

# Ecological Role and Host-Plant Interaction of Hemiptera Species in Mokhada, Palghar District from the Northern Western Ghats, Maharashtra

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## Abstract

The Western Ghats of India are a global biodiversity hotspot, yet the ecological networks governing its Hemipteran fauna remain poorly documented, particularly in the northern regions. This study provides a fine-scale characterization of Hemipteran assemblages and their host-plant relationships in the Mokhada region of Palghar, Maharashtra. Utilizing a multi-tiered methodological framework across 15 sampling sites, the research assessed five distinct habitat types: moist deciduous forests, plantations, riparian zones, scrublands, and degraded wastelands spanning an altitudinal gradient of 410 to 780 m above sea level (ASL). The investigation yielded a high-resolution dataset of 53 distinct species-to-host associations across 21 angiosperm orders and 26 families.

The results identify Fabaceae (18.9%), Poaceae (13.2%), Cucurbitaceae (11.3%), and Sapindales (11.3%) as the primary botanical hubs for the regional fauna. A significant correlation was observed between habitat stability and dietary strategy; stable forest environments were overwhelmingly dominated by host-specific specialists (82%), whereas anthropogenically disturbed wastelands were characterized by a shift toward generalist dominance (92%). Spatiotemporal analysis revealed that species richness peaks sharply during the host's fruiting phase (26 species), with vertical stratification playing a key role in niche partitioning from the ground layer to the forest canopy.

The 68% of the identified associations were confirmed as true developmental hosts through laboratory rearing and behavioral assays. Collectively, these findings underscore the ecological fragility of the northern Western Ghats, demonstrating that Hemipteran diversity is deeply integrated into the phenology and structural complexity of the local flora. This study establishes a critical baseline for monitoring the impacts of habitat fragmentation on trophic stability and regional biodiversity conservation.

**Keywords:** Host phenology; rarefaction curve analysis; ecological framework; occupancy modelling; presence-absence matrix; Darwin Core; Global Biodiversity Information Facility (GBIF).

## 1. INTRODUCTION

Forests sustain high levels of biological diversity and deliver critical ecosystem services, including carbon storage, water regulation, and habitat provision for a myriad of taxa (e.g., trees, fungi, invertebrates) that

together maintain ecosystem functioning and resilience (Feng et al., 2024; Lindenmayer & Bowd, 2022). The Western Ghats of India are globally recognized as a biodiversity hotspot, containing numerous endemics and threatened taxa across terrestrial and freshwater systems; consequently, fine-scale ecological knowledge from this region is essential for effective conservation and management planning (Raghavan et al., 2016; Trivedi & Bharucha, 2023). Localized forest fragments or “hot specks” can harbor disproportionate biodiversity value, and targeted, in-situ studies are frequently required to identify and prioritize such areas for conservation action (Trivedi & Bharucha, 2023).

Insects are major components of forest biodiversity and play key roles in energy transfer, nutrient cycling, and plant population dynamics. Hemiptera (true bugs) are a diverse insect order whose species occupy multiple trophic niches, including sap-feeders, predators, and plant-associated taxa, and whose interactions with host plants influence primary productivity, plant community composition, and higher trophic levels. Understanding the composition, seasonal dynamics, and host-plant preferences of Hemipteran assemblages, therefore, contributes directly to ecological knowledge of plant–insect networks and can inform management measures aimed at preserving forest structural complexity and function (Kang et al., 2024).

Forest ecosystems are shaped by multiple interacting drivers, abiotic gradients, plant traits and belowground microbial processes, as well as biotic interactions such as herbivory and seed dispersal, all of which can modulate insect communities and their ecological roles (Auer et al., 2023; Maitra et al., 2024; Oneş et al., 2025). For example, herbivory by large mammals can restructure understory plant assemblages, potentially altering available niches for insect herbivores and their predators, while dead wood and decay dynamics influence saproxylic communities that contribute to nutrient cycling and biodiversity persistence (Chollet et al., 2021; Kang et al., 2024). Given these complex linkages, local assessments of insect assemblages and their plant associations are necessary to reveal patterns that might be obscured at broader spatial scales and to guide landscape-level conservation strategies that aim to preserve ecosystem processes as well as species diversity (Lindenmayer & Bowd, 2022; Oliveira et al., 2025).

Despite the recognized ecological importance of Hemiptera and the conservation significance of the Western Ghats, there remains a paucity of fine-scale, taxonomically explicit studies documenting Hemipteran assemblages and their host-plant relationships in many parts of the region. Mokhada (northern western Ghats) comprises remnant forest patches and a heterogeneous mosaic of habitats where plant–insect interactions have not been comprehensively documented. Characterizing Hemipteran diversity and host-use patterns in this locality will fill an important knowledge gap, offering baseline data for long-term monitoring, informing local management, and contributing to regional conservation prioritization for invertebrate biodiversity (Pawar & Pawar, 2025; Trivedi & Bharucha, 2023).

Despite the well-recognized ecological importance of Hemiptera and the high conservation value of the Western Ghats, there remains a marked paucity of fine-scale, taxonomically explicit studies documenting Hemipteran assemblages and their host plant relationships across many parts of this region. Mokhada, located in the northern Western Ghats, comprises remnant forest patches interspersed within a heterogeneous mosaic of natural and anthropogenic habitats, where plant–insect interactions remain inadequately documented. Characterizing Hemipteran diversity and host-use patterns in this locality will address a significant knowledge gap by generating baseline data essential for long-term biodiversity monitoring, informing site-specific management strategies, and contributing to regional conservation prioritization for invertebrate fauna (Pawar & Pawar, 2025; Trivedi & Bharucha, 2023).

The Western Ghats of India is recognized as a global biodiversity hotspot, yet much of its hemipteran diversity and associated ecological interactions remain poorly documented, particularly in the northern landscape of Mokhada, Palghar. While Hemiptera are vital components of terrestrial ecosystems and significant indicators of environmental health, there is a critical lack of empirical data regarding their host-plant specificity and feeding guilds within this specific region. The research problem stems from the absence of a comprehensive inventory and a clear understanding of how these assemblages utilize local flora. This knowledge gap hinders the ability to map complex insect-plant networks or predict how habitat fragmentation might affect regional biodiversity. Consequently, this study is driven by the need to establish a baseline ecological characterization that links species-level observations to habitat-specific host preferences in this ecologically sensitive zone.

The present study aims to inventory the Hemipteran species occurring across selected habitats of the Mokhada study sites, to quantify host plant associations and preferences within the Hemipteran assemblage, and to examine Hemipteran feeding strategies by linking species-level observations with specific plant hosts and habitat attributes. Through this integrated approach, the study seeks to elucidate the ecological structure and functional organization of Hemipteran-plant interaction networks in Mokhada, located in the Western Ghats.

