- *Avicennia marina,* C- *Avicennia officinalis,* D- *Bruguiera cylindrica,* E- *Bruguiera gymnorhiza,* F- *Bruguiera sexangula*

Figure 4.5.1b. Major mangrove plants found across the study sites: G- *Ceriops tagal*, H- *Excoecaria agallocha*, I- *Rhizophora mucronata*

Figure 4.5.2a. Major mangrove associates across study sites: A- *Acanthus ilicifolius,* B- *Acrostichum aureum,* C- *Barringtonia racemosa,* D- *Calophyllum calaba*

Figure 4.5.2b. Major mangrove associates across the study sites: E- *Cerbera odollam*, F- *Volkameria inermis*, G- *Crinum viviparum*, H- *Derris trifoliata*, K- *Pandanus sp.*, L- *Pongamia pinnata*, M- *Terminalia catappa*, N- *Thespesia populnea*

Table 4.5.2. Classification of the study sites according to the dominant mangrove species present

Mangrove type	Sites
Avicennia	Site 1, Site 7
Bruguiera	Site 4, Site 8
Rhizophora	Site 5, Site 6,
Mixed	Site 2, Site 3, Site 9, Site 10

The 10 sites under investigation fall under four different types of mangroves. Mixed mangrove stands dominate and are found across 4 study sites. *Avicennia*, *Bruguiera*, and *Rhizophora* dominated in two sites each, and *Rhizophora* present dominantly in one site.

Table 4.5.3. IndVal analysis of species to mangrove affinities

Mangrove Type	Indicator Species	IndVal
Rhizophora	*Cheiracanthium indicum*	1
Rhizophora	*Heteropoda indicus*	1
Rhizophora	*Thelacantha brevispina*	1
Rhizophora	*Murricia* sp.1	1
Rhizophora	*Cyclosa quinqueguttata*	0.84
Bruguiera	*Corinnomma severum*	0.84
Bruguiera	*Hersilia longivulva*	0.72
Bruguiera	*Castianeira zetes*	0.59
Bruguiera	*Cheiracanthium poonaense*	0.57
Mixed	*Neoscona bengalensis*	0.65
Mixed	*Argiope pulchella*	0.76
Mixed	*Vailimia* sp.1	0.63
Mixed	*Pritha nana*	0.61
Mixed	*Cyrtophora cicatrosa*	0.61
Mixed	*Gnathopalystes flavidus*	0.59
Avicennia	*Heteropoda* sp.1	0.61
Avicennia	*Hamataliwa* sp.1	0.57
Avicennia	*Clubiona drassodes*	0.54
Avicennia	*Parawixia dehaani*	0.52

The indicator value (Dufrêne & Legendre, 1997) to find the species associated with habitat types revealed that the species have a specific affinity towards a particular mangrove type. IndVal reflects the level of habitat fidelity and specificity. 5 species show a strong affinity (IndVal=1) towards mangroves *Rhizophora*, *Cheiracanthium indicum, Heteropoda indicus, Thelacantha brevispina, Murricia* sp.1, and *Cyclosa quinqueguttata.* 4 species, including *Corinnomma severum, Hersilia longivulva, Castianeira zetes,* and *Cheiracanthium poonaense,*

showed IndVal ranging from 0.57-0.84 in the *Bruguiera* dominated mangroves. 6 species have strong affinity towards the mixed mangrove patches; *Neoscona bengalensis, Argiope pulchella, Cyrtophora cicatrosa, Gnathopalystes flavidus, Pritha nana,* and *Vailimia* sp.1, out of which 3 are araneids. Mangroves dominated with the genus *Avicennia* strongly supported 4 species with IndVal ranging from 0.52-0.61, including *Heteropoda* sp.1, *Hamataliwa* sp.1, *Clubiona drassodes,* and *Parawixia dehaani*.

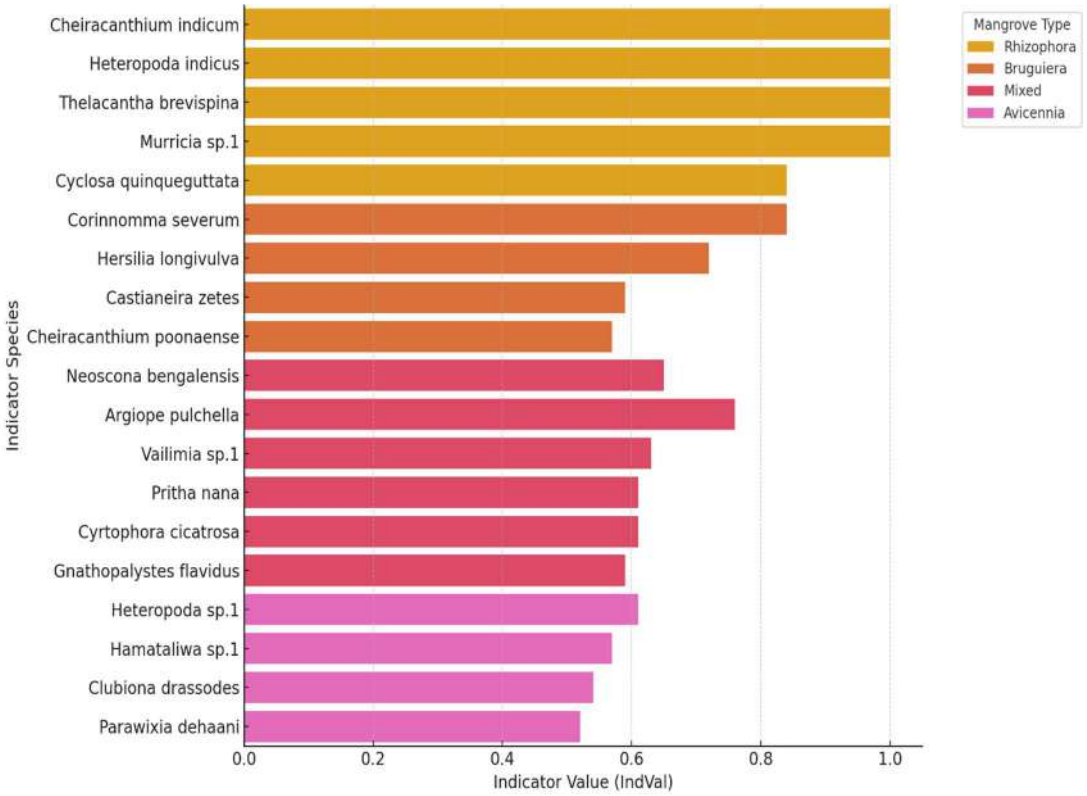


Figure 4.5.3. Bar chart showing the indicator species values (IndVal) across the habitat types

Indicator values (IndVal) of spider species linked with different mangrove types based on the dominant true mangrove species recorded from the study sites. Values range from 0 to 1, with 1 denoting perfect indication (i.e., species occurs exclusively and consistently in a single habitat type). The analysis highlights strong habitat fidelity in *Rhizophora*-dominated zones and broader species overlap in *Avicennia* and mixed mangrove habitats.

Table 4.5.4. Site-wise summary of environmental parameters – mean temperature, relative humidity, and canopy cover

Site	Temperature (°C)	Humidity (%)	Canopy cover (%)
site 1	28.716°C	74.37%	64.33%
site 2	28.45°C	81.01%	92.46%
site 3	27.525°C	77.72%	73.03%
site 4	27.502°C	73.36%	54.26%
site 5	28.737°C	76.12%	69.03%
site 6	28.611°C	72.41%	61.07%
site 7	28.002°C	78.95%	49.03%
site 8	28.458°C	72.58%	51.28%
site 9	28.13°C	80.68%	87.04%
site 10	27.99°C	79.66%	88.74%

Table 4.5.5. Species showing significant multivariate GLM (FDR corrected) association with environmental predictors, including canopy cover, temperature, and humidity

Species	Predictor	Log Coefficient	Adjusted p
Argyrodes ambalikae	Canopy	7.55	0.007544
Argyrodes flavescens	Canopy	-20.17	0.0001
Amyciaea forticeps	Canopy	2.59	0.03089
Achaearanea durgae	Canopy	-4.47	0.000595
Bijoaraneus mitificus	Canopy	9.57	0.000062
Camaricus formosus	Canopy	3.26	0.024603
Cyclosa quinqueguttata	Canopy	603.26	0.0001
Cyclosa sp.1	Canopy	86.06	0.0001
Drassodes sp.1	Canopy	248.85	0.032686
Olios milleti	Canopy	-4.21	0.0209
Oxyopes birmanicus	Canopy	-4.54	0.004836
Phintella vittata	Canopy	3.64	0.001398
Pritha insularis	Canopy	153.95	0.03089
Stenaelurillus lesserti	Canopy	-7.17	0.010158
Tetragnatha mandibulata	Canopy	-9.69	0.00017
Tylorida striata	Canopy	187.25	0.0001
Tylorida ventralis	Canopy	-2.51	0.000062
Argyrodes ambalikae	Humidity	-44.57	0.011748
Argyrodes argentatus	Humidity	-22.56	0.014844
Acusilas coccineus	Humidity	-1500.82	0.000001
Argyrodes flavescens	Humidity	106.95	0.000003
Amyciaea forticeps	Humidity	-26.85	0.000361
Araneus sp.1	Humidity	-1483.46	0.000095
Bijoaraneus mitificus	Humidity	-39.2	0.007495
Castianeira zetes	Humidity	-1601.76	0.0001
Cheiracanthium poonaense	Humidity	-1524.56	0.0001
Clubiona drassodes	Humidity	-1006.93	0.0001
Corinnomma severum	Humidity	-1048.54	0.0001

Cyclosa quinqueguttata	Humidity	-1601.77	0.0001
Hamadruas sikkimensis	Humidity	41.77	0.007942
Marengo crassipes	Humidity	46.77	0.003363
Mimetus indicus	Humidity	40.5	0.019672
Myrmaplata plataleoides	Humidity	-19.1	0.032866
Olios milleti	Humidity	31.42	0.001682
Pritha insularis	Humidity	-1574.56	0.0001
Tetragnatha mandibulata	Humidity	-46.36	0.0001
Tylorida striata	Humidity	-1925.47	0.0001
Tylorida ventralis	Humidity	12.4	0.004187
Achaearanea durgae	Temperature	1.57	0.0001
Argiope anasuja	Temperature	-0.74	0.032554
Bijoaraneus mitificus	Temperature	-0.87	0.002927
Camaricus formosus	Temperature	0.88	0.000001
Castianeira zetes	Temperature	-68.76	0.0001
Cheiracanthium danieli	Temperature	2.51	0.0001
Clubiona drassodes	Temperature	-52.81	0.0001
Corinnomma severum	Temperature	-40	0.0001
Crossopriza lyoni	Temperature	3.16	0.01692
Curubis tetrica	Temperature	0.36	0.034982
Cyclosa hexatuberculata	Temperature	-0.5	0.033462
Cyclosa quinqueguttata	Temperature	-68.86	0.0001
Cyrtophora cicatrosa	Temperature	0.36	0.027985
Drassodes sp. 1	Temperature	-30.61	0.0001
Epeus sp.1	Temperature	1.21	0.034982
Eriovixia sp.1	Temperature	1.4	0.01692
Eriovixia excelsa	Temperature	-0.92	0.013461
Hippasa agelenoides	Temperature	0.48	0.022813
Hyllus semicupreus	Temperature	0.21	0.010946
Indopadilla insularis	Temperature	0.27	0.034982
Miagrammopes extensus	Temperature	1.24	0.034982
Mimetus indicus	Temperature	1.16	0.024062
Neoscona elliptica	Temperature	-57.81	0.0001
Neoscona mukerjei	Temperature	1.5	0.01692
Oxyopes shweta	Temperature	0.52	0.009982
Pardosa sp.1	Temperature	-0.56	0.030675
Pardosa sumatrana	Temperature	28.74	0.0001
Phintella vittata	Temperature	-0.43	0.000101
Pritha sp.1	Temperature	-0.44	0.045202
Rhene flavigera	Temperature	-0.59	0.007632
Stenaelurillus lesserti	Temperature	2.07	0.000382
Tetragnatha mandibulata	Temperature	3.64	0.0001
Tetragnatha viridorufa	Temperature	-0.29	0.00862
Thanatus elongatus	Temperature	14.46	0.045202
Thiania bhamoensis	Temperature	0.42	0.024062
Tylorida striata	Temperature	-5.89	0.045202

The FDR-corrected Multivariate Generalised Linear Model (GLM) (Wang et al., 2012) identified 52 species whose abundance is structured by at least one of the measured habitat gradients, where their FDR-corrected p-values were < 0.05. temperature emerged as the stronger driver, with 37 species, 21 showed a positive correlation, whereas 16 species showed a negative correlation. 21 species were influenced by humidity. 6 positively influenced species were there, and 15 were negatively influenced species. the percentage of canopy cover is the third predictor. A total of 17 species were influenced by canopy cover. 10 were positively influenced and 7 were negatively influenced by a denser canopy.