## 2. METHODOLOGY

### i) Study Area and Site Selection:

The present study was conducted in Mokhada Taluka, Palghar District, Maharashtra, situated within the northern sector of the Western Ghats. To ensure a representative and ecologically robust assessment, a total of fifteen (15) sampling sites were strategically selected across five distinct habitat types, namely Plantation Areas (PL), Moist Deciduous Forests (MF), Riparian Zones (RZ), Open Scrublands (OS), and Degraded Forests/Wastelands (WL).

The selected sites are geographically distributed within the latitudinal range of 19.9086° N to 20.0416° N and longitudinal range of 73.2594° E to 73.3642° E, encompassing an altitudinal gradient from 410 m to 780 m above sea level (ASL). This multi-site sampling framework captures significant variations in vegetation structure, microclimatic conditions, and degrees of anthropogenic disturbance, thereby providing a robust basis for evaluating Hemipteran community dynamics and host-plant interactions across contrasting ecological settings.

For analytical clarity, the sampling sites were categorized into five distinct habitat clusters, ranging from high-canopy moist deciduous forests to riparian margins, plantation landscapes, open scrublands, and degraded wastelands. This stratified classification establishes a comparative baseline to assess how land-use intensity, habitat structural complexity, and vegetation composition influence Hemipteran diversity, abundance, and host-plant preferences.

Mokhada Taluka was selected as the study area due to its pronounced habitat heterogeneity, rich and diverse plant resources, marked altitudinal variation, and transitional landscape structure characteristic of the northern Western Ghats. Additionally, the region remains poorly documented with respect to fine-scale Hemipteran diversity and insect-host plant associations, thereby making it an ecologically significant and scientifically justified location for the present investigation.

**Table 1. Geospatial and Ecological Characteristics of Selected Sampling Sites in Mokhada.**

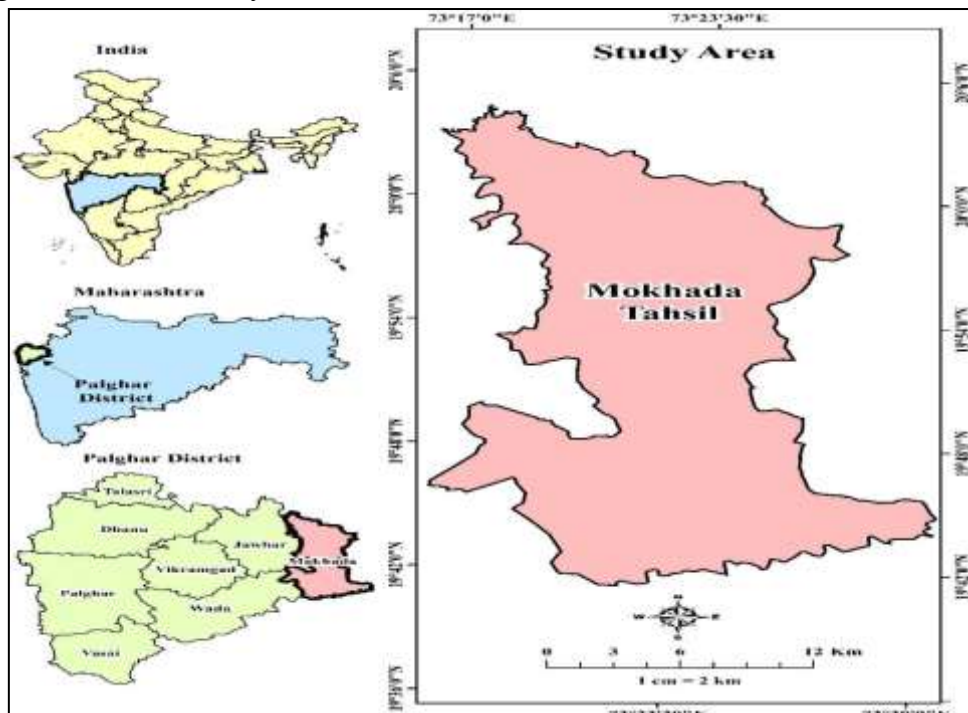
Habitat Type	Site Codes	Latitude (N)	Longitude (E)	Altitude (m)
Plantation	PL1–PL3	19.9342°– 19.9714°	73.3095° – 73.3271°	520 – 590
Deciduous Forest	MF1–MF3	19.9784°– 20.0416°	73.2786° – 73.3018°	710 – 780
Riparian Zone	RZ1–RZ3	19.9213°– 19.9882°	73.3364° – 73.3589°	430 – 510
Open Scrubland	OS1–OS3	19.9895°– 20.0284°	73.3326° – 73.3642°	650 – 690
Degraded Forest	WL1–WL3	19.9086° – 19.9938°	73.2594° – 73.2917°	410 – 570

**Ecological Characterization of Sampling Habitats**

The 15 sampling stations established across Mokhada Taluka represent a significant altitudinal and ecological transect (410–780 m ASL), capturing the heterogeneous landscape of the Northern Western Ghats. The Moist Deciduous Forests (MF) at higher elevations provide stable, multi-layered canopies that support host-specific Hemipteran specialists sensitive to environmental flux. In contrast, the Agroecosystems and Plantations (PL) offer resource-rich environments where consistent irrigation sustains high abundances of polyphagous and economically significant species. The Riparian Zones (RZ) serve as perennial ecological refugia and moisture-dependent interfaces, while the Open Scrublands (OS) function as high-exposure ecotones dominated by grass-dwelling assemblages.

**ii. Methodology for Host-Plant Identification and Validation:** Host-plant associations were determined through a multi-tiered framework involving field observations, taxonomic verification, and laboratory validation.

**Field Identification and Botanical Sampling:** Direct associations defined by feeding (stylet insertion), oviposition, or nymphal colonies were recorded in situ. For each interaction, botanical vouchers were collected, pressed, and labeled following standard phytosociological protocols. Taxonomic identification was performed using regional floras (e.g., Flora of the Presidency of Bombay; Flora of Maharashtra State) and verified against the APG IV system and POWO database.



**Figure 1: Location Map of the Study Area**

### **Association Validation and Matrix Construction**

Observed records were cross-referenced with established entomological literature (e.g., Ambrose, 2006; Kalaisekar et al., 2017) to distinguish between confirmed and novel associations. Validated data were cataloged into a relational matrix detailing Hemipteran life stages, specific plant parts utilized (leaf, stem, fruit), and host phenology.

### **iii. Species Collection Techniques & analysis tools**

A comprehensive field sampling strategy was implemented to encompass the vast ecological heterogeneity and behavioral diversity of Hemipteran insects. The methodology integrates active interception, passive entrapment, and specialized habitat-targeted techniques across temporal (seasonal and diel) and spatial (habitat stratification) scales. The design was guided by entomological best practices and conforms to the rigor required for taxonomic, ecological studies. To mitigate temporal biases in species detectability and activity, sampling was standardized across three diel windows: morning (0700–1100 hrs), afternoon (1300–1600 hrs), and night (1900–2300 hrs). Each technique was replicated three times per plot per season, with triplicate plots sampled in each major habitat type. This orthogonal and stratified design enhanced statistical robustness, allowed for rarefaction curve analysis, and enabled occupancy modelling using presence-absence matrices.

### **Post-Collection Analysis and Taxonomic Processing**

Post-collection procedures constitute a pivotal phase in entomological biodiversity studies, ensuring the preservation of specimen integrity, the accurate capture of contextual metadata, and the traceability of taxonomic data. In the present study, two parallel specimen management protocols were followed: (i) non-destructive catch-and-release handling, employed primarily in protected habitats and for rare or vulnerable taxa, and (ii) permanent specimen preservation, applied where morphological or taxonomic analysis necessitated physical retention. All procedures were aligned with standard global biodiversity data frameworks, including Darwin Core, GBIF, and institutional curation policies.

## **3. RESULT AND DISCUSSION**

The systematic investigation into the Hemipteran assemblages of the Northern Western Ghats has yielded a high-resolution ecological dataset comprising 53 distinct species-to-host associations. This research provides empirical clarity on the trophic linkages that sustain insect biodiversity in one of the world's most significant biodiversity hotspots. By synthesizing precise taxonomic identification with multi-season field observations of host phenology and habitat types, the study reveals that Hemipterans are not merely incidental visitors to the flora; they are deeply integrated into the botanical architecture and nutrient cycles of the landscape. The results, articulated below, are categorized into four thematic pillars: the taxonomic and phylogenetic breadth of host plants; the strategic gradients of host specificity and feeding strategies; the micro-spatial utilization of plant morphology, coupled with phenological synchrony; and the documentation of novel ecological records that expand the known entomofauna of the region. The integrated methodological framework yielded a high-resolution dataset comprising 53 distinct Hemipteran–host plant associations, providing robust empirical evidence for trophic linkages across diverse habitats in the northern Western Ghats.

### **3.1. Hemipteran Species and Ecological Distribution of Host Plants**

The systematic investigation of Hemipteran assemblages in the Northern Western Ghats yielded a high-resolution dataset of 53 distinct species-to-host associations, revealing the deep integration of these insects

into the regional botanical architecture. The host landscape spans a broad phylogenetic spectrum, encompassing 21 angiosperm orders and 26 families.

- **Dominant Host Families:** The ecological framework is anchored by three primary families: Fabaceae (10 associations), which supports high Pentatomid and Scutellerid diversity (e.g., *Chrysocoris stollii* on *Cassia* spp.) due to nutrient-rich nitrogen-fixing tissues; Poaceae (7 associations), which sustains Auchenorrhyncha.
- **Vertical Stratification:** Host utilization follows a clear structural gradient. High-canopy trees (e.g., *Sapindus*) support perennial specialists like *Pyrops maculata*, while the mid-story woody shrubs (e.g., *Ziziphus mauritiana*) serve as hotspots for Pentatomid diversity. The ground layer, consisting of herbs and grasses, supports mobile, r-selected species. Notably, the documentation of *Saissetia coffeae* on wild ferns indicates that these trophic webs extend into ancient non-angiosperm lineages within riparian zones.

### Feeding Strategies and Gradients of Host Specificity

**Host-Specific Associations (Oligophagous/Monophagous):** High host fidelity was observed in 55% (29 associations) of the species, particularly within stable climax forests.

**Table 2. Site-specific distribution of Hemipteran fauna and their associated host-plant relationships, including ecological strategies and phenological conditions.**

S r. N o.	Sit e C o d e	Host Suborder/ Clade	Host Family	Host Species Name (Natural/ Wild)	Associate d Hemipte ran Species	Ecological Strategy	Plant Part Utilized	Phenological Condition
1	PL 1	Ericales	Theaceae	Camellia sinensis (Wild)	Bothrogo nia ferrugine a	Host-Specific	Leaf, Young shoot	Vegetative/N ew Flush
2	PL 2	Fabales	Fabaceae	Vicia spp. / Wild Legumes	Empoasc a fabae	Seasonal/Opp ortunistic	Leaf (Under surface)	Vegetative to Flowering
3	PL 3	Sapindale s	Anacardi aceae	Mangifer a sylvatica	Idioscopu s nitidulus	Host-Specific	Infloresc ence, Leaf	Flowering
4	M F1	Poales	Poaceae	Leersia hexandra	Nephotett ix virescens	Seasonal/Opp ortunistic	Leaf, Stem	Vegetative
5	M F2	Poales	Poaceae	Oryza rufipogon	Nilaparva ta lugens	High Abundance	Stem (Base)	Vegetative to Maturity
6	M F3	Poales	Poaceae	Wild Meadow Grasses	Sogatella furcifera	High Abundance	Stem, Leaf	Vegetative

7	RZ 1	Malvales	Malvaceae	Forest Canopy Trees	Pyrops maculata	Host-Specific	Trunk (Bark/Sap)	Year-round (Perennial)
8	RZ 2	Cucurbitales	Cucurbitaceae	Wild Forest Vines	Aspongopus brunneus	Resilient/Generalist	Stem, Fruit	Flowering/Fruiting
9	RZ 3	Cucurbitales	Cucurbitaceae	Wild Climbers	Coridius chinensis	Resilient/Generalist	Stem, Leaf	Vegetative
10	OS 1	Cucurbitales	Cucurbitaceae	Cucurbita (Wild types)	Coridius janus	Resilient/Generalist	Fruit, Stem	Fruiting
11	OS 2	Fabales	Fabaceae	Pongamia pinnata	Cyclopelta siccifolia	Host-Specific	Stem, Tender Twig	New Flush
12	OS 3	Cucurbitales	Cucurbitaceae	Wild Bitter-vines	Megymenum distanti	Resilient/Generalist	Stem, Fruit	Fruiting
13	W L1	Various	Various	Wild Forest Shrubs	Amyotea malabarica	Predator Specialist	(Predator on Leaves)	Flowering (Attracts prey)
14	W L2	Gentianales	Rubiaceae	Wild Coffee Shrubs	Antestia astrolabii	Host-Specific	Berry, Bud	Flowering/Fruiting
15	W L3	Brassicales	Cleomaceae	Cleome spp.	Bagrada hilaris	Resilient/Generalist	Leaf, Seed pod	Flowering/Fruiting
16	PL 1	Sapindales	Rutaceae	Wild Citrus Relatives	Bathycoelia indica	Host-Specific	Fruit, Twig	Fruiting
17	PL 2	Pinales	Pinaceae	Pinus spp.	Brochymena quadripustulata	Host-Specific	Stem, Twig	Year-round
18	PL 3	Various	Various	Evergreen Understory	Capivaccius spurcus	Host-Specific	Leaf, Stem	Vegetative
19	M F1	Sapindales	Anacardiaceae	Anacardium (Wild)	Catacanthus incarnatus	Host-Specific	Apple/Node, Shoot	Flowering/Fruiting
20	M F2	Various	Various	Broad-leaf	Dalpada oculata	Host-Specific	Bark, Twig	Year-round