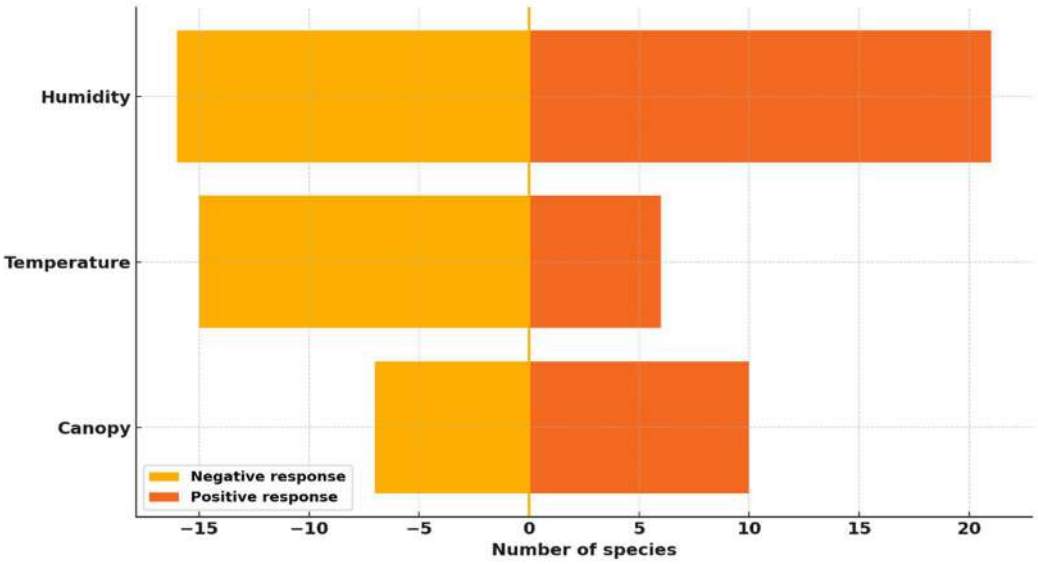


Figure 4.5.4. Mirrored bar chart of species responses by predictors

The mirror bar chat shows humidity has a supreme positive correlation with spider taxa, followed by canopy cover and temperature. Even though a larger number of species respond to the temperature, strong coefficient values towards humidity make it a solid environmental variable that controls the spider diversity and their abundance.

Table 4.5.6. Significant taxa influenced by all predictors

Species	Canopy Coeff	Humidity Coeff	Temperature Coeff
Bijoaraneus mitificus	9.57	-39.2	-0.87
Cyclosa quinqueguttata	603.26	-1601.77	-68.86
Tetragnatha mandibulata	-9.69	-46.36	3.64
Tylorida striata	187.25	-1925.47	-5.89

Bijoaraneus mitificus, Cyclosa quinqueguttata, Tetragnatha mandibulata, and *Tylorida striata* are the four taxa significantly responding to the canopy cover, humidity, and temperature.

Figure 4.5.5. Significant taxa responding to the Humidity, Temperature, and Canopy cover

4.6. Response of the spider assemblage to selected anthropogenic proxies

In this analysis, we measured the Disturbance Index (DI) by calculating canopy openness, stump counts, and plastic and debris density across all study sites. The data were compared with species richness and the Shannon diversity index (Table 4.6.1).

Table 4.6.1. Site-wise summary of Disturbance Index (DI), Plastic debris density (m^2), and diversity metrics

Sites	Openness (%)	z-Openness	z-Stump	Disturbance Index	Plastic debris density ($m^{2)}$	Species richness (S)	Shannon diversity (H)
Site 1	35.67	0.294	0.477	0.771	1.5	91	4.108089
Site 2	7.54	-1.467	-1.502	-2.969	2.16	122	4.510584
Site 3	26.97	-0.251	-0.603	-0.854	1.94	121	4.408982
Site 4	45.74	0.924	0.926	1.85	0.86	90	4.082644
Site 5	30.97	0	0.027	0.027	1.76	105	4.218146
Site 6	38.93	0.498	1.466	1.964	1.96	79	4.005343
Site 7	50.97	1.252	0.297	1.549	1.76	80	4.118171
Site 8	48.72	1.111	1.196	2.307	0.61	83	4.04924
Site 9	12.96	-1.128	-1.232	-2.36	0.99	127	4.485792
Site 10	11.26	-1.234	-1.052	-2.286	2.03	117	4.47701

The standardized disturbance index (DI), fused by the canopy openness and stump density, shows a coherent gradient in the spider richness and diversity. Sites with low DI marked greater species richness and the Shannon value index. The sites include 2 (-2.969), 9 (-2.36), 10 (-2.286), and 3 (-0.854). The species richness ranged from 117 - 127. Lower disturbance indicates a healthy mangrove vegetation. Sites 1 (DI=0.771) and 5 (DI=0.27) showed an intermediate level of disturbance and species richness. Four sites showed significantly high values in DI, ranging from 1.5 to 2.3. Sites 8, 6, 4, and 7 have lower species richness, ranging from 79 to 90.

Analysis of the plastic pollution based on the plastic debris density index doesn't exert any pressure on the spider assemblage. Site 2, showing a high debris density of 2.16 items/m^2, supports 122 species, whereas site 6, with a similar debris load of 1.96 items/m^2, sustains only 79 species. Sites (10,6, and 3) with a high plastic debris index of 2.03, 1.96, and 1.94 show varying species richness of 117, 79, and 121, respectively, and Shannon diversity. Site 7, with a lower plastic debris density (0.61), shows a comparatively lower species richness and Shannon index.

Figure 4.6.1. Dual-axis bar chart showing site-wise variation in disturbance and plastic debris density

The dual-axis bar chart reveals distinct variation in both disturbance index and plastic debris density. Sites are arranged in the ascending order of their disturbance index and the corresponding plastic debris densities. Sites 2, 9, and 10 showed a negative disturbance level; in contrast, sites 4, 6, and 8 showed a higher disturbance index. But plastic debris density didn't show any particular pattern; sites 2, 10, 3, and 6 showed a higher value.

Table 4.6.2. Pearson correlation summary assessing Disturbance (DI) and Plastic debris density (PDD) related to species richness and Shannon diversity

	Metric	r	p-value	Significance (α=0.05)
Disturbance Index (DI)	Species Richness	–0.806	0.0049	**p < 0.01**
Disturbance Index (DI)	Shannon Diversity	–0.815	0.0041	**p < 0.01**
Plastic Debris Density	Species Richness	+0.279	0.435	n.s.
Plastic Debris Density	Shannon Diversity	+0.377	0.282	n.s.

The Pearson correlation signifies that the disturbance index of canopy openness and stump density has a negative correlation to spider richness and diversity. By contrast, plastic debris density shows an insignificant correlation with spider assemblage.

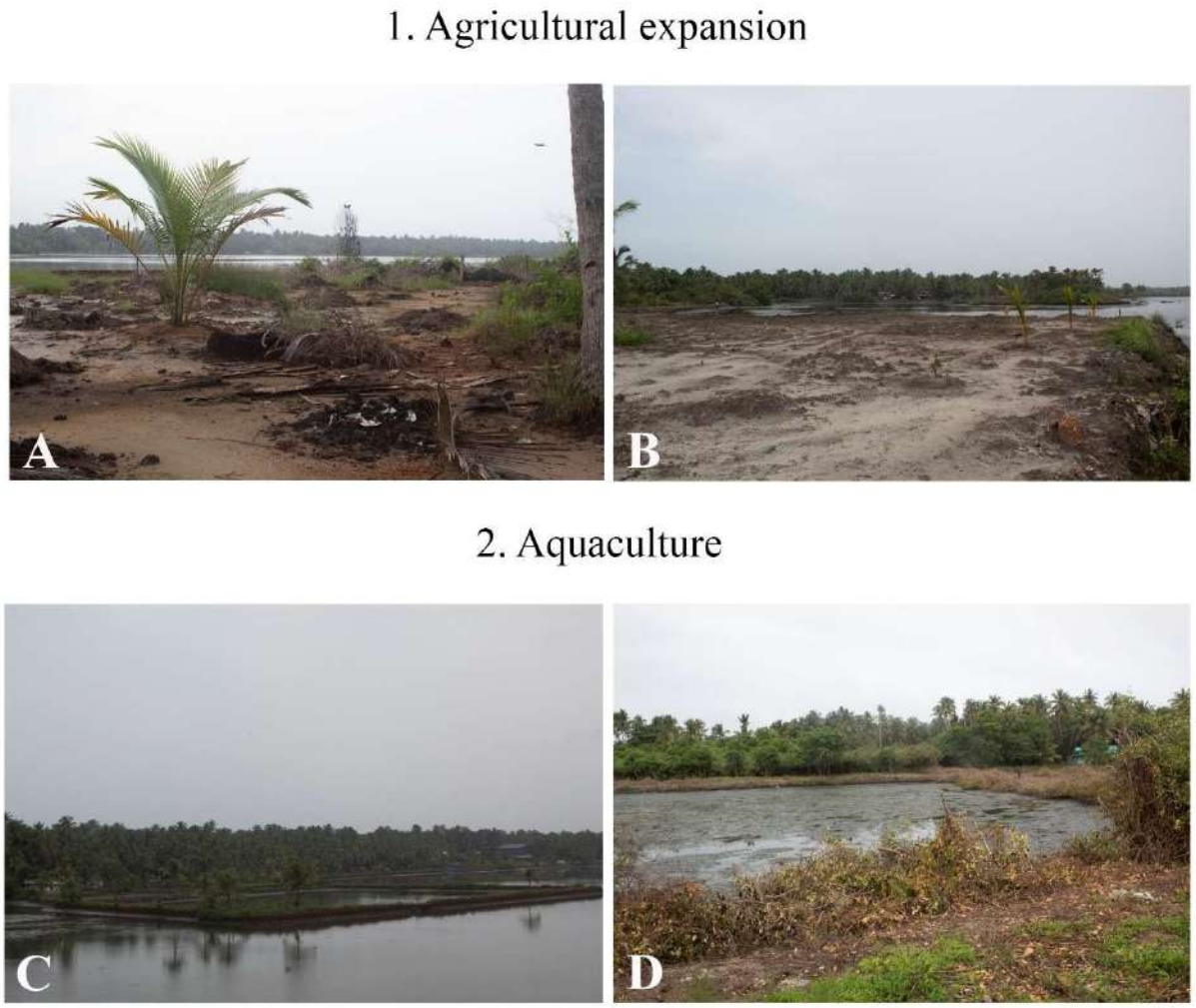
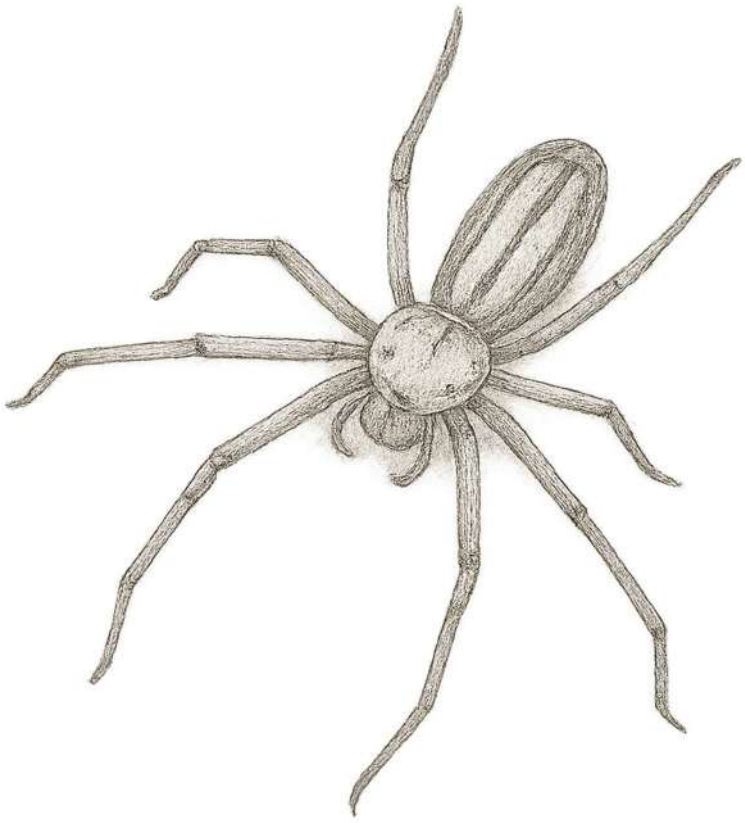


Figure 4.6.2a. Major anthropogenic threats to mangrove ecosystems in different study stations: A- Chettuva, Thrissur; B- Kumbla, Kasaragod; C- Chettuva, Thrissur; D- Tirur, Malappuram.

Figure 4.6.2b. E- Azheekkal, Alappuzha; F- Tirur, Malappuram; G- Chettuva, Thrissur; H- Uppala, Kasaragod; I- Kumarakom, Kottayam.

Figure 4.6.2c. J- Beypore, Kozhikode; K- Mangalavanam, Ernakulam; L- Poovar, Thiruvananthapuram; M- Valapattanam, Kannur.



CHAPTER 5
DISCUSSION

Kerala is a narrow alluvial strip located in the iron-rich laterite midland plain of gneisses and schists, situated on the irregular, steep slopes of the Western Ghats, influenced by the biennial southwest and northeast monsoons. With the impeccable geophysical peculiarities, Kerala hosts a mosaic of ecosystems. This includes sandy coastal dunes, beaches, brackish backwater lagoons, mangroves, freshwater wetlands, riparian lands, luxurious tropical evergreen forests, semievergreen moist deciduous forests, mist-shrouded sholas, grasslands, wildlife corridors, and human-fabricated agroecosystems. These habitats make Kerala a biodiversity hotspot. Exploratory studies on the diversity of spiders have been previously done in many of the ecosystems mentioned above.

5.1. The faunal inventory of spiders in the mangrove ecosystems of Kerala

We enlisted 191 species that belong to 102 genera and 21 families from the entire sampling sites of Kerala mangroves (Table 4.1.1). This is approximately 10 % of the total species, 20 % of the genus, and 33 % of the families represented from India. Salticidae, with 40 species, is the dominant family in the checklist. Araneidae (39 species) is the second dominant family. Together, they constitute 41 % of the entire spiders obtained from the study. Theridiidae, Oxyopidae, and Lycosidae exhibited a median range of diversity with 15, 12, and 10 species, respectively. Tetragnathidae, with 7 species, and Uloboridae and Hersiliidae, with 6 species each, represent orb weavers along with Araneidae in the ecosystem. Cheiracanthidae and Thomisidae are represented by 8 species each. The tenth dominant family with 6 species was Sparassidae. Corinnidae and Clubionidae are represented with 5 species each. Five families represented with 4 species each: Scytodidae, Pholcidae, Filistatidae, Philodromidae, and Gnaphosidae. Mimetidae, with 2 species, and Pisauridae, along with Eresidae, represented only by one species each (Figure 4.1.3).