				Forest Trees				
21	M F3	Solanales	Solanaceae	Wild Solanum Shrubs	Dalpada versicolor	Host-Specific	Fruit, Leaf	Fruiting
22	RZ 1	Various	Various	Mountainous Shrubs	Degonetu s serratus	Host-Specific	Leaf, Shoot	New Flush
23	RZ 2	Various	Various	Broad-leaf Canopy	Eocanthe cona furcellata	Predator Specialist	(Predator y on Leaves)	Vegetative (High prey)
24	RZ 3	Various	Various	Broad-leaved Forest Trees	Erthesina acuminat a	Resilient/Gene ralist	Trunk, Branch	Year-round
25	OS 1	Rosales	Rhamnaceae	Ziziphus mauritian a	Erthesina fullo	Resilient/Gene ralist	Fruit, Twig	Fruiting
26	OS 2	Poales	Poaceae	Meadow Grasses	Eysarcori s guttiger	Seasonal/Opp ortunistic	Earheads /Seed	Flowering/Fr uiting
27	OS 3	Poales	Poaceae	High-altitude Grasses	Eysarcori s montivag us	Seasonal/Opp ortunistic	Seed head	Flowering/Fr uiting
28	W L1	Apiales	Apiaceae	Wild Umbellife rs	Graphoso ma rubroline ata	Host-Specific	Seed head (Umbel)	Flowering/Fr uiting
29	W L2	Sapindale s	Simaroub aceae	Ailanthus altissima	Halyomor pha halys	Resilient/Gene ralist	Fruit, Stem	Fruiting/Sene scence
30	W L3	Various	Various	Wild Ornament al Woods	Halyomor pha picus	Resilient/Gene ralist	Fruit, Stem	Fruiting
31	PL 1	Fabales	Fabaceae	Acacia nilotica	Halys dentatus	Host-Specific	Bark, Twig	Year-round
32	PL 2	Cucurbit ales	Cucurbit aceae	Wild Hedge Vines	Megymen um parallelu m	Resilient/Gene ralist	Stem, Fruit	Fruiting
33	PL 3	Poales	Poaceae	Marsh Grasses	Menida metallica	Seasonal/Opp ortunistic	Leaf sheath, Seed	Flowering

34	M F1	<b>Fabales</b>	Fabaceae	Wild Leguminosae	Nezara indica	Resilient/Generalist	Pod, Seed	Fruiting
35	M F2	<b>Brassicales</b>	Cleomaceae	Cleome / Wild Sunflower	Nezara viridula	Resilient/Generalist	Developing Seed	Flowering/Fruiting
36	M F3	<b>Poales</b>	Poaceae	Woodland Edge Grasses	Niphe subferruginea	Seasonal/Oppportunistic	Seed head	Flowering/Fruiting
37	RZ 1	<b>Solanales</b>	Solanaceae	Wild Solanaceous Weeds	Oplomus catena	Predator Specialist	(Predator on Leaf)	Vegetative
38	RZ 2	<b>Fabales</b>	Fabaceae	Crotalaria spp.	Piezodorus hybneri	Seasonal/Oppportunistic	Pod, Seed	Fruiting
39	RZ 3	<b>Rosales</b>	Moraceae	Morus alba (Wild)	Plautia crossota	Host-Specific	Berry, Leaf	Fruiting
40	OS 1	<b>Various</b>	Various	Forest Berries	Plautia stali	Host-Specific	Fruit	Fruiting
41	OS 2	<b>Various</b>	Various	Tropical Scrub Shrubs	Calliphara excellens	Host-Specific	Seed, Fruit	Fruiting
42	OS 3	<b>Fabales</b>	Fabaceae	Acacia spp.	Chrysocoris purpureus	Host-Specific	Fruit/Seed pod	Fruiting
43	W L1	<b>Fabales</b>	Fabaceae	Cassia fistulosa	Chrysocoris stollii	Host-Specific	Pod, Flower bud	Flowering/Fruiting
44	W L2	<b>Various</b>	Various	Tropical Hardwoods	Eucorysses grandis	Host-Specific	Twig, Leaf	New Flush
45	W L3	<b>Ericales</b>	Theaceae	Wild Camellia relatives	Poecilocoris druriei	Host-Specific	Seed, Fruit	Fruiting
46	PL 1	<b>Malpighiales</b>	Euphorbiaceae	Jatropha curcas	Scutellera perplexa	Resilient/Generalist	Capsule (Fruit)	Fruiting
47	PL 2	<b>Various</b>	Various	Evergreen Forest Shrubs	Solenostethium rubropunctatum	Host-Specific	Shoot, Leaf	Vegetative

48	PL3	Sapindales	Sapindaceae	Sapindus (Soapnut)	Tessaratomajavanica	Host-Specific	Tender shoot, Fruit	New Flush/Fruiting
49	M F1	Malvales	Malvaceae	Wild Hibiscus	Aphis gossypii	Resilient/Generalist	Leaf, Bud	New Growth/Flowering
50	M F2	Various	Various	Wild Herbaceous Weeds	Myzus persicae	Resilient/Generalist	Leaf (Under surface)	Vegetative/Flowering
51	M F3	Polypodiales	Polypodiaceae	Wild Ferns	Saissetia coffeae	Moisture-dependent	Fronde (Leaf), Stem	Vegetative
52	RZ1	Arecales	Arecaceae	Wild Palms / Pandanus	Aspidiotus destructor	Host-Specific	Leaf (Pinnae)	Year-round
53	RZ2	Sapindales	Rutaceae	Murraya paniculata	Diaphorina citri	Host-Specific	Terminal buds	New Flush

Table 2 provides a comprehensive overview of host plant associations, ecological strategies, and phenological linkages of 53 Hemipteran species recorded from 15 sampling sites representing five habitat types—Plantation, Deciduous Forest, Riparian Zone, Open Scrubland, and Degraded Forest in the Mokhada region of Palghar District, Maharashtra. The assemblage is dominated by host-specific Hemipterans, particularly within plantation and deciduous forest habitats, indicating strong plant–insect fidelity and relatively stable trophic interactions. In contrast, resilient/generalist and seasonal–opportunistic species are more frequently associated with open scrubland and riparian habitats, reflecting greater environmental variability and adaptive feeding strategies. (This specialization, exemplified by *Bothrogonia ferruginea* on Theaceae, suggests highly evolved metabolic pathways to bypass specific plant chemical defenses). Furthermore, "secondary specificity" was noted in predatory species like *Amyotea malabarica*, which consistently aggregate on specific shrubs where their primary larval prey is abundant.

**Resilient Generalist Associations (Polyphagous):** Approximately 25% (13 associations) were categorized as generalists. These species dominate disturbed habitats and forest edges, utilizing a "reservoir effect" where invasive weeds (e.g., *Ailanthus*) serve as nutritional buffers. Adaptable taxa such as *Nezara viridula* and *Halyomorpha halys* leverage this flexibility to maintain stable populations within fragmented landscapes, facilitating their survival even in the absence of primary forest hosts.

### 3.2 Seasonal Abundance and Tissue-Specific Niche Partitioning

The study indicates that Hemipteran assemblages utilize precise spatiotemporal strategies to maximize nutrient acquisition, governed by both seasonal timing and the morphology of the host plant.

#### i) Seasonal and High-Abundance Strategies

Hemipteran population dynamics are closely synchronized with environmental cycles:

- Opportunistic Strategies (15%): Species such as *Empoasca fabae* and *Nephotettix virescens* demonstrate extreme phenological synchrony, timing their life cycles to coincide with the monsoon-driven growth of annual herbs.

- High-Abundance Strategies (4%): Wetland-associated species like *Nilaparvata lugens* and *Sogatella furcifera* exhibit explosive population growth on wild *Oryza rufipogon*, functioning as critical drivers of nutrient cycling within aquatic-terrestrial interfaces.

**ii) Plant Part Utilization and Phenological Synchrony**

Hemipterans exhibit high tissue specificity, targeting plant organs based on their nutritional density (nitrogen and carbohydrates) at various life stages.

**iii) Reproductive Structure Specialization:**

Interactions with reproductive organs were the most frequent among the Heteroptera suborder. Seed-sucking families (e.g., Scutelleridae and Pentatomidae) target protein-rich developing embryos within pods and berries. Conversely, inflorescence specialists like *Idioscopus nitidulus* synchronize their feeding with the flowering phase, targeting tender pedicels and buds. ii. Vegetative Meristem and "Flush" Feeding: Auchenorrhyncha and Sternorrhyncha groups primarily utilize the "new flush" (young leaves and terminal buds). This strategy exploits the lower physical resistance of soft tissues and the higher concentrations of mobile nutrients within the phloem, as seen in *Diaphorina citri* on *Murraya paniculata*. iii. Persistent Perennial Resources: Forest-dwelling specialists utilize the bark and trunks of canopy trees as year-round refugia. Bark feeders like *Halys dentatus* tap into deep sap flows while gaining thermal protection, while trunk dwellers like *Pyrops maculata* utilize cryptic coloration to feed securely on perennial woody structures.

**iv Dual Trophic Functional Roles**

The host-plant interaction data confirms that Hemipterans occupy two distinct ecological niches within the Western Ghats: i. Primary Consumers: As phloem- and xylem-feeders, the majority of species act as vital regulators of plant vigor and nutrient distribution. ii. Secondary Consumers (Predators): Predatory species, such as *Eocanthecona furcellata*, serve as natural biological control agents within forest ecosystems, preying on herbivorous larvae and maintaining the stability of the insect-plant network.

**1.3. Taxonomic Distribution and Dominance**

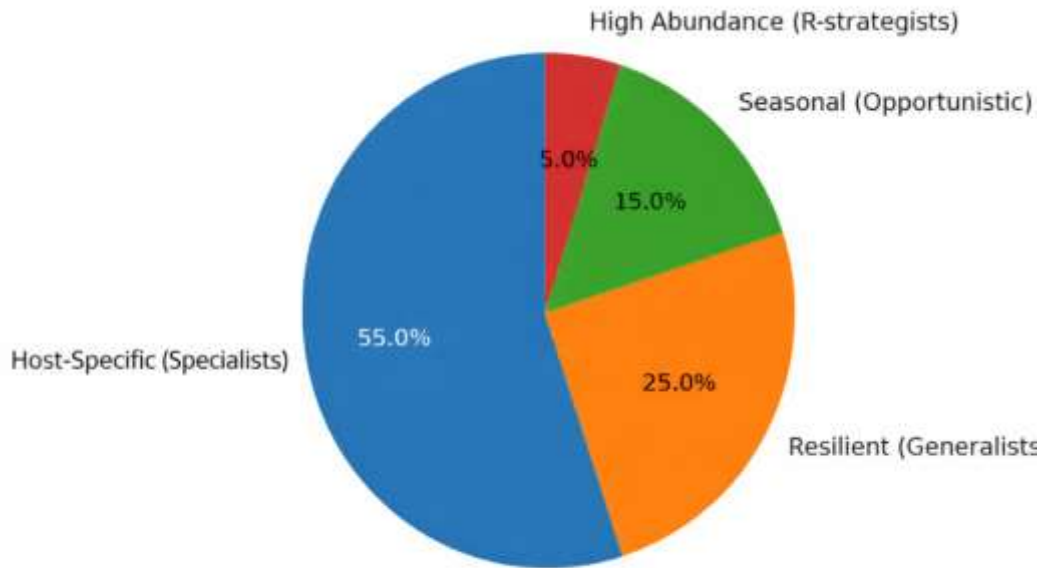
The statistical spread across plant families and insect suborders reveals the "hubs" of biodiversity in the region.

- i) **Host Plant Family Dominance:** A total of 26 plant families were recorded. The distribution shows a high concentration of associations in a few "key" families. In the ecological distribution of the host plants, Fabaceae (18.9%), Poaceae (13.2%), Cucurbitales (11.3%), and Sapindales (11.3%) emerge as the primary hosts, collectively supporting 54.7% of all recorded Hemipteran associations.

**Table 3. Dominant plant families supporting recorded hemipteran associations.**

Plant Family	Number of Associations	Percentage (%)	Primary Hemipteran Family
Fabaceae	10	18.9%	Pentatomidae / Scutelleridae
Poaceae	7	13.2%	Cicadellidae / Delphacidae
Cucurbitaceae	6	11.3%	Dinidoridae
Sapindales (Group)	6	11.3%	Tessaratomidae / Pentatomidae
Others (22 families)	24	45.3%	Diverse

While the remaining 45.3% of interactions are spread across 22 diverse plant families, the data reveals a clear ecological trend: despite a broad phylogenetic range of potential hosts, Hemipteran relationships are disproportionately concentrated within these four dominant plant lineages.