Studies regarding the spider diversity in the mangroves of Kerala are not well explored. Notable works are done by Sebastian et al. (2005), Vishnudas et al. (2021), and Vineetha & George (2021). Sebastian et al. studied the diversity of spiders in an urban mangrove forest and identified 51 species from 16 families. They reported Araneidae and Salticidae as the dominant families, with nearly an equal number of species from both families. Vishnudas et al. enlisted 70 species from 16 families from the mangrove ecosystem of Poovar, Thiruvananthapuram. This study follows the same pattern of dominant families as the present study: Salticidae, Araneidae, Theridiidae, and Oxyopidae. Vineetha & George selected three sampling sites from North Malabar and identified 63 species from 13 families. This study also pictured Araneidae and Salticidae as the predominant families. The three notable studies from the mangroves of Kerala show a similar trend of familial prevalence.

The mosaic biotopes of Kerala have witnessed profound spider diversity explorations. Sudhikumar et al. (2005c) conducted a preliminary study on the diversity of spiders in the Mannavan Shola forest and reported 72 species, 57 genera, and 20 families. They reported Araneidae as the dominant family. A seasonal variation and diversity of spiders in the rice field of Kuttandu were studied by Sudhikumar et al. (2005a) also reported 94 species and 64 genera from 20 families. This study marked Lycosidae as the dominant family. The mixed forest type of Parambikulam was investigated for spider diversity by Sunil et al. (2008). They came along with 94 species, 64 genera, and 20 families. Araneidae and Theridiidae dominated the ecosystem. Jose et al. (2018) recorded 112 species from 21 families from a lateritic biotope of the Kavvayi river basin. They sampled a variety of ecosystems, including sacred groves and mangroves. Araneidae and Salticidae sprawled the biotope with maximum diversity. Jobi & Sudhikumar (2020) studied the spider diversity of Pathiramanal Island. They identified 147 species from 26 families; Araneidae, Salticidae, Theridiidae, and Tetragnathidae were the dominant families. Sumesh & Sudhikumar (2002) studied the spider diversity in the sacred groves of Northern Kerala and came up with 257 species from 28 families. This is the study that recorded the maximum number of

spider species from Kerala. Compared to the studies in mangroves, the majority of the explorations regarding spiders resulted in a rich diversity. The consistency of the early works is also repeated in our work. Araneidae and Salticidae dominated, accounting for 41% of the total spider diversity. The consistent dominance of these families may be due to their high adaptability, versatility in selecting microhabitats, plasticity in foraging, and effective strategies. The entire checklist can be divided into three according to the foraging strategies they adopt; in that sense, the spiders obtained can be web builders, hunters, or specialists. This reflects the habitat heterogeneity of the ecosystem. The comparatively large number of web-crawling spiders indicates the presence of web anchoring points.

The spatial gradient of spiders, especially in their abundance and richness patterns, changes significantly among the study sites (Table 4.1.2). 995 individuals (± 195.7 standard deviation) and 101 species (± 19 SD) changes in average. Abundance ranges from 642 to 1287 individuals. Species richness starts from 79 to 127, indicating that at least 79 species can be found in any of the sampling units. The highest abundance recorded was found at site 3 (1287 individuals), and the least at site 7 (642 individuals). This suggests the localized floral architecture could have a great influence on the richness and abundance of spiders in the study units. The study of Sudhikumar et al. (2005c) in the Mannavan Shola forest recorded 72 species from 20 families in just 5 days of investigation. They emphasised that this great diversity resulted from a very complex habitat structure and microclimatic factors. In the present study, we recorded the highest species richness from site 9 (127 species), and 79 species from site 6 had the lowest (Table 4.1.2).

The species accumulation curve

The species accumulation curve shows a two-phase pattern, as usual, a steep slope, and an asymptotic phase (Figure 4.1.2). The slope abruptly increases between sites 1 (91 species) and 4 (168 species). It shows an average of 26 species additions per site till site 4, indicating a hasty capture of common or widely distributed taxa across the study sites. Beyond site 4, the slope declines sharply and adds only 2 to 4 species per sampling unit. By site 10, the slope reaches an

asymptote. The accumulation curve shows a perfect Michaelis-Menten fit with an estimated species richness of 195. Since the number of species was 191. The sampling completeness is 97.9% which shows a satisfactory collection with good effort. This species accumulation curve emphasizes that the obtained species richness is a true proxy of estimated species richness. The remaining 2.1 percent indicates the rarest taxa, which could potentially be cryptic or highly endemic to unique microhabitats or influenced by other narrow ranges of environmental variables. Meanwhile, the sampling completeness indicates that the guild dynamics, dominance pattern, influence of other parameters, and disturbances are adequately represented (Figure 4.1.2).

Site-wise species richness across 10 sites of Kerala

Figure 4.1.4 shows that the number of species from any study site of the present study shows a substantially high richness that exceeds the previously recorded notable works. Vineetha & George (2021) identified 63 species from the mangroves of the North Malabar, 51 species from Mangalavanam urban mangroves by Sebastian et al. (2005), and 41 species by Anannya & Malamel (2025) from Kumbalangi mangroves. We recorded 79 species from Alappuzha district (site 6), which is the site having the lowest species richness.

Site 9 (Kollam) exhibited the highest richness with 127 species. Field observation showed dense prop root networks and intact mangrove fringes with minimal disturbance. Similarly, high values were reported by Sebastian et al. (2005), positively correlating the high species richness with root density along with the habitat complexity. Sites 2 and 3, Kannur and Kozhikode, respectively (122 and 121), also maintained a high species richness due to the intact mangrove floral composition with a lower level of disturbance. Sites 10 and 5, Thiruvananthapuram and Thrissur, with species richness of 117 and 105, respectively, preserved a mid-range of species richness with a comparatively homogeneous mangrove flora. Species richness at site 1 (Kasaragod) was 91, whereas site 4 (Malappuram) recorded 90 species, indicating a less complex ecosystem with more disturbance. Sites 6, 7, and 8 (Ernakulam, Alappuzha, and Kottayam) remained at the lower range with species numbers 79, 80, and 83, respectively. This may be due

to the low habitat complexity and high anthropogenic stress. Muthukumaravel et al. (2013) identified 9 species from a mangrove area in Tamil Nadu, which is the lowest number of spiders recorded from any habitat type in India. They reported this is due to the increased logging, reduced root density, and canopy cover. Langelloto & Denno (2004) experimentally proved that the prey species of spiders increases with canopy cover, and they also noted a 30-40 percent decline in the spider population with a decrease in the canopy cover.

5.2. Site-wise Diversity: index-driven assessment based on Shannon, Simpson, Chao1, Margalef, Pielous Evenness, and Fisher's alpha

Table 4.2.1 indicates the comparative diversity indices of spiders from mangroves. The richness ranged from 79 (site 6 - Ernakulam) to 127 (site 9 - Kollam) (Figure 4.2.1). The Shannon diversity index ranged from 4.005 at site 6 to 4.577 at site 2 (Figure 4.2.2). Shannon-Weiner diversity index is the measure of entropy; it fuses both species richness and how evenly they are distributed in the habitat. The Shannon diversity index ranges from 0 to 5 (Shannon, 1948). The index shows a maximum at site 2, but the species richness is high at site 9. This is because the species at site 2 has a more evenly distributed spider community than site 9. A high range (from 4.408 - 4.510) of the Shannon index is shown by sites 2, 9,10, and 3. Values with a medium range were exhibited in sites 5, 7, and 1; 4.082, 4.118, and 4.108, respectively. Three sites have a comparatively low range (4.005 to 4.082) of value: sites 4, 8, and 6. The high range indicates a high diversity and better evenness. A lower Shannon index shows dominance of certain species in the habitat (Figure 4.2.2).

Simpson's diversity index (1-D) is a probability-based interpretation of dominance structure and evenness robustness (Table 4.2.1). The values always fall between 0 and 1. A value close to 1 indicates a fairly balanced community in abundance. This index is designed to clear out the rarity crash. The values of all sites ranged from 0.972 to 0.985. The highest value obtained from site 2 (0.985) indicates a more stable community. Sites 9, 10, and 3 stay at the high range (0.984 for sites

9 and 10, 0.983 for site 3). All other site values ranged from 0.972 to 0.979 (Figure 4.2.2). Site 6 has the minimum value of the index, 0.972, indicating a less balanced, weakly resilient community (Figure 4.2.2).

The Chao1 richness estimator is based on singletons and doubletons in the sampling pool (Table 4.2.1). This gives an understanding of how many species are hiding deeply under any microhabitat or any other hidden corners of the ecosystem. This gives a fused value with observed richness and estimated species count (Chao, 1984). Even though the Chao1 estimator is high at every site, the increased values are marginal. The difference ranged from 0.13 to 4.4 species. The largest gap was shown at site 9 (Figure 4.2.1), which is the richest of all sites in the study. The richness is 127, and the Chao1 is 131.4, which is a 4 to 5 species gap. This indicates a sampling completeness of 96.65 %. The smallest values were at sites 1, 2, 4, 5, 6, 8, and 10, with estimator values 91.3, 123, 92.6, 105.17, 79.12, 83.125, and 117.8, all showed 99 % sampling completeness. Sites 3 and 7 (Chao1-123.5 and 82, respectively) have a sampling completeness of 97.97 % and 97.5 % based on the estimator. This shows a much more effort should be given to complete the sampling. In short, the Chao1 estimator showed a near-perfect sampling completeness with only a slight variation in the expected vs. observed richness, emphasizing that the sampling design of the transect (50m×2m) is perfect in spider collection in mangroves (Figure 4.2.2).

In ecological studies, Margalef's index (d) is a richness estimator that measures the diversity with a standardized species richness irrespective of the sample size variation in sampling units (Table 4.2.1). The lower limit of this index is 0, and there is no theoretical upper limit for this index. The values range from 11.48 to 18.13 (Figure 4.2.4). The highest value obtained from site 9, meaning high richness, often correlates with high ecosystem stability and lower disturbance. Akamagwuna et al. (2022) surveyed the microinvertebrates of the various sites from the Afrotropical region and found a higher value of Margalef's index at undisturbed and very intact ecosystems. This correlates that site 9 is a prime spot for maintaining the biodiversity of spiders. Sites 2, 3, and 10 also showed higher values: 16.95, 16.75, and 16.65, respectively, indicating that

they also have an undisturbed ecosystem with complex vegetation. Sites 5 and 1 have a moderate value (15.11 and 13.13). Sites 4, 8, and 7 have a lower Margalef's index, showing the increased level of disturbances and decreased habitat complexity. The very low value of this index results from site 6 (11.48). This is potentially because of the high level of disturbance and habitat homogeneity.

Pielou's evenness index (J'), the value's lower limit is 0, and the upper limit is 1 (Table 4.2.1). The values close to 1 indicate a more even community. A drop in the J' indicates habitat simplification or disturbance (Pielou, 1966). Figure 4.2.3 shows that sites including 10, 7, 2, and 9 showed a high spectrum of index value (0.926 to 0.940). Sites 3, 6, 8, and 1 exhibit mid-range values (average of 0.91). Sites 4 and 5 showed a lower value of 0.90. Fishers' alpha has no theoretical upper limit. It helps to compare the diversity of ecosystems with different sample sizes, in particular. It has no sensitivity towards the most abundant species. This index compares and gives weights to more singletons and doubletons. The values obtained stretch from 20.94 to 37.96. The high value obtained from site 9 indicates a hyperdiversity. High diversity alerts also hit sites 10, 2, 3, and 5: the values are 33.6, 33.4, 32.73, and 29.87. Moderate fishers' alpha was exhibited by sites 1, 7, 4, and 8, with an average value of 23.92. The lower value indicates a simplified vegetation and highly disturbed habitat, and the site was 6, with a value of 20.94 (Figure 4.2.4).

Assessment of Normality by the Shapiro-Wilk test and Selection of Appropriate Statistical Methods

The Shapiro-Wilk test is a formal statistical test that checks whether the distribution follows a normal distribution or not (Table 4.2.2). The W-statistic values fall between 0.507 and 0.737 with a very low p-value below 0.001. This tells us that the distribution is not normal or does not follow a Gaussian distribution. The W stat must reach 1 to get a normal distribution (Razali & Wah, 2011). Since the Shapiro-Wilk test results reject the normality hypothesis and deviate from the Gaussian distribution, we should choose the non-parametric tests for further analysis. Under these circumstances, we cannot follow parametric tests they could be greatly influenced by the

type 1 errors. Ecologically, this non-normal distribution emphasizes the role of habitat heterogeneity and other factors that may influence the spider populations of different sampling units. Stanska et al. (2018) studied the diversity of epigeal spiders in different ecosystems of Poland. They demonstrated that a low value of W-stat could potentially indicate the influence of habitat complexity and environmental factors. Lowest W-stat values at sites 1 and 6 may have a high influence from microclimatic factors and vegetation structure. Sites 4, 5, and 8 (0.56, 0.57, and 0.53, respectively) also align towards the low value spectrum, indicating greater influence by habitat architecture and other factors. A mid-value exhibited by sites 7 and 10 with W-stat values of -0.64 and 0.69. The highest values were exhibited by sites 2, 3, and 9 (0.73 for 2 and 0.71 for 3 and 9).

Decoding abundance gradient by the Kruskal-Wallis test

A well-made check for actual difference in sampling units was done by the non-parametric alternative test of ANOVA, the Kruskal-Wallis (Table 4.2.3). It helps to measure the abundance pattern between the 10 sites. Our H value is 53.87 with degrees of freedom 9, and the p value is 0.00000319. The p-value less than 0.05 indicates an asymmetrical distribution of spiders in the study sites. The values also indicate that the changes are not random. This pronounced inter-site variation in the spider assemblage reflects the habitat heterogeneity, microhabitat preferences, and sound environmental factors. Our results are parallel with the findings of De et al. (2023). They sampled spiders across 27 sites and grouped them according to the level of disturbance. The H value of the study was 18.062, and the p value was less than 0.05, as in Table 4.2.3. They found there are significant differences in the three categories; likewise, the spider assemblage in our study sites also shows a pronounced variation.

Dunn's post hoc test to understand pairwise divergence

Table 4.2.4 gives Dunn's post hoc results. A significant H-value obtained from Kruskal-Wallis indicates that at least one of the study sites shows a significant difference. Dunn's post hoc test, followed by Bonferroni correction, pinpoints which pairs show a difference among all the

study sites. It refines the differences between the sites through a Z-statistic. The site-specific difference in the present study indicates a heterogeneous distribution in the spider assemblage. The positive Z-stat indicates the first group surpasses the second group. Negative value indicates the second group is dominated. Site 2 consistently outmatches sites 6, 7, and 8, where the Z-stat ranges from 3.85 to 4.48, and the p-values were ≤ 0.005. This indicates that habitat complexity supports a rich fauna of both spiders and their prey species. The negative Z-stat values for site 7 versus sites 9 and 10 (Z=-3.75, -3.57 with p-value ≤0.016) and site 8 versus site 9 (Z=-3.28, p-value 0.046) indicate that site 7 is outranked by sites 9 and 10 for the first site, and site 8 is outranked by site 9 (Table 4.2.4).

Multidimensional Diversity Profiles of the Spider Assemblage in Mangroves by Chao1/Jost and Hill Number

Hill numbers (Table 4.2.5) help to transform the raw species count and the score of entropy into intuitive species equivalents and give a view on richness (0D), balance (1D), and dominance (2D) (Hill, 1973; Chao & Jost, 2012). The Chao1/Jost richness estimator-0D revealed a predominant gradient in species richness across the 10 sampling units, from 79.3 at site 6 and a maximum value of 132 at site 9 - Kollam. The Chao1/Jost index is the extrapolated species richness. All the 0D values remained closer to the actual or observed species richness, indicating that the study sites are well sampled, with a sampling completeness of 95% altogether. The rest of the 5 % suggests that the presence of a mere number of rare taxa across the sampling units.

Shannon's effective number of species (1D) varied from 54.84 at site 6 to 90.97 at site 2, which reflects that the sampling sites show variation in both species number and their evenness in the distribution across the study sites. Sites 9 (1D = 88.75) and 10 (1D = 87.97) keep up with site 2, with a great value showing a rich and evenly distributed community across those sites. In contrast with the richest sites, site 4 (1D = 59) and site 8 (1D = 57.35), along with site 6, had the lowest value, indicating the quality of the habitat (Table 4.2.5).

2D - The Simpson's effective number spanned from 36.87 at site 6 to the maximum value at site 2 (70.02). The values indicate the variation in the community structure. Sites 8 and 1 also remained at a lower base, with the values ranging from 38 to 39, while sites 9,10, and 3 have a higher value (61-64) of 2D (Table 2.4.5).

In general, site 2 – Kannur, constantly showed the highest diversity across all three dimensions, suggesting that the site is ideal to support a stable community of spiders due to its habitat complexity and heterogeneity. Meanwhile, the values obtained from site 6 remained low in all three dimensions: 0D, 1D, and 2D. This implies that the site is not ideal for spider community growth. These notably low values also suggest that site 6 might have a homogeneous and simple, or disturbed habitat, compared to site 2. In site 7, the diversity is moderate, but the 2D value remained at a lower base. This is surprisingly due to the numerical abundance of a few taxa. To conclude, structural complexity and the disturbance level have a prime role in governing the spider assemblage. The combined usage of Hill number (0D, 1D, 2D) and extrapolated Chao1/Jost richness gives a solid concept regarding the araneofauna in the mangrove ecosystem (Table 4.2.5).

Diversity profile curves by Hill numbers

Figure 4.2.5 is the plot that shows the effective number of species in the community against the parameter q, providing insight into the relative weight given to rare and common taxa across all study sites. At q = 0, every species counts; at q = 1, it gives weights to the species according to their frequency; and the q = 2, it gives weights to the dominant species. The diversity profile curve (Figure 4.2.5) gives a complete spectrum of richness and dominance of the communities in the study sites. All sites showed a slope pattern in general. The steep slope is shown by site 9, it drops steeply from 132 to 88, then to 66, indicating a high richness but low evenness an improper distribution of species across site 9. The high value of q = 0 indicates the presence of rare taxa, but that vanishes when common species dominate. Whereas site 2 shows a declining gentler slope from 122 to 90, then to 70, indicating a more stable homeostatic community in terms of species richness and evenness. At q = 0, sites 9, 2, and 3 (132, 122, 121) have higher values, and the lower

cohort includes sites 6 (79), 7 (80), and 8 (83). At q = 1, sites 2, 10, and 3 (90, 87, 82) remained at the top, and the lower clade included sites 6, 8, and 7 (54, 57, 61). The order q = 2 was higher for site 2 (70), 10 (64), and 7, 3 (61), and the lower level was kept by the sites 6,8, and 7, the values ranged from 36 to 49. Overall, site 9 dominates in row richness but falls at q =1 and 2, indicating a clear dominance in site 9 by numerically abundant taxa (Figure 4.2.5). Even though the numerical abundance is higher at site 9, the plot shows that site 2 has the leadership among all dimensions. Making site 2 the ideal site to support maximum spider diversity.

Standardizing and comparing sampling by the Rarefaction curve

Figure 4.2.6 is the rarefaction curve plotting the expected number of species against the cumulative number of species collected with minimum errors. Plotting rarefaction is the best method of standardizing the sampling efforts. The steep indicates a high discovery rate, as the encounter reduces, the steep begins to saturate and reaches an asymptote when the sampling never adds any new encounters of species. Sites reaching the plateau, indicating sampling completeness. Sites 9, 2, 10, and 3 show the steepest curves, indicating a high species richness, whereas sites 6 and 7 show the slowest and flattest of all sites, followed by sites 4 and 5. The curves help to eliminate the observer's bias during sampling. Our results correlate with a significant study by Basset et al. (2012). They compared the arthropod diversity of two different ecosystems forest habitat with a closed canopy and a non-forest habitat. The rarefaction curve plotted for these two ecosystems concluded that the forest ecosystem with a complex canopy earned a steeper curve, whereas the non-forest habitat resulted in a flatter curve. Our rarefaction also resulted in a steeper slope for the complex mangroves among the study sites (Figure 4.2.6).

Inventory completeness and singleton dynamics by Coverage-based completeness curve

Figure 4.2.7 is the coverage-based completeness curve plot estimates species richness against the fraction of total individuals represented by observed species richness. This curve standardizes by inventory completeness and the number of singletons. The curve is more effective

for samples with different evenness. All 10 sites have different rates of curvature. Sites 6, 5, 7, and 8 have a steep slope at the initial stage and early plateau, indicating a lower number of singletons. A few common species dominate the assemblage, thereby quickly falling off the new species and singleton inventory. On the other hand, sites 9, 3, and 2 show a delayed plateau and gradual steep slope, implying the number of singletons due to the complex habitat structure and less disturbance (Figure 4.2.7). Our study has a closer similarity to the studies done by Private et al. (2021). The coverage-based completeness curve across four habitats - forest, forest edge, garden, and orchard - showed a significant difference in the plateau. The plot of forest shows a slower plateau than the three other plots. This indicates that habitat complexity influences the species richness of spiders.

Beta diversity: A Bray-Curtis perspective

Table 4.2.6 is the Bray-Curtis results, which quantify how two habitats or communities differ in species abundance. Since it weighs the abundance of a community, this index is sensitive to the numerical matrix of the most abundant species than rare species. This feature of this index makes it ideal to understand the relative shifts in communities in chosen habitats. Table 4.2.6 shows the most and least dissimilar habitats. The high value was 0.557 between sites 1 and 4, and the low value was between sites 7 and 8 (0.189). The value 0.557 indicates that sites 1 and 4 share less than half of their spider species. This indicates a great species turnover, that is, over 55.7 % species are unique to either one of the sites. A study regarding the spider assemblage of two different ecosystems, one invaded plant ground and a normal habitat ground. The Bray-Curtis dissimilarity index showed a d value of 0.506, concluding that the spider assemblage of the two ecosystems is entirely different. Sites 7 and 8 with d=0.189 have the greatest degree of compositional overlapping, followed by sites 3 and 10 (d=0.348), and sites 1 and 10 (0.359) (Figure 4.2.8). Intermediate dissimilarity values between 0.346 to 0.547 among the rest of the sites in the heatmap (Figure 4.2.8) account for the gradient of beta diversity, predominantly influenced by the habitat structure and disturbance level. The Bray-Curtis of our study sites gives a statistical spotlight on the overall species turnover.

Presence-absence pulse through Jaccard dissimilarity

Paul Jaccard (1901) formulated the index as a measure to find the species turnover based on presence-absence data in diversity studies. Table 4.2.5 gives the maximum turnover of 0.585 and the minimum turnover of 0.060 between sites, implying two contradictory conclusions. The maximum value was between sites 2 and 6, giving a conclusion that more than 50 % of the species do not show overlapping between those sites. Whereas the minimum species turnover shown by sites 7 and 8 means that they are almost identical in species turnover. This could likely be due to the geographical distance between them. Since the distance between them is comparatively lower, there is a great probability of overlapping. The lower tire was also formed by the following pairs of sites, 3 and 10, and site 2 and 9, with values 0.155 and 0.182, respectively. This emphasizes that distance is not the only factor in overlapping. The factors like habitat complexity and climatic factors could also influence the species turnover. Site 2 also showed significant divergence with sites 4, 7, and 8, underscoring that species existence is primarily influenced by multiple factors (Figure 4.2.9). The Jaccard index heatmap shows the pairwise composition similarities between spider communities across the study sites (Figure 4.2.9). Rodriguez et al. (2016) looked at the temperate grasslands of Argentina dominated by different plant species through the lens of Jaccard. They obtained a similar result that supports ours: the geographically closer and structurally similar habitat has a tendency to overlap the spider species composition. Jaccard index reduces the noise by abundance and gives the species turnover.

NMDS Ordination plot

The Non-metric Multi-Dimensional Scaling (NMDS) is an ordination method that converts the high-dimensional abundance data into a two-dimensional plot (Figure 4.2.10). In this study, all sites are plotted and positioned on a two-dimensional scale. This method preserves the order of dissimilarities. The NMDS ordination with stress ≤ 0.15 reveals a primary compositional gradient spanning from site 1 and site 6, with these two sites at negative and positive ends, suggesting these are the most divergent groups in the collection sites, individually governing their population.

Meanwhile, the sites within the large ellipse remaining close together are sites 7 and 8. This indicates that the most similar habitats have similarities in habitat conditions (Figure 4.2.10).

Vegetation parameters and spider assemblage: significance testing by PERMANOVA

To assess the variation in the vegetation structures and the spider assemblage in mangroves, we applied the PERMANOVA on Bray-Curtis dissimilarities. To prove this, canopy cover and the Leaf Area Index of both High Vegetation (LAI HV) and Low Vegetation (LAI LV) are taken into consideration. The p-values of these three factors turned out to be significant after PERMANOVA (Table 4.2.8).

The leaf area index is the total one-sided surface area of leaves in the upper stratum of the canopy. The LAI HV tests the variation in the upper canopy leaf area (Table 4.2.8a) with pseudo-F = 2.426, and the p = 0.01 indicates that the upper canopy leaf area has 11.8 % influence on the total community shifts of the spider assemblage. The rest of the 88 % of the species could be influenced by other microhabitat factors. The LAI LV (Table 4.2.8b) also showed statistical significance towards the distribution of spiders in mangroves. The pseudo-F = 8.13 and the p = 0.106 indicate significance. The PERMANOVA tells that about 31.12% of the variation in spider assemblage is influenced by the foliage of shrub-sized plants in the mangrove ecosystem. We chose canopy cover as the third predictor, which is the proportion of the ground surface masked by the vertical projection of the foliage. Apart from leaf area, canopy cover showed a greater R^2 value, which is 0.4756, indicating that 47.56 % of the community shift of spiders is dependent on the total canopy cover (Table 4.2.8c). The pseudo-F of 16.33 and the p-value of 0.009 also supported this result. Ramberg et al. (2020) performed PERMANOVA in two different ecosystems with 40% and 70% canopy and found that ≈ 30% of the total community shifts are driven by canopy cover with a p-value of 0.01. This study further supports our findings.

Season-wise spider composition

A significant species turnover has been observed across the three seasons in the mangrove ecosystem. From a total of 191 species (Table 4.1.1), 16.8% which is 32 species, show seasonal overlap. A high species turnover that is 147 species (Figure 4.2.11) was identified during the post-monsoon season. This surge in the species richness could be due to the recolonization of prey species and regrowth of foliage in mangroves. The foliage dynamics studies (Ramachandran et al., 2014, & Hogarth, 2015) emphasize that the post-monsoon season is marked by the growth of new leaves in mangroves globally. Pre-monsoon season also showed a profound richness with a subtle dip; 145 species were found in the pre-monsoon season (Figure 4.2.11). The minimum exposure to water opens maximum availability of substratum during the pre-monsoon, which could be the reason for a similar richness. This close resemblance in the species richness in the two seasons suggests nearly similar prey availability. Meanwhile monsoon season collapses the richness; a sharp decline in the species richness has been observed during the monsoon, 62 species, which is about 32 % of the total species richness (Figure 4.2.11). This is because of the physical disturbance in the habitat, predominantly due to rainfall.

The Venn diagram (Figure 4.2.12) shows the seasonal overlap and exclusivity of spiders across the three seasonal windows, pre-monsoon, monsoon, and post-monsoon. 32 species form a core assemblage that we can find in all three seasons. These ecological generalists can withstand all the seasonal fluctuations and heterogeneous habitat conditions (Wise, 1993; Cardoso et al., 2011). The highest species overlap was noticed between pre- and post-monsoon seasons. 84 species (43.97%) were found in both seasons, suggesting that these seasons provide a more stable and viable environment for the spider assemblage. The monsoon season presented a profound drop in the species richness and overlap. Only 4 species are shared with the pre-monsoon season, and 11 with the post-monsoon season, and it has only 15 species unique to the season. This drop in the species overlap suggests that disturbance is the major driver of spider diversity. The low numbers in the monsoon season suggest that it could be due to the flooding, heavy rainfall, reduced sunlight

and temperature, and high humidity. De et al. (2023) suggest that these factors could greatly affect the web construction, foraging, mating, and dispersal patterns of spiders. 25 species were exclusively found during the pre-monsoon, and 20 species during the post-monsoon season. These unique species are likely to explore the seasonally specific niche. In conclusion, the seasonal dynamics in species assemblages signify the temporal-seasonal partitioning of species occurrence. Monsoon season acts as an ecological filter, whereas the pre-monsoon and post-monsoon seasons promote maximum species richness and share about 44 % of the total species richness.