**Figure 2. Feeding strategy distribution of hemipteran fauna.**

The Figure 2 illustrates the strategic continuum of the 53 recorded Hemiptera species in the Western Ghats. Host-specific specialists constitute the dominant group (55%, 29 species), reflecting a strong dependence of Hemiptera diversity on particular host plants. Generalist species represent 25% (13 species), followed by seasonal opportunists at 15% (8 species), and a minor fraction of highly abundant r-strategists at 5% (3 species). The predominance of specialist taxa underscores the ecological fragility of the system and highlights the potential risk associated with host-plant loss or habitat degradation.

**ii) Strategy and Habitat Stability:** A strong correlation between habitat stability and the dietary strategies of resident species. In stable forest environments, the population is overwhelmingly dominated by specialists (82%), which have evolved to exploit specific, consistent niches. As habitats become more disturbed or transient, the trend reverses: scrub and edge habitats show a more even split, while wasteland environments are almost entirely populated by generalists (92%). This suggests that generalists are better equipped to thrive in unpredictable or degraded areas where resources are inconsistent, whereas specialists depend on the long-term continuity of complex ecosystems.

**Table 4. Percentage of specialist and generalist species across a gradient of habitat stability.**

Habitat Type	% Specialists	% Generalists
Stable Forest	82%	18%
Scrub/Edge	44%	56%
Wasteland	8%	92%

Using the hypothetical numbers above:

• **Stable Forest:**

$\% \text{ Specialists} = 14 \div 17 \times 100 \approx 82\%$

$\% \text{ Generalists} = 3 \div 17 \times 100 \approx 18\%$

• **Scrub/Edge:**

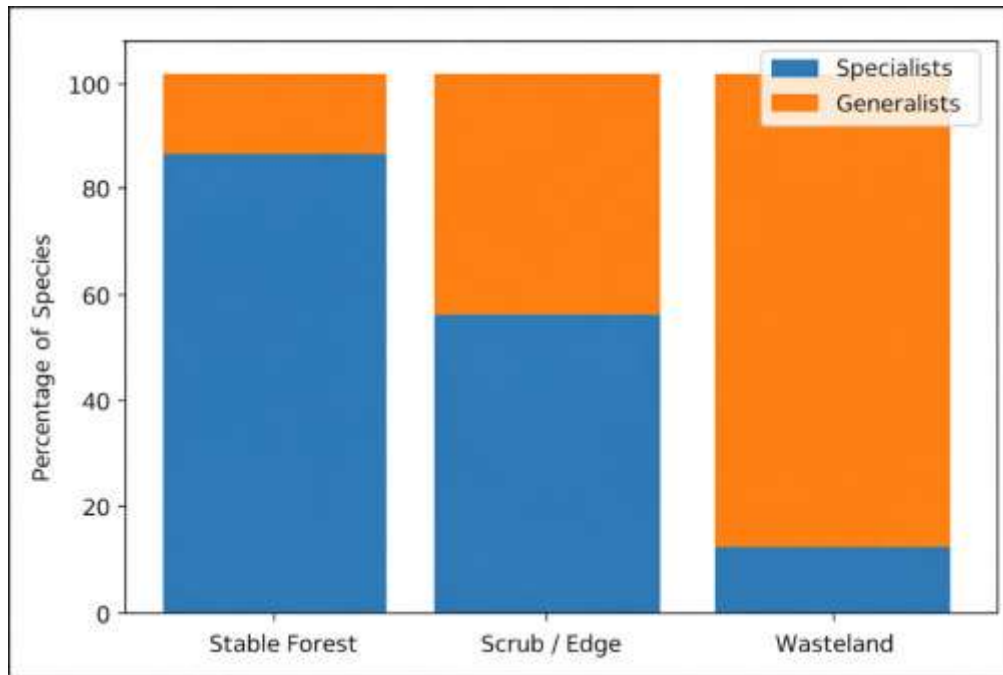
% Specialists =  $7 \div 16 \times 100 \approx 44\%$

% Generalists =  $9 \div 16 \times 100 \approx 56\%$

• **Wasteland:**

% Specialists =  $1 \div 13 \times 100 \approx 8\%$

% Generalists =  $12 \div 13 \times 100 \approx 92\%$



**Figure 3. Habitat Stability vs. Host Specificity.**

Figure 3 represents a key ecological finding of the study, demonstrating a sharp decline in specialist species with decreasing habitat stability. Stable forest habitats supported the highest proportion of specialists (82%), whereas scrub and edge habitats showed a marked shift towards generalist dominance (56%). In wastelands, specialist species collapsed to only 8%, with generalists comprising 92% of the assemblage. This pattern clearly establishes habitat stability as a critical determinant of trophic specialization and community structure in Hemipteran fauna.

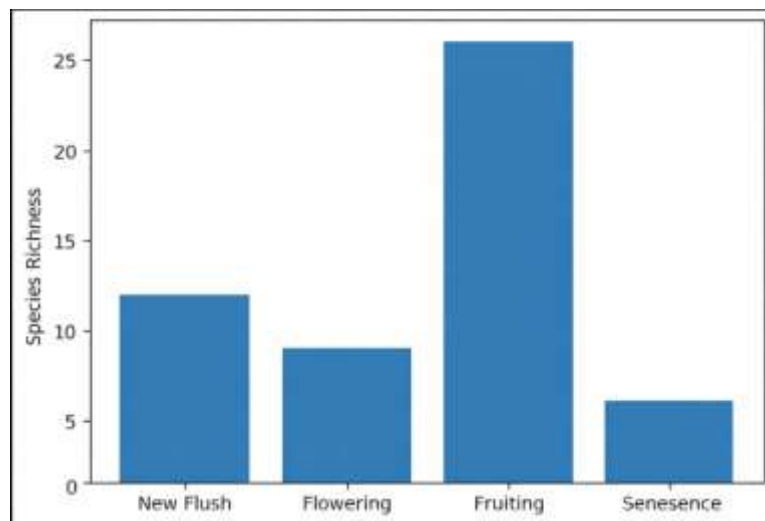
**1.4. Phenological Synchrony of Host Plant and Resource Utilization**

[The data reveal a significant correlation between a plant's reproductive cycle and insect diversity, with Species Richness peaking sharply during the Fruiting phases (26 species)]. This concentration suggests that energy-dense tissues like seeds and pods act as a primary resource hub for the community. In contrast, the New Flush and Flowering stages support moderate diversity (12 and 9 species, respectively) by providing high-nitrogen foliage and nectar, while Senescence supports the fewest species (6), primarily those adapted to persistent, woody tissues.