5.3. Foraging Guilds of spiders in mangroves - An analysis

The same class of species that exploit similar resources in the same way come under a guild. The guild symbolizes the ecosystem's multifunctionality, niche partitioning, and resilience. Spiders can be classified under separate guilds based on their foraging strategies. Table 4.3.1 presents the total guilds identified in the study. Twenty-one families are categorized under eight strategically different foraging guilds, according to Cardoso et al. (2011). Ambush hunters are keen predators that apply and wait-and-apply strategy to capture prey. Their agility can suppress the prey in a fraction of a second. Thomisidae is the one and only family that comes under ambush hunters. Ground hunters include a group of cursorial spiders that primarily run with endurance and speed on the ground rather than making a symmetrical web. Lycosidae and Gnaphosidae are the two families found under the guild of ground hunters. Orb weavers are spiders that construct a two dimensional, symmetrical, sticky orb web to capture flying arthropods. Araneidae, Tetragnathidae, and Uloboridae together constitute this guild, making them one of the numerically abundant guilds in the study. The presence of a high number of orb weavers indicates a complex and rich vegetation. Other hunters are a broad group of actively hunting spiders, predominantly jumpers, stalkers, and wandering spiders. Like their foraging techniques, the microhabitats they prefer broadly vary from ground to foliage. Six families, including Cheiracanthiidae, Clubionidae, Sparassidae, Salticidae, Oxyopidae, and Scytodidae, make them the most abundant guild in the

entire mangrove area. Hersiliidae and Filistatidae constitute the sensing web builders that spin a web with sheet-like fragments purely to detect the presence of prey rather than their entanglement. Sheet web builders include two families, including Eresidae and Pisauridae. They build slightly inclined and horizontal two-dimensional mats of silk, capped by an irregular tangled cap of threads designed to capture low-flying or ground-dwelling arthropods. Space web builders are masters of three-dimensional cob web makers, including two families, Pholcidae and Theridiidae. They make a web with random scaffolds of silks suspended in vegetation to capture airborne prey. Specialists are a group of spiders that focus on a particular diet or niche-specific prey, like spiders that exclusively feed on ants. They depend on a narrow spectrum of prey species reduces competition from other families. This includes Corinnidae, Mimetidae, and Philodromidae (Table 4.3.1).

A percentage guild composition of species coming under each guild was calculated and represented in a pie chart (Figure 4.3.1). 39.3 % of species were other hunters, which is the predominant guild of all. The second most abundant guild was orb-weavers (27.2%). 9.9% of species were space web builders, followed by 6.8% ground hunters. Specialists and sensing web builders constitute 5.8%. 4.2% of the entire spiders were ambushers, and only 1% were represented by sheet web builders.

A stacked bar chart of spiders comparing the guild composition across 10 study sites reveals a mosaic of functional roles (Figure 4.3.2). Every site has a predominant percentage of other hunters, roughly accounting for 35 - 40 % of the total guild counts, followed by 20 - 30 % orb weavers. Space web and sensing web builders represent approximately 5-10 percent; even though the percentage is low, they are consistently represented in all sites. Whereas, the ground hunter and specialists represented less than 5 % only present in some sites. At a glance, sites 2 and 3 peak in overall guild abundance, suggesting a maximum habitat complexity in terms of both rich canopy layers and forest floor, and the resource availability (Richert & Lockley, 1984). Sites 9 and 10 also showed a higher guild abundance. Sites 6,7, and 8 showed a lower abundance in the guild.

5.4. Site-specific Endemic taxa in the mangrove ecosystems

Site-specific spider taxa exclusive to particular sites are considered site-specific endemics (Table 4.4.1). We reported a single-site occurrence in sampling localities rather than true endemics with a globally restricted range. Despite their site-concentrated distribution, they play a vital role in species turnover, making the community stable and indicating whether the communities are complex or simple. Table 4.4.1 enlists the species exclusive to each sampling unit. Site 1 doesn't have any endemic species, indicating a homogenous microhabitat, high connectivity with other ecosystems, and other mangroves or probable dominance by other numerically abundant taxa. Site 2 has the maximum number of exclusive species. *Cheiracanthium* sp. 3, *Castianeria* sp. 2, *Curubis* sp. 2, *Cyrtarachne* sp.1, *Cyrtophora citricola, and Scytodes thoracica* are the six species that are endemic to site 2. This might be due to the complex habitat structure serving as the baseline for a heterogeneous niche pattern. Site 3 has four unique species, including *Cheiracanthium aizwalense, Lycosa* sp. 3*, Mimetus* sp. 1*,* and *Psellonus* sp. 1. This might also be due to the highly complex vegetation structure and reduced competition due to maximum resources. Sites 4 and 5 had 3 species each as endemic species. Making them a moderately complex regime in terms of habitat complexity. *Acusilas coccineus*, *Cheiracanthium poonaense*, and *Pritha insularis* were unique to site 4, and *Thelacantha* sp. 1, *Cheiracanthium indicum*, and *Hyptiotes indicus* were limited to site 5. Sites 6 (*Lycosa mackenziei, Scytodes pallida)* and 8 each had two endemic species (*Filistata* sp. 1, *Pritha nana)*. Sites 7, 9, and 10 had only one endemic taxon each - *Hamataliwa* sp. 1, *Drassodes* sp. 2, and *Lycosa* sp. 2, respectively (Table 4.4.1). The sites with one and two species as endemics remain at the lower regime in the study might be due to simplified habitat or increased disturbance level. The findings correlate with the study of Perry et al. (2021), who found the diminishing population of site-specific arthropod species in a Nature Reserve of Pennsylvania, even with a slight loss of canopy or a small amount of disturbance. The current report reinforces the fact that canopy structure is the prime factor in maintaining the unique fauna of spiders. Figure 4.4.1 shows the relative number of unique taxa along all the study sites in Kerala mangroves. Site 1 doesn't

have any local endemics; sites 2 and 3 remained at the top tier with 6 and 4 endemic species, respectively. Sites 4 and 5 retained a moderate level with three endemic species each, and the rest of the sites remained at the lower tier with two and one unique species.

Mapping Range-restricted Taxon by Weighted Endemism (WE) and Corrected Weighted Endemism (CWE)

Weighted Endemism (WE) and Corrected Weighted Endemism (CWE) are lenses through which range-restricted species have been statistically documented with the support of a p-value. WE are the sum of the inverse range sizes of all species at each site. A high value indicates a greater proportion of range-restricted taxa. CWE is the proportion of WE to the total species richness. Endemism stands for the local confinement of a taxon to one site and cannot be found anywhere else. Table 4.4.2 lists the values of WE and CWE and the respective p-values. We can determine which site has the greater complexity to support locally confined taxa.

Site 1 barely registers on the endemism checklist. The values of WE and CWE and the p-values emphasize no endemism at all. Site 2, in contrast, shows a higher value in both WE and CWE (26-078 and 0.214) and significant p-values, both less than 0.05. This indicates the presence of an endemic taxon and supporting complex habitat. Site 3 also shows a higher value of WE (23.79), but shows an insignificant p-value when it comes to corrected endemism; this unusual value might be obtained due to the presence of a lot more widely distributed numerically abundant taxon. Therefore, the weighted endemism gets diluted when it is converted into corrected endemism. In terms of endemism, sites 4 and 5 also exhibited moderate values, but the p-values turned out to be insignificant. This might also be due to the dominance of a widely distributed taxon in all sites. Sites 5 (WE = 20.36, p = 0.264), 6 (WE = 16.31, p = 0.910), 7 (WE = 12.30, p = 1.000), 8 (WE = 13.77, p = 0.991) and 10 (WE = 20.68, p = 0.226) all comes under a low to no endemism category. In the case of site 9, even though it shows a higher WE value, the p-value turned out to be insignificant, and the post-correction of WE also showed an insignificant value. This indicates that even though site 9 shows richness as site 2, the WE value is masked as uniqueness due to the

presence of a greater number of taxa with a wide range of distribution. Altogether, site 2 turned out to be the ideal habitat for both wide and narrow range (endemic) species (Table 4.4.2).

The violin plot (Figure 4.4.2) based on the WE shows that sites 2, 3, and 9 burst through the violin's upper tail. The dots are placed above the 95th percentile of the null. Site 2 with WE 26.07 significantly deviates from the usual pattern. Site 9 is the next higher WE closed behind at 25.19, and site 3 with 23.73. These three sites are the predominant sites showing significant endemism. This might be due to the complex floral diversity and canopy structure, along with unique microhabitat characteristics. All other sites had lower WE values, not supported by p-values; therefore, all the dots are in the inflated region of the violin. This means we cannot reject the null hypothesis of endemism at these sites. In other words, the signal of rarity is not exceptional, but it is exactly what we can predict just from sampling these many species.

5.5. Habitat association of spiders based on the mangrove flora, temperature and humidity

Table 4.5.1 is the list of true mangrove and associated flora in the study area. 15 true mangroves were identified from the study area, which is 21.4% of the total mangroves represented in the world (Hogarth, 2015). We have also cataloged 33 species of mangrove-associated flora ranging from grasses to trees. We categorized the mangrove sites under four classes according to the dominating true mangrove species in the sampling station. We classified the sampling units into *Avicennia - dominated*, *Bruguiera* - dominated, *Rhizophora* - dominated, and a mixed habitat (Table 4.5.2). *Avicennia* dominated in sites 1 and 7. *Bruguiera* in sites 4 and 8. Sites 5 and 6 are dominated by *Rhizophora.* Sites 2, 3, 9, and 10 were dominated by a mixed flora of true mangroves, mainly by *Avicennia, Bruguiera, Rhizophora, Excoecaria, Sonneratia,* and *Kandelia*. All these plants have their architectural specialities have a direct role in maintaining biodiversity in general. We found that *Bruguiera* has the thickest canopy, followed by *Rhizophora* and *Avicennia*. We also recorded site-wise temperature and humidity across all the sites during the study period. Together with the temperature, humidity, and canopy, we performed statistical

analysis- IndVal and Multivariate GLM to understand how species assemblage responds to these factors.

Comparing the overall richness in the 10 study sites. *Rhizophora* - dominated habitats account for 18.12% of the total richness. 16.84% of the total species richness was recorded from *Avicennia*-dominated ecosystems. *Bruguiera* supported 17.04% of the entire species reported from the study. Meanwhile, a major part of the species obtained from the study were from mixed habitats. 47.98% of the spiders were obtained from a mixed habitat where many of the true mangroves were randomly distributed. Many of the species-rich sites were mixed habitats, like sites 2 and 9. This suggests that a heterogeneous floral pattern can support a more diverse spider community than a homogeneous habitat.

Habitat Fidelity of spiders across different mangrove types: a vision through IndVal

Table 4.5.3 gives the IndVal of spider species across the different mangrove types. The values range from 0 to 1. A value close to 1 indicates that the species corresponding will be exclusive to that habitat, and a value below 0.5 is not considered to be tightly linked with that particular habitat. The IndVal (Table 4.5.3) helps to unveil the linkage of spider species to that habitat. Among the four mangrove types that we classified according to the dominant true mangroves present, four species (*Cheiracanthium indicum, Heteropoda indicus, Thelacantha brevispina, Murricia* sp.1) showed exclusivity in *Rhizophora*-dominated habitat with an IndVal of 1and the fifth species (*Cyclosa quinqueguttata)* showed 0.84. Three out of five species were orb-web spiders, suggesting that the *Rhizophora*-dominated ecosystem can sustain a well-preserved orb-weaver guild. The *Bruguiera*-dominated ecosystem had 4 species (*Corinnomma severum, Hersilia longivulva, Castianeira zetes,* and *Cheiracanthium poonaense*) with higher values ranging from 0.57-0.84; two of the species were specialists. The *Avicennia*-dominated habitat also had four species, but with low IndVal values that were close to 0.5. *Heteropoda* sp.1 (0.61), *Hamataliwa* sp.1(0.57), *Clubiona drassodes* (0.54)*, Parawixia dehaani* (0.52) were bound to *Avicennia.* Meanwhile, the mixed habitat supported six species with a

moderate affinity value ranging from 0.59-0.65. It included three orb weavers (*Neoscona bengalensis*, *Argiope pulchella,* and *Cyrtophora cicatrosa*), 2 other hunters (*Vailimia* sp.1, *Gnathopalystes flavidus*), and one sensing we builder (*Pritha nana).*

Figure 4.5.1 shows the bar chart of indicator species and their corresponding values, and the colour of bars suggests particular habitat types. Species-wise IndVal has been plotted to understand how many species show true affinity towards the corresponding habitats. Figure 4.5.1 substantiates the overall IndVal analysis with *Rhizophora* - dominated system as the centre of exclusivity, with a greater IndVal close to 1. This emphasizes that this habitat is structurally diverse and has a greater microhabitat range with less overlap. Bruguiera and mixed mangroves showed a moderate level of exclusivity; hence, they act as a sharing zone for both distinctive and general species. *Avicennia* turned out to be the habitat with low IndVal, indicating a less complex habitat and a greater range of species overlap.

Table 4.5.4 shows a site-wise summary of ecologically relevant factors. We analysed 3 variables: temperature, humidity, and canopy cover for every 10 sites during the study period. Temperature ranges from 27.50°C to 28.74°C, suggesting a relatively stable thermal regime. Humidity was high across all sites, from the lowest at site 2 (72.41 %) to the highest value at site 6 (81.01 %), revealing highly humid habitat conditions varying at each site. Canopy cover shows a high degree of variation across the sites. Its lowest value starts as low as 49.03 % to as high as 92.46 % at site 2. Canopy cover difference influences the light penetration, overall temperature, and habitat complexity.

Species association with environmental variable: GLM analysis

The table (4.5.5) with FDR corrected Multivariate Generalized Linear Model (GLM) values tells how the presence, absence, or chance of finding a species changes with selected microclimate variables, including canopy cover, humidity, and temperature. This analysis tells which factor is responsible for the presence or absence of species in the habitat. GLM helps to isolate the true ecological signals from a whole bunch of data, particularly when multiple

ecological factors are involved. The test helps to identify the ecologically sensitive species for the corresponding variables and how species respond to them. Finding species-environmental associations is the key to understand the habitat association of spiders.

The GLM analysis of Canopy cover (Table 4.5.5) revealed that it has a predominant role in determining species-specific spider occurrence dynamics. 17 species showed a response to the changes in canopy cover. 10 species showed a positive response, whereas 7 species showed a negative response (Figure 4.5.2). *Cyclosa quinqueguttata* (Log coefficient=603.26), *Drassodes* sp.1 (248.85), *Tylorida striata* (187.25), *Pritha insularis* (153.95), and *Cyclosa* sp.1 (86.06) showed high positive values with significant p-values, indicating that these species prefer shaded canopy-rich areas to survive and reproduce. *Argyrodes flavescens* (-20.17), *Tetragnatha mandibulata* (-9.69), and *Stenaelurillus lesserti* (-7.17) are three species out of seven showing a negative association with canopy cover. This indicates a preference for patchy and more open canopy cover. Therefore, many species prefer canopy density as a positive variable for substance and existence where whereas others prefer openness. Ultimately, the results indicate that canopy cover serves as a structural and microclimatic variable that sieves species based on their functional traits, since many of the positively correlated species are web builders.

From the GLM analysis (Table 4.5.5), temperature serves as the major determinant of spider assemblage in mangroves. A total of 36 species responded to the variable temperature. 21 positively and 16 negatively (Figure 4.5.2). *Pardosa sumatrana* (28.74)*, Thanatus elongatus* (14.46)*, Crossopriza lyoni* (3.16), *Tetragnatha mandibulata* (3.64*), and Stenaelurillus lesserti* (2.07) are the species with a higher log coefficient value. They show a positive correlation to the temperature, and preferably choose a warmer microclimate to exist. Conversely, some species show a negative correlation with temperature and prefer shaded areas for survival. *Cyclosa quinqueguttata* (-68.86), *Neoscona elliptica* (-57.81)*, Castianeira zetes* (-68.76)*, Clubiona Drassodes* (-52.81)*, Drassodes* sp.1 (-30.61), preferably chose cooler and shadier niches to exist.

Species like *Phintella vitata* and *Corinnomma severum* also showed a negative association, suggesting that an increased temperature could exert pressure on them.

Humidity also emerged as an important ecological filter in the distribution of mangrove spiders. According to the GLM output (Table 4.5.5), 21 species showed a significant response to humidity. 6 species showed positive and 15 showed negative affinity towards this variable (Figure 4.5.2). *Argyrodes flavescens* (106.95), *Mimetus indicus* (40.5)*, Hamadruas sikkimensis* (41.77)*, Marengo crassipes* (46.77), *Olios milleti (*31.42*),* and *Tylorida ventralis* (12.4) were the six species that showed a positive correlation to humidity. 15 species showed a great negative log coefficient to humidity: *Tylorida striata* (-1925.47)*, Castianeira zetes* (1601.77), *Pritha insularis* (-1574.56), *Pritha insularis* (-1524.56), and *Acusilas coccineus* (-1500.82). This suggests a strong discontinuity in species tolerance to ambient humidity levels. A core number of species showed a negative correlation to moisture.

The output of GLM analysis across three variables: canopy cover, humidity, and temperature, reveals unique yet coinciding environmental variables shaping the spiders in the mangroves of Kerala. The species sorting gradients with log coefficients and p-values suggest the direction and strength of the ecological responses of species. These results collectively provide captivating evidence that ecological filters operate at a microclimatic level in the community dynamics of spiders. Canopy offering structural complexity, humidity as the moisture stressor, and temperature as thermal niche sorting.

GLM output shows striking sensitivity among the mangrove spiders based on canopy cover, humidity, and temperature. Four species turned out to be the microclimate-sensitive species (Table 4.5.6). *Cyclosa quinqueguttata, Bijoaraneus mitificus,* and *Tylorida striata* (603.26, 9.57, 187.25) showed a positive correlation to the canopy cover. All three species also showed a negative association with both temperature and moisture, with coefficient values -1601.77, -39.2, and -1925.47 for humidity, respectively, and -68.86, -0.87, and -5.89 for temperature, respectively. All three species belong to the functional guild of orb web weavers, so this emphasizes that orb

weavers prefer dense canopies, cooler and less humid conditions in the atmosphere. These are the basic microclimatic features for an orb-weaving spider to survive in the mangrove ecosystem. Meanwhile, *Tetragnatha mandibulata* contradicts the trend by showing a negative association with the canopy (-9.69) and humidity (-46.36), and unlike the other three species, it shows a positive association with temperature (3.64). Implying it may prefer more warmer, open, and drier microclimate. Studies of Janzen (1967) suggest that the microclimatic variables, such as temperature and humidity, play a significant role in the community composition of spiders, which exactly coincides with our results. Since they are poikilotherms, slight shifts in temperature or humidity will affect their habitat stability, prey-capturing efficiency, and physiological features. Basset et al. (2003) suggest that canopy cover also plays a vital role in light penetration, leaf litter density, and structural complexity to maintain the spider assemblage. Collectively, these findings uphold that spider community composition is not randomly assembled, but finely tuned by intersecting abiotic gradients, especially temperature and humidity, along with canopy density.

5.6. Response of spider assemblage to selected anthropogenic variables

Mangroves are one of the vulnerable and crucial ecosystems on the frontline of anthropogenic pressure. Understanding how selected anthropogenic pressures, like canopy openness for deforestation, stump count for logging, and plastic debris density (PDD), as pollution. Quantifying and comparing the disturbance index (DI) derived from the standardised variables, canopy openness, stump count, and plastic debris density, with the Shannon diversity index gives insight into community shifts according to the disturbance, thereby predicting the current status of each study site sampled (Table 4.6.1).

The DI ranged from -2.969 to 2.307. Negative value indicates a less disturbed site, and a positive value indicates a high level of disturbance (Table 4.6.1). The biodiversity index showed a significant relationship with the disturbance index. The site reported with a high DI showed

reduced species richness. Sites 6 (1.964), 7(1.549), and 8(2.307) with species richness 79, 80, and 83, respectively. In contrast, site 9 showed a low DI (-2.36), indicating a complex and less disturbed habitat hosting a pronounced species richness 127 with a robust Shannon index 4.48. Similarly, site 2 also showed the expected relationship, like site 9, with a low DI= - 2.969 and high species richness and Shannon value (S = 122 and H = 4.51). Sites 10 and 3 also showed negative values in DI and were marked with high species richness. Lower positive values of DI 1.85 (site 4), 0.771 (site 1) indicate a moderate species richness ranging from 90-95, making it a transitional zone. The case of site 5 is different, DI = 0.027 with an openness index of 0; the species richness of this site was 105.

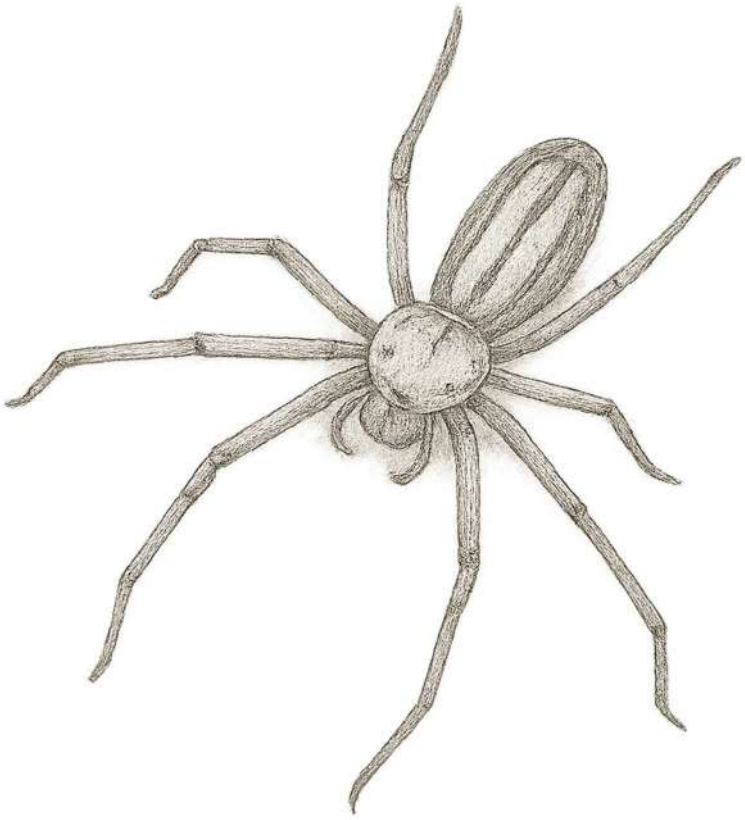
In contrast, plastic debris density -PDD (Table 4.6.1) showed no significance concerning species richness and Shannon diversity index. PDD values at sites 2 (2.16), 10 (2.03), and 9 (0.99) were surprisingly higher, showing higher richness. PDD of 1.96 at site 6 showed lower species richness. Sometimes sites with lower values show lower richness at site 8, PDD is 0.61, and species richness was 83. This shows there is no regular pattern for plastic debris density with species richness or Shannon index. This suggests that even though the plastic pollution can be visible, but not yet disruptive ecologically as long as their microhabitats, including litter, trunk, or canopy, remain intact. This also suggests that spiders might have tolerance or they strategically ignore the plastic load in the ecosystem. Most of the spiders reported from our study occupied the vertical strata rather than the ground, where plastic pollution is visible.

Dual-axis bar chart (Figure 4.6.1) shows the cumulative relationship between the disturbance index (DI) and the plastic debris density (PDD). The chart clearly shows that there is no significant relationship between these proxies. Sites are arranged as (Figure 4.6.1) ascending order of the DI values and the respective PDDs. Sites 2, 9, and 10 show highly negative DI, indicating a structurally intact habitat, but paradoxically report high PDD, suggesting that the plastic contamination is not always coupled with canopy structure. In contrast, sites 6,7, and 8 with higher positive DI values reflect significant degradation of habits.

Spearman's rank correlation coefficient test was done to measure the statistical dependence of variables (Table 4.6.2). A robust and statistically significant correlation was observed between disturbance index and species richness ($r = -0.806$ and $p = 0.0049$) and Shannon index ($r = -0.815$ and $p = 0.0041$). This means that as the structural complexity increases, the diversity and richness increase. Meanwhile, plastic debris density (PDD) did not exhibit a meaningful association with richness ($r = +0.279$ and $p = -0.435$) and Shannon diversity index ($r = +0.377$ and $p = -0.282$).

Spiders, owing to their ecological sensitivity, trophic position, and habitat specificity, serve as valuable bioindicators for assessing the health of mangrove ecosystems. A structurally complex and species-rich spider community often reflects intact habitat conditions, high prey availability, and relatively low anthropogenic disturbance. Conversely, reduced richness, altered guild composition, or dominance by a few generalist species may indicate habitat degradation, pollution, or fragmentation. Spiders respond rapidly to microhabitat changes due to deforestation and logging. But the plastic debris density seems unconnected to their assemblage. Their diversity patterns provide indirect yet reliable signals of ecosystem integrity. Therefore, evaluating spider assemblages offers a robust, non-invasive tool to gauge the ecological health of mangroves, linking faunal diversity directly with ecosystem resilience and functionality.

These findings highlight a significant contrary relationship between anthropogenic disturbance and the species richness of spiders. Increased disturbance level in the mangroves leads to a marked decline in the community heterogeneity and population shifts of spiders. The study of Basset et al. (2008) in the tropical forest system affirms that habitat disturbance can decrease the diversity and richness of spiders. The insignificance between plastic debris density and the species richness of spiders aligns with the work of Kolend et al. (2021), who described that plastic could act as an opportunistic microhabitat for spiders where whereas we observed spiders avoiding the debris in mangrove floors.



CHAPTER 6

SUMMARY AND CONCLUSIONS

The present study investigates the diversity, guild composition, habitat association, their correlation with environmental factors, and their response to selected anthropogenic pressures in selected areas from mangroves of ten districts of Kerala. This study is structured on six major objectives. The present study engaged in a standardised field survey and sampling methods to collect, quantify diversity assessment, functional guild analysis, endemism evaluation, and correlation between environmental factors, floral structures, and selected anthropogenic proxies.