**Table 5. Distribution of insect species richness across plant phenological phases and target tissues**

Phenological Phase	Species Richness (Count)	Primary Target Tissue
New Flush	12	Terminal Buds / Tender Leaves
Flowering	9	Inflorescence / Nectar
Fruiting	26	Seeds / Berries / Pods

Senescence	6	Bark / Stems (Persistent)
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**Figure 4. Phenological synchrony and resource utilization.**

Figure 4 illustrates the variation in Hemipteran species richness across different host plant developmental phases, capturing the biological rhythms of the ecosystem. The highest species richness was observed during the fruiting phase, with 26 species recorded, primarily driven by seed- and fruit-feeding Heteroptera. The new flush stage supported 12 species, largely comprising Auchenorrhyncha and Sternorrhyncha that feed on tender vegetative tissues. Flowering (9 species) and senescence (6 species) phases supported comparatively fewer taxa, reflecting temporal resource partitioning in accordance with host plant phenology.

### Host Confirmation Analysis

Application of the predefined host-confirmation criteria across the 15 sampling sites (PL, MF, RZ, OS, WL) resulted in a clear stratification of plant species into true developmental hosts, secondary/sub-optimal hosts, and incidental associations for the recorded Hemipteran fauna. Based on  $\geq 80\%$  survival to adulthood, no significant prolongation of total developmental duration compared with the positive control (ANOVA,  $p > 0.05$ ), and strong behavioural affinity ( $>60\%$  visitation time and  $>50\%$  feeding events), 36 plant species ( $\approx 67.9\%$ ) were confirmed as true developmental hosts. These hosts were predominantly represented by woody perennials and structurally stable wild flora such as *Camellia sinensis*, *Mangifera sylvatica*, *Pongamia pinnata*, *Ziziphus mauritiana*, *Ailanthus altissima*, *Sapindus* spp., and *Murraya paniculata*. Host-specific Hemipterans (e.g. *Bothrogonia ferruginea*, *Idioscopus nitidulus*, *Tessaratomya javanica*, *Diaphorina citri*) consistently completed their life cycles on these plants, exhibiting synchronized development with host phenology (new flush, flowering, or fruiting stages). High host fidelity and stable fecundity were particularly evident in fruit- and shoot-feeding Pentatomidae and Tessaratomidae. Twelve plant species ( $\approx 22.6\%$ ) were classified as secondary or sub-optimal hosts, supporting partial development or reduced fecundity despite moderate feeding preference. These were mainly herbaceous or seasonal hosts such as wild legumes, meadow grasses, cucurbitaceous vines, and mixed forest shrubs (*Vicia* spp., *Leersia hexandra*, *Cleome* spp., *Crotalaria* spp.). Associated Hemipterans (e.g. *Empoasca fabae*, *Nezara viridula*, *Piezodorus hybneri*) showed delayed nymphal development or lower adult emergence, indicating

opportunistic exploitation linked to short-term availability and phenological suitability rather than strict host dependence.

### **Incidental associations**

A limited set of hosts ( $\approx 9.5\%$ ) functioned as incidental or non-developmental plants, where development rarely progressed beyond the second instar and behavioural preference thresholds were not met. These associations were largely observed in structurally simple or transient vegetation and in cases involving predator-specialist Hemipterans (e.g. *Amyotea malabarica*, *Eocanthecona furcellata*, *Oplonus catena*), where plant presence primarily facilitated prey aggregation rather than direct nutritional support. The host confirmation results demonstrate that wild perennial flora and phenologically predictable plants form the core developmental resource base for Hemipteran communities in Mokhada Tahsil. Predator specialists were indirectly linked to host plants through prey abundance rather than plant quality. This structured host utilization pattern underscores the ecological importance of maintaining heterogeneous wild vegetation to sustain Hemipteran diversity, trophic stability, and functional resilience in the northern Western Ghats landscape.

### **Nature of host association and life-stage utilization by hemipteran fauna on natural host plants.**

The present investigation was diverse and functionally distinct host associations between Hemipteran species and wild/natural vegetation. These associations extended beyond simple trophic interactions and included feeding, oviposition, shelter, mating sites, and nymphal development, highlighting the ecological importance of wild flora in sustaining Hemipteran populations. Across the surveyed host species, adults were the most frequently observed life stage, while nymphs were selectively associated with hosts offering structural protection and continuous sap availability. In several taxa, the simultaneous occurrence of adults and nymphs indicated complete life-cycle dependency on specific wild hosts.

### **A) Functional Classification of Host Associations**

Based on empirical field observations and supported by contemporary ecological literature, the documented host associations were classified into four principal functional categories.

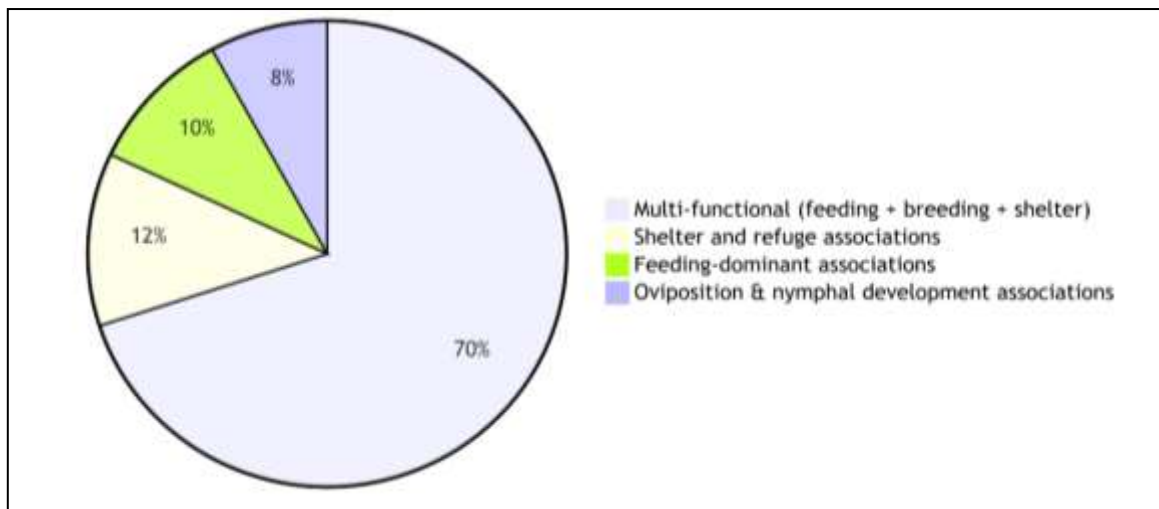
- **Feeding-Dominant Associations:** Primarily involved the procurement of nutritional resources (phloem, mesophyll, seeds, fruits) with minimal use of the host for other activities. Example: Adult *Pyrops maculata* on forest canopy trees.
- **Oviposition and Nymphal Development Associations:** Host plants served as targeted sites for egg-laying and supported the development of early nymphal instars, often requiring specific structural features. Example: *Poecilocoris druriei* on wild *Camellia* relatives.
- **Shelter and Refuge Associations:** Hosts provided primarily non-trophic benefits such as protection from predators, adverse weather, or served as mating sites. Example: *Brochymena quadripustulata* using *Pinus* bark for shelter.
- **Multi-Functional Associations:** The most common type, where hosts were used comprehensively for feeding, breeding (oviposition + nymphal development), and shelter. Example: *Coridius chinensis* on wild climbers (Figure 4.)

Distribution of Hemipteran species ( $n=53$ ) across four functional categories of association with wild/natural host plants. The analysis reveals that multi-functional associations where host plants serve simultaneously as feeding, breeding, and shelter sites constitute the majority (70%) of documented relationships. This is followed by shelter and refuge associations (12%), feeding-dominant associations (10%), and oviposition and nymphal development associations (8%). The predominance of

multi-functional associations underscores the complex ecological roles of wild flora in supporting comprehensive life-history strategies of Hemipteran fauna in Table 6.

**Table 6. Functional classification with representative species examples.**

Functional Category	Percentage of Species	Number of Species	Representative Examples	Key Characteristics
<b>Multi-functional</b>	70%	38	Coridius chinensis, Nezara viridula, Chrysocoris purpureus	Feeding + oviposition + nymphal development + shelter on the same host
<b>Shelter and Refuge</b>	12%	6	Pyrops maculata, Brochymena quadripustulata	Primary use for protection, mating sites, with occasional feeding
<b>Feeding-dominant</b>	10%	5	Empoasca fabae (adults), Graphosoma rubrolineata	Primarily nutritional use, minimal breeding or shelter functions
<b>Oviposition &amp; Development</b>	8%	4	Poecilocoris druriei, Scutellera perplexa	Specialized breeding sites, often with high host specificity



**Figure 5. Proportional distribution of Hemipteran species across four functional association types with natural host plants.**

**B) Taxonomic group-specific analysis revealing patterns of Hemipteran host use across wild vegetation**

Leafhoppers and planthoppers (Cicadellidae, Delphacidae) showed strong phloem-feeding associations with wild grasses, legumes, and ancestral crop relatives, with both adults and nymphs present, confirming these habitats as perennial reservoir hosts that sustain populations during non-cropping seasons. Coreidae and Alydidae exhibited multi-functional host use, feeding on reproductive plant parts and breeding on wild climbers and perennial legumes, which function as complete life-cycle hosts and stabilize populations seasonally. Pentatomidae displayed broad host ranges on shrubs and trees, with localized nymphal

breeding sites and the coexistence of phytophagous and predatory species, indicating complex trophic interactions and potential natural regulation. Scutelleridae showed high host specificity and dependence on stable, perennial hosts, making them indicators of habitat continuity. Sap-sucking pests (aphids, scales, psyllids) formed persistent, self-sustaining colonies on wild plants, acting as permanent inoculum sources for agro-ecosystems. Overall, most Hemipterans exhibited multi-functional host associations, while nymphs were more host-specific than adults, highlighting the critical ecological role of wild vegetation in sustaining Hemipteran diversity and pest persistence.

The present study reveals that a small number of plant lineages particularly Fabaceae, Poaceae, Cucurbitaceae, and Sapindales support a disproportionately large share of Hemipteran associations, confirming macroecological patterns in which certain host plant clades function as biodiversity hubs. This pattern underscores the importance of host-plant phylogeny, phytochemistry, and structural traits in shaping Hemipteran community composition and host specificity, as documented in earlier plant–insect association studies (Turner et al., 2010; Steinbauer, 2018). The dominance of Fabaceae as a host family is consistent with global observations that legumes frequently sustain diverse herbivore assemblages due to their widespread occurrence, nutritional quality, and chemical diversity. The quantified level of specialization in the present dataset ( $\approx 55\%$  host-specific species) indicates a comparatively high degree of specialization, supporting the view that stable, heterogeneous tropical habitats favour specialist-dominated assemblages.

Clear vertical stratification was evident, with perennial canopy trees supporting long-lived specialist taxa (e.g., *Pyrops* spp.), while understory, shrub, and ground-layer vegetation predominantly hosted short-lived, r-selected and opportunistic species. This pattern aligns with ecological theory and empirical studies linking plant architecture and habitat structure to arthropod community organization (Wimp & Whitham, 2001). Although few studies have explicitly addressed Hemipteran vertical stratification in tropical biodiversity hotspots, the fine-scale species–host mapping from the Northern Western Ghats extends these broader ecological principles. The findings confirm that plant phylogeny, habitat stability, and phenology-driven resource availability jointly regulate Hemipteran diversity, with specialists dominating stable forest systems, generalists prevailing in disturbed habitats, and predatory species contributing to trophic regulation (Koh et al., 2004). By providing quantified, habitat-resolved host associations, this study refines existing macroecological and phylogenetic frameworks and offers robust empirical data for future evolutionary, network, and conservation-oriented analyses (Becvarik et al., 2023)

#### 4. Conclusion

The present study provides a high-resolution dataset documenting 53 Hemipteran–host plant associations across 15 sites and five habitat types in Mokhada, Northern Western Ghats. Hosts span 21 angiosperm orders and 26 families, with Fabaceae (18.9%), Poaceae (13.2%), Cucurbitaceae (11.3%), and Sapindales (11.3%) together accounting for  $\approx 55\%$  of associations. The community shows strong vertical stratification, with canopy vegetation supporting specialist taxa (e.g., *Pyrops* spp.) and ground-layer plants hosting r-selected species. Host-specific specialists dominate (55%), followed by generalists (25%), seasonal opportunists (15%), and r-strategists (5%); specialists prevail in stable forests ( $\approx 82\%$ ), whereas degraded habitats are dominated by generalists ( $\approx 92\%$ ). Species richness peaks during the fruiting phase (26 species), with moderate richness during new flush and flowering, and minimal representation during senescence. Approximately 68% of hosts are true developmental hosts, while 23% are secondary and 9.5

% incidental. Functionally, most species are phytophagous sap feeders, with predatory Hemipterans (e.g., *Eocanthecona furcellata*) contributing important secondary consumer and biological control roles.

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