Intensive field sampling resulted in 191 species under 102 genera belonging to 21 families. The site-wise data showed a marked variability in species composition and their abundance according to the complexity of vegetation. Quantification of alpha diversity using different biodiversity indices, including Shannon–Wiener diversity (H′), Simpson's dominance (D), Margalef's richness (d), Fisher's alpha (α), and Pielou's evenness (J′). The Kruskal - Wallis test to understand the inter-site variation showed significance. Sites 2- Kannur, site 9- Kollam, and site 3- Kozhikode were the species-rich sites. These findings suggest that structurally complex and minimally disturbed sites support maximum spider populations. Analysed guild by following Cardoso et al. (2011) and found 8 functional guilds according to their behaviour and niche preferences. Even though there is no strict endemic species restricted to Kerala's mangrove, the weighted Endemism and Corrected Weighted Endemism showed species restricted to certain sites. It could be due to restricted habitat preference or due to the randomness of the sampling. To address the fifth objective, environmental parameters, including canopy cover, ambient temperature, and relative humidity, and found that all the predictors play a significant role in keeping spider assemblages. The results exposed high taxonomic richness and noticeable site-wise heterogeneity, with guild-level analysis based on foraging strategies indicating clear functional partitioning influenced by canopy cover and vegetation complexity. The absence of strictly endemic species, despite the presence of site-restricted taxa, underscores the role of habitat filtering and species turnover rather than phylogeographic isolation in driving beta diversity across mangrove

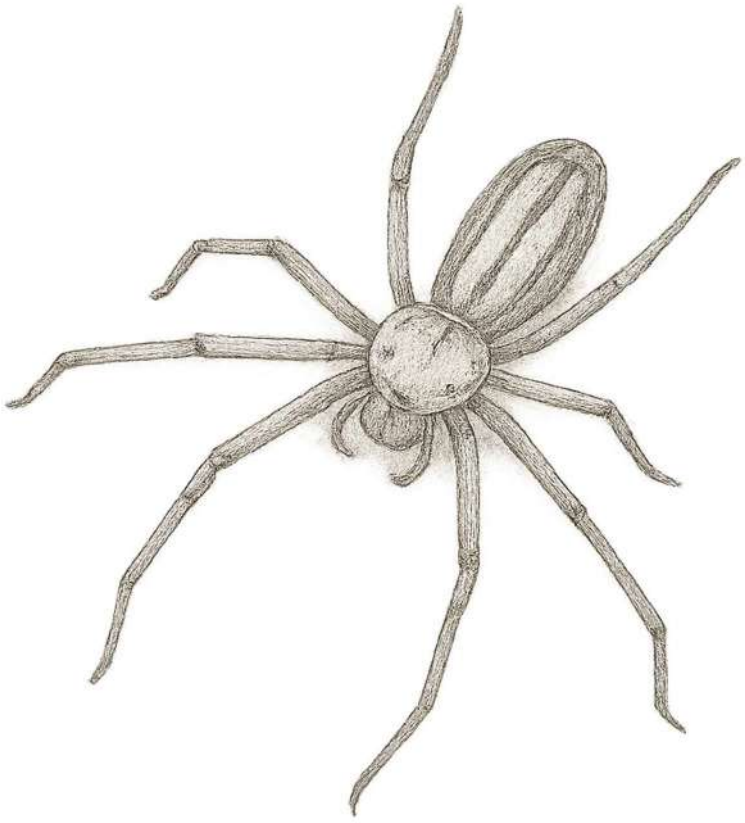
landscapes. The disturbance index score of canopy cover as an indication of deforestation, stump count for logging, and plastic debris count as an indicator of visible pollution in mangroves.

Overall, this study provides the first comprehensive checklist of spiders from the entire mangrove patch in Kerala. This study establishes that spider species have a direct association with habitat, especially the floral structure. The canopy structure plays a prime role in determining the spider assemblage in a site. The study also establishes that spiders can serve as a bioindicator of the ecosystem as a whole. The integrative approach adopted here, spanning taxonomic, functional, spatial, and environmental dimensions, proposes a strong framework for ecological valuation and conservation planning in structurally complex coastal habitats.

Compared to earlier mangrove spider diversity studies conducted in India and abroad, this research pushes beyond simple species checklists by integrating diversity indices, guild structure, habitat associations, and site-wise ecological comparisons from the mangroves of Kerala. While many previous works documented faunal inventories or broad community patterns, the present study provides fine-scale quantitative analysis using Shannon–Wiener, Simpson, richness estimators, and similarity measures, offering a more detailed view of how spider assemblages respond to habitat conditions. This work also highlights endemic and indicator taxa, linking them to ecosystem health—an angle often overlooked in earlier mangrove surveys.

This study on the diversity of spiders in Kerala's mangrove ecosystems offers a scientific basis for strengthening conservation policy and enhancing environmental education within coastal communities. By documenting species richness, guild composition, and habitat associations, the research provides concrete evidence of how spider assemblages reflect mangrove ecosystem health and habitat quality. Such data can guide policymakers in identifying vulnerable zones, prioritising restoration in degraded areas, and developing regulations that minimise anthropogenic pressures. Moreover, the findings create opportunities for environmental outreach by transforming spiders from overlooked organisms into accessible indicators of ecological balance. Integrating this

knowledge into community awareness programs and citizen science initiatives can foster a sense of stewardship, encouraging local people to engage actively in mangrove protection and sustainable coastal management.



CHAPTER 7
RECOMMENDATIONS

1. **Incorporate molecular barcoding to overcome taxonomic challenges:** Juvenile and sub-adult individuals were excluded due to taxonomic challenges. This may result in the underestimated species richness and dominance. Incorporation of molecular barcoding could enable a complete picture of species inventory.
2. **Include comprehensive indices for anthropogenic disturbances:** Anthropogenic influences quantified only by three variables. Integrating some comprehensive indices, including heavy metal assays, salinity shifts, eDNA for pollutants, and land use classification for a better anthropogenic pressure profile.
3. **Genus-level guild matrix:** The present guild study is based on a broad family-level assumption. Understanding and creating a genus-level trait matrix based on foraging strategies and web architecture could add a more precise functional classification and understanding of niche preferences of spiders at the genus level.
4. **A microhabitat level data analysis:** Adopting stratified sampling focusing on microhabitats like edges, shady areas, exposed areas, and litter zones to capture a full-scale habitat level variability.
5. **Conservation prioritization:** The high beta diversity, guild composition, and site-specific unique species indicate that mangroves have a significant role in keeping spiders and their prey arthropods; therefore, each mangrove should be considered as a distinct conservation unit.

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Family Araneidae

Acusilas coccineus

Anepsion maritatum

Arachnura angura

Argiope aemula

Argiope anasuja

Argiope pulchella

Bijoaraneus mitificus

Cyclosa bifida

Cyclosa confraga

Plate 1

Cyclosa hexatuberculata

Cyclosa neilensis

Cyclosa quinqueguttata

Cyclosa sp1

Cyclosa sp2

Cyclosa sp3

Cyrtophora cicatrosa

Cyrtophora unicolor

Eriovixia excelsa

Plate 2

Plate 3

Eriovixia poonaensis

Eriovixia sp1

Gasteracantha geminata

Herennia multipuncta

Neoscona bengalensis

Neoscona mukerjei

Neoscona nautica

Neoscona sp1

Neoscona sp2

Neoscona sp3

Parawixia dehaani

Thelacantha brevispina

Family Cheiracanthiidae

Cheiracanthium danieli

Cheiracanthium indicum

Cheiracanthium melanostomum

Cheiracanthium sp1

Plate 4

Family Clubionidae

Clubiona bengalensis

Clubiona drassodes

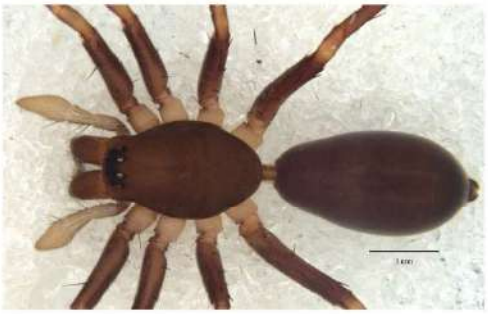
Clubiona sp1

Clubiona sp2

Simalio sp1

Family Corinnidae

Castianeira zetes



Castianeira sp1

Corinnomma severum

Corinnomma sp1

Plate 5

Family Eresidae

Stegodyphus sarasinorum

Family Filistatidae

Pritha sp1

Family Gnaphosidae

Drassodes sp1

Zelotes sp

Family Hersiliidae

Hersilia savignyi

Hersilia sp1

Family Lycosidae

Hippasa agelenoides

Lycosa sp1

Plate 6

Pardosa sumatrana

Pardosa sp1

Pardosa sp2

Family Mimetidae

Mimetus indicus

Mimetus sp1

Family Oxyopidae

Hamadruas sikkimensis

Hamadruas sp1

Hamadruas sp2

Hamataliwa sp1

Hamataliwa sp2

Oxyopes birmanicus

Plate 7

Oxyopes hindostanicus

Oxyopes shweta

Oxyopes sp1

Oxyopes sp2

Peucetia viridana

Family Philodromidae

Philodromus sp1

Psellonus planus

Psellonus sp1

Thanatus elongatus

Plate 8

Family Pholcidae

Crossopriza lyoni

Pholcus phalangioides

Smeringopus pallidus

Family Pisauridae

Dendrolycosa gitae

Family Salticidae

Bianor angulosus

Brettus cingulatus

Chalcotropis pennata

Curubis tetrica

Curubis sp1

Epeus sp1

Plate 9

Habrocestum sp1

Hyllus semicupreus

Indopadilla insularis

Myrmaplata plataleoides

Myrmarachne melanocephala

Myrmarachne sp1

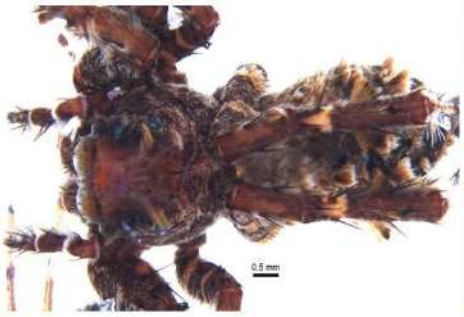
Phintella vittata

Plexippus petersi

Plexippus sp1

Plate 10

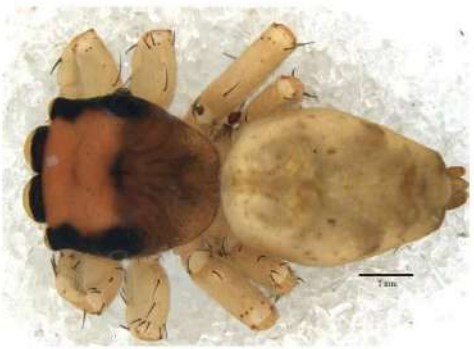
Portia sp1



Portia sp2

Thiania bhamoensis

Toxeus sp



Vailimia sp1

Family Scytodidae

Scytodes fusca

Scytodes thoracica

Scytodes sp1

Family Sparassidae

Gnathopalystes flavidus

Heteropoda venatoria

Heteropoda sp1

Plate 11

Olios milleti

Thelcticopis moolampilliensis

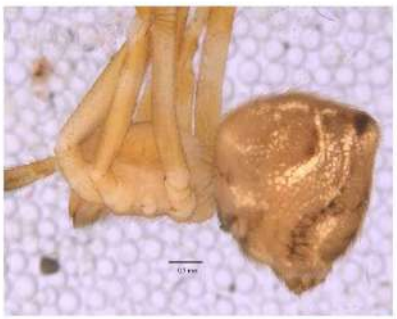
Family Tetragnathidae

Tetragnatha hasselti

Tetragnatha mandibulata

Tetragnatha sp1

Family Theridiidae



Achaearanea durgae

Argyrodes ambalikae

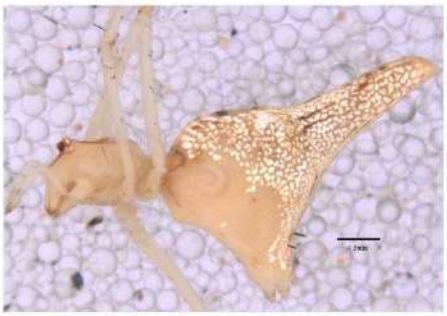
Argyrodes flavescens

Plate 12

Argyrodes sp1

Ariamnes flagellum

Chrysso angula



Meotipa sp1

Nesticodes rufipes

Nihonhimea mundula

Propostira quadrangulata

Steatoda sp1

Theridion sp1

Plate 13

Family Thomisidae

Amyciaea forticeps

Bomis sp1

Camaricus formosus

Runcinia sp1

Thomisus sp1

Plate 14

Family Uloboridae

Uloborus plumipes

Uloborus sp2

Plate 15

LIST OF PUBLICATIONS

- **Vishnudas, E. H.**, Anis, K. V. & Sudhikumar, A. V. 2022. First description of the male comb-footed spider, *Chrysso urbasae* (Tikader, 1970) (Araneae: Theridiidae) with redescription of the female. *Serket 19*(1), 85-89.
- Maddison, W. P., Ruiz, G. R. S., Ng, P. Y. C., **Vishnudas, E. H.** & Sudhikumar, A. V. 2022. *Kelawakaju* gen. nov., a new Asian lineage of marpissine jumping spiders (Araneae, Salticidae, Marpissina). *ZooKeys 1130,* 79-102. doi:10.3897/zookeys.1130.87730
- **Vishnudas, E. H.** & Sudhikumar, A. V. 2022a. First report of *Prosoponoides* Millidge & Russell-Smith, 1992 (Araneae: Linyphiidae) from India, with description of a new species from the Western Ghats. *Arachnology 19*(1), 63-65. doi:10.13156/arac.2022.19.1.63
- **Vishnudas, E. H.** & Sudhikumar, A. V. 2022b. A new synonymy in the spider genus *Prosoponoides* Millidge & Russell-Smith, 1992 (Linyphiidae: Linyphiinae). *Arachnology 19*(2), 580-581. doi:10.13156/arac.2022.19.2.580
- **Vishnudas, E. H.** & Sudhikumar, A. V. 2021. First report of the small daddy long leg spider *Micropholcus fauroti* (Simon, 1887) (Araneae: Pholcidae) female from India with redescription of the male. *Serket 18*(1), 59-63.

PRESENTATIONS

- Participated and presented a paper titled “Comparison of araneofauna in relation to habitat complexity of two selected ecosystem” in the three-day **International Conference on Advance Research, INSIGHT 2024**, held at MES Keveeyam College, Valanchery in February 2024.
- Participated and presented a paper titled “Considering spiders as an indicator taxon prior to conservation plans” in the Two-day **International Seminar on Advanced Techniques in Biological Research,** held at KKTM Government College, Pullut in November 2023.

PARTICIPATIONS AND TRAININGS

- Completed a short-term course on **Basics of Map Preparation using Geographic Information System (GIS),** jointly organised by Teaching Learning Centre, ScholarsConnect – Research's Forum of Christ College and Department of Geology and Environmental Science, Christ College (Autonomous), Irinjalakuda in November 2023.
- Participated in the **National Faculty Development Program on Research and Publication Ethics (RPE)**, organised by Christ College (Autonomous), Irinjalakuda, Thrissur, Kerala, in association with the Kerala State Higher Education Council and Directorate of Research, University of Calicut, in October 2023.
- Participated in the **hands-on workshop on R Programming for Data Analysis** organised by the Department of Statitics, Christ College (Autonomous), Irinjalakuda, Thrissur, Kerala in August 2023.
- Participated in DST-SERB sponsored **National Seminar on Spiders of Western Ghats**, organised by Deva Matha College, Kuravilangad, Kerala in February 2021.

Serket (2022) vol. 19(1): 85-89.

First description of the male comb-footed spider, *Chrysso urbasae* (Tikader, 1970) (Araneae: Theridiidae) with redescription of the female

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Abstract

The male of *Chrysso urbasae* (Tikader, 1970) is first described from Kerala, India with redescription of female. This species was originally described from Sikkim, India only with female specimen. Morphological description of male and redescription of female with detailed photographs are provided.

Keywords: Spider, first report, redescription, Theridiidae, *Chrysso*, India.

Introduction

The genus *Chrysso* O. Pickard-Cambridge, 1882 contains 64 known species with the type species *C. albomaculata* O. Pickard-Cambridge, 1882 (World Spider Catalog, 2022). *Chrysso urbasae* (Tikader, 1970) was first described by Tikader in 1970 as *Linyphia urbasae*. The species was mistakenly placed in the genus "*Linyphia*". Breitling transferred *L. urbasae* to *C. urbasae* in 2015 by analyzing the habitus and diagram of epigyne in the original description (Breitling, 2015). Although the precise positioning of the species is ambiguous, the habitus image and the diagram of female genitalia along with parental care exhibited by *C. urbasae* certainly validates its position in this heterogenous polyphyletic genus *Chrysso*, in family Theridiidae (Barrion *et al.*, 2013; Jin, 2018; Sen *et al.*, 2015). Even though they are common in Southeast Asia, the male of this

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doi: 10.3897/zookeys.1130.87730
https://zookeys.pensoft.net

RESEARCH ARTICLE

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Kelawakaju gen. nov., a new Asian lineage of marpissine jumping spiders (Araneae, Salticidae, Marpissina)

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https://zoobank.org/57F636A8-D488-446F-9210-CBFA33A78998

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Abstract

The genus *Kelawakaju* Maddison & Ruiz, **gen. nov.**, is described for a lineage of bark-dwelling Asian marpissine jumping spiders that represent a dispersal to Eurasia separate from that of the *Marpissa-Mendoza* lineage, according to the phylogeny recovered from analysis of four gene regions. All species of *Kelawakaju* are new to science except *Kelawakaju frenata* (Simon, 1901), **comb. nov.**, which is transferred from *Ocrisiona* Simon, 1901. *Kelawakaju frenata* is known from Hong Kong, Guangdong, Guangxi, and likely Taiwan. The five new species are *Kelawakaju mulu* Maddison & Ruiz, **sp. nov.** (type species of *Kelawakaju*, from Sarawak, Malaysia, ♂♀), *K. intexta* Maddison & Ruiz, **sp. nov.** (from Sarawak, ♂), *K. leucomelas* Maddison & Ng, **sp. nov.** (Singapore and Johor Bahru, ♂♀), *K. sahyadri* Vishnudas, Maddison, & Sudhikumar, **sp. nov.** (India, ♂♀), and *K. singapura* Maddison & Ng, **sp. nov.** (Singapore, ♂♀).

Keywords

Classification, Dendryphantini, molecular phylogeny, new genus, new species, Salticinae, Salticoida, taxonomy

First report of *Prosoponoides* Millidge & Russell-Smith, 1992 (Araneae: Linyphiidae) from India, with description of a new species from the Western Ghats

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Abstract

Prosoponoides is one of the smallest genera from the second largest family Linyphiidae, first described by Millidge & Russell-Smith in 1992. All known species are described from Asia but the genus has not previously been reported from India. A morphological description of the new species, digital photographs, and drawings are provided.

Keywords: *Kenocymbium* • Kerala • *Ketambea* • Linyphiinae • sheet-web builders

Introduction

Linyphiidae is one of the largest spider families of ecribellate sheet-web builders. The diversity of linyphiid spiders is greater in the north temperate regions. *Prosoponoides* is among the smallest genera in the subfamily Linyphiinae. Millidge & Russell-Smith (1992) initially described the genus *Prosoponoides* for three species: *Prosoponoides hamatum* Millidge & Russell-Smith, 1992, (type species), *P. kaharianus* Millidge & Russell-Smith, 1992, and *P. simile* Millidge & Russell-Smith, 1992. Since then, three more species have been described, *P. jambi* Tanasevitch, 2017, *P. sinense* (Chen, 1992), and *P. youyiensis* Liu & Chen, 2020, all recorded from Asia. Most species are reported from China and Indonesia (World Spider Catalog 2022).

Prosoponoides is morphologically very similar to *Kenocymbium* Millidge & Russell-Smith,1992 and *Ketambea* Millidge & Russell-Smith, 1992, but there are several distinguishing features. *Prosoponoides* shares three characters with *Ketambea* including a small paracymbium and filiform embolus in the male palp and epigyne with an atrium (Figs. 1C, 2C). *Prosoponoides* can be separated from *Ketambea* by the presence of a second membrane on the lamella of the male palp and an extremely chitinized parmula in the female epigyne (Figs. 1C, 2C). *Kenocymbium* can be distinguished from *Prosoponoides* by the absence of a paracymbium in the male palp and presence of tubular spermathecae in the female epigyne (Figs. 1C, 2D).

Material & methods

All specimens were collected by visual searching and hand collection into plastic vials containing 75% ethanol. Morphological examination was undertaken under a Leica M205C stereomicroscope. The digital images were taken using a Leica DMC4500 digital camera attached to the stereomicroscope and edited with the software package Leica Application Suite (LAS), version 4.3.0 LAS montage facility. Female genitalia were dissected as in Levi (1965) and Chen *et al*. (2021) and examined after digesting with KOH. The male palp was dissected and treated with gently boiling KOH and the embolic division dissected out by breaking the non-chitinous, membranous connection between suprategulum and radix. All measurements are in millimetres. Measurement data for legs are as follows: total length (femur, patella, tibia, metatarsus, tarsus). The specimens studied are housed in the Centre for Animal Taxonomy and Ecology (CATE), Department of Zoology, Christ College (Autonomous), Irinjalakuda, Kerala, India.

Abbreviations: Male palp: ALP = anterior projection of lamella, DLP = dorsal projection of lamella, E = embolus, EM = embolic membrane, L = lamella, LLP = lateral projection of lamella, P = paracymbium, PLP = posterior projection of lamella, SM = second membrane, ST = subtegulum, T = tegulum; Epigyne: CD = copulatory duct, CO = copulatory opening, FD = fertilization duct, Pa = parmula, S = spermatheca; Somatic characters: ALE = anterior lateral eye, AME = anterior median eye, PLE = posterior lateral eye, PME = posterior median eye.

Linyphiidae Blackwall, 1859

Prosoponoides Millidge & Russell-Smith, 1992

Type species: *Prosoponoides hamatum* Millidge & Russell-Smith, 1992

Prosoponoides biflectogynus sp. nov. (Figs. 1–4)

Etymology: the specific epithet refers to the Latin words for "two turns" of the copulatory duct of the epigyne.

Material examined: 3♂♂, 2♀♀, INDIA: Vettilappara, Kerala, 10.292°N 76.514°E, 28 September 2021, E. H. Vishnudas & A. V. Sudhikumar (CATE 5644901).

Diagnosis: The new species is most closely related to *Prosoponoides sinense* (Chen, 1991) known from the mainlands of China (Hainan) and Vietnam. The male of *P. biflectogynus* sp. nov. can be distinguished from that of *P. sinense* by the prominent anterior hump on the tegulum and a filiform embolus without a wide membrane (Fig. 3). Unlike *P. sinense*, the radix of the pedipalp of *P. biflectogynus* has a median constriction (Fig. 1D). The LLP has a strongly acanthoid apophysis (Fig. 1D) which is blunt in *P. sinense*. The cymbium of the male palp has a basal triangular apophysis (Figs. 1C, 3B). The female can be distinguished by the elliptical atrium and the presence of a tiny and highly sclero-

Arachnology (2022) **19** (2), 580–581

A new synonymy in the spider genus *Prosoponoides* Millidge & Russell-Smith, 1992 (Linyphiidae: Linyphiinae)

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Introduction

The family Linyphiidae Blackwall, 1859 is the second largest family of spiders after Salticidae and one of the least studied families in India. The southern Asian genus *Prosoponoides* was erected by Millidge & Russell-Smith in 1992. The Greek word *Prosopon* means a face and -*oides* stands for appearance. The ventral view of the female epigyne resembles a face, thus the name *Prosoponoides*. At present, the genus has eight described species from China, Thailand, Indonesia, Vietnam, and India (World Spider Catalog 2022). Most of the species are systematically classified by analysing the female epigynal morphology and the structure of embolic division and supertegulum of the male palp (Millidge 1993). The important taxonomic features of the genus *Prosoponoides* lie within the conformation and shape of the copulatory duct, the position of the fertilization duct, and the shape and size of the parmula in the female genitalia. For males, a special and important emphasis has been given to the shape and conformation of the embolic division, the length and orientation of the embolus, and the structure of the suprategulum of the male copulatory organ to avoid confusion in the systematics of the genus (Millidge 1997). The placement of newly described species from India by Vishnudas & Sudhikumar (2022) could be the same species described by Domichan & Jose in 2022. The obscurity in the placement of *P. biflectogynus* Vishnudas & Sudhikumar, 2022 may be due to the lack of detailed and labelled illustrations and high quality photographs of the species *P. idukkiensis* Domichan & Jose, 2022. Chen *et al.* (2020) followed a method of dissecting the embolic division and analysing its structure, which enhanced the credibility of species level identification. Dissecting out the embolic division could expose the structure of the radix, the secondary membrane, and the base of the embolus. Vishnudas & Sudhikumar (2022) also adopted this methodology to avoid possible confusion in the description of *P. biflectogynus*, whereas the description of *P. idukkiensis* lacked these details. Most species of the genus *Prosoponoides* show similarities in their general appearance. In order to confirm the species, detailed examination of genitalia is necessary.

Material and methods

All specimens were collected by visual searching and hand collection into plastic vials containing 75% ethanol. Morphological examination was undertaken under a Leica M205C stereomicroscope. The digital images were taken using a Leica DMC4500 digital camera attached to the stereomicroscope and edited with the software package Leica Application Suite (LAS), version 4.3.0 LAS montage facility. Female genitalia were dissected as in Levi (1965) and Chen et al (2020) and examined after digesting with KOH. The male palp was dissected and treated with gently boiling KOH and the embolic division was dissected out by breaking the non-chitinous membranous connection between suprategulum and radix.

Abbreviations: ALE = anterior lateral eyes, PLE = posterior lateral eyes.

Linyphiidae Blackwall, 1859

Linyphiinae Blackwall, 1859

Prosoponoides Millidge & Russell-Smith, 1992

Prosoponoides idukkiensis Domichan & Jose, 2022

Prosoponoides idukkiensis Domichan & Jose, 2022: 20626, figs. 1–4, imgs. 1–11.

Prosoponoides biflectogynus Vishnudas & Sudhikumar, 2022: 63, figs. 1A–E, 2A–D, 3A–C, 4A–B. **New synonymy**.

Justification for synonymy: Careful examination of photographs and illustrations of the holotype of *P. biflectogynus* revealed that this species has all the diagnostic features of *P. idukkiensis*. General morphological features of the male, e.g. juxtaposed ALE & PLE, heart-shaped sternum, leg formula 1243, absence of stridulatory ridges, yellowish legs with spines, are analogous. The male pedipalp also shows a considerable amount of similarity in the conformation and shape of its structures: distally pointed small paracymbium, laterally narrowed well-developed lamella, and filiform embolus. The female epigynum also shows significant similarities: semi-elliptical with atrium separated by septum, highly sclerotized tongue-shaped parmula connected to septum dividing atrium arising from dorsal side. The species *P. biflectogynus* should thus be considered as a junior synonym of the species *P.* idukkiensis; compare Domichan & Jose (2022) figs. 1–4 and images 1–11 with Vishnudas & Sudhikumar (2022) figs. 1–4.

Remarks: Examination of the photographs and illustration of *P. idukkiensis* does not shows the clear path of the fertilization duct due to the presence of muscle tissues (see Domichan & Jose (2022) images 8–11). Therefore, the number of turns cannot be counted distinctly; it is possible there are two turns rather than one and half as in *P. hamatum* and *P. youyiensis* Millidge & Russell-Smith, 1992: compare Vishnudas & Sudhikumar (2022) fig. 2D with Domichan & Jose (2022) images 10–11). The position and the shape of

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First report of the small daddy long leg spider *Micropholcus fauroti* (Simon, 1887) (Araneae: Pholcidae) female from India with redescription of the male

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Abstract

Pholcids are the commonly and abundantly occurring synanthropic spiders with worldwide distribution. Small daddy long leg spider *Micropholcus fauroti* (Simon, 1887) has been reported from many countries across the globe. So far only male of *M. fauroti* has been reported from Poona, India. In the present study, female of *M. fauroti* is reported for the first time from India.

Keywords: *Micropholcus fauroti*, Daddy long leg spider, synanthrope, first report, India.

Introduction

Long legged spider genus *Micropholcus* Deeleman-Reinhold & Prinsen, 1987 belongs to family Pholcidae which presently includes 1842 named species (World Spider Catalog, 2021) with about 4000-5000 estimated species worldwide (Huber *et al.*, 2017). This versatile group of spiders inhabit from leaf litters to tree canopies and from dark caves to most modern buildings. Many members of this family are often confused with daddy long legs of order opiliones because of the exceptionally elongated and pseudo-segmented legs (Huber, 2009). Modern taxonomic practices including molecular phylogeny made this group more precise and vivid by shifting, merging and synonymizing many genera. Pholcidae include small to medium ecribellate spiders with six or eight eyes usually with very long fragile legs having a pseudosegmented tarsi ending in three claws. The current studies regarding Indian pholcids ensures 6 genera and