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Understory Vegetation Influences Insect Diversity in Rubber Plantations of Kanyakumari, India

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Insects play a crucial role in maintaining ecological balance, and their decline has detrimental effects on various organisms. Globally, rubber plantations have been associated with a reduction in insect diversity. However, the impact of monoculture rubber plantations on biodiversity in India, particularly in Kanyakumari, is not well understood and has received little research attention. This study aimed to assess the status of insect diversity in rubber plantations in this region. Kanyakumari, Tamil Nadu, with its extensive monoculture rubber plantations, provides an ideal setting for this investigation. Three adjacent rubber plantations with varying topography and understory vegetation were selected for the study. Data was collected between July 2021 to January 2022 and analysis was done using biodiversity indices - Simpson and Shannon-Weiner indices. Results indicated that insect diversity was significantly higher in one plantation when compared to the other two plantations. Canopy and understory vegetation were identified as key factors influencing insect diversity. Plantations with dense understory vegetation consisting of

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diverse native plant species exhibited greater insect richness. The predominant insect orders across all plantations were Hymenoptera (29.70%) and Diptera (29.40 %). However, the impact of rubber plantations on individual insect species varied based on their habitat preferences. Seasonal fluctuations in diversity were particularly noticeable during the monsoon season. Further comparative studies are needed to understand the broader implications of rubber plantations on insect diversity across the district.

Keywords: Insect diversity; monoculture rubber plantations; Kanyakumari; seasonal fluctuations.

1. INTRODUCTION

Insects are integral to ecosystem functions such as pollination, pest control, and nutrient cycling, yet their populations are declining globally due to habitat loss and agricultural expansion [1]. The objectives of our study were threefold: to identify the diversity of insects in these plantations, to observe seasonal variations, and to determine the effects of physicochemical parameters of soil and water on insect diversity.

Kappukadu, with its extensive rubber plantations, provides a unique opportunity to study these dynamics in a region where rubber cultivation plays a significant economic role. This research is particularly relevant in the context of the United Nations Sustainable Development Goals (SDGs), particularly Goal 15: Life on Land, which emphasizes the need to protect, restore, and promote sustainable use of terrestrial ecosystems. By understanding insect diversity and its determinants, we contribute to the broader goals of conserving biodiversity and promoting sustainable agricultural practices.

Studying these sites is crucial for several reasons. First, it helps in assessing the impact of rubber monoculture on local biodiversity, providing insights into how such practices can be managed to mitigate negative ecological effects. Second, the findings can inform better agricultural practices that balance economic benefits with ecological sustainability. Third, understanding the seasonal variations and environmental factors affecting insect populations can lead to more effective conservation strategies, ensuring that these vital organisms continue to support ecosystem services critical for human well-being and agricultural productivity [2,3].

Studies on insect populations in rubber plantations have been conducted globally, particularly in Southeast Asia. These studies are significant because they provide insights into the impact of monoculture plantations on biodiversity. For instance, research in Thailand, Malaysia, and Indonesia has highlighted how rubber plantations affect insect diversity, comparing these ecosystems with natural forests. These studies have shown that rubber monocultures typically support fewer species and lower insect abundance compared to more diverse habitats [4–10].

This underscores the ecological costs of expanding rubber cultivation. The findings have prompted calls for more sustainable agricultural practices, such as integrating agroforestry and maintaining patches of natural vegetation within plantations to support biodiversity. These efforts align with the principles of sustainable development and conservation.

However, comprehensive studies on the impact of rubber plantations on insect biodiversity are less common in India, despite the country's significant rubber production [11–12]. This gap may be due to limited funding, lack of awareness, or prioritization of economic benefits over ecological considerations. Nonetheless, the growing recognition of biodiversity's role in ecosystem services and agricultural productivity is driving more research and policy changes aimed at balancing agricultural development with ecological sustainability.

2. METHODOLOGY

The selected rubber plantations were located in Kappukadu village, Vilavancode taluk, Kanyakumari District, Tamil Nadu, India. These sites are situated between 8º17'14" N and 8º17'9" N latitude and 77º11'55" E and 77º11'57" E longitude. Three plantations were chosen for the study, with areas of 3 hectares, 1.5 hectares, and 2 hectares, respectively.

Plantation 1 (Fig. 1) featured dense understory vegetation and a substantial litter layer. Within this plantation, there was a site with newly planted rubber saplings intercropped with plantain. Plantation 2 had sparse shrubs and lacked grass cover (Fig. 1), with a thin litter layer and natural water springs. Plantation 3 (Fig. 1) was located near a residential area, characterized by a minimal litter layer and scattered shrubs.

2.1 Sampling Method

Data was collected over seven months, from July 2021 to January 2022, with weekly visits to each plantation between 6 am and 8 am. Foliage-dwelling and fast-moving insects were observed using the direct observation method. For fast-flying insects, such as dragonflies, random sampling and counting were conducted. Quadrats of 2 m x 2 m were placed in various locations within each plantation to record the number of slow-moving insects. Sticky traps were hung in different spots of each plantation in the evening and checked the next morning, with the trapped insects collected. Pitfall traps, made using cups and bottles, were buried at different locations in the plantations; water was used instead of killing agents to prevent insects from escaping. Containers filled with water were placed under light bulbs in various locations to trap nocturnal insects. Insect samples were also collected by digging soil and leaf litter and handpicking. The collected insects were examined under a microscope and photographed [13–15]. The stated methods were applied to all three plantations during the period of study.

2.2 Identification

The insects were identified using Insect identification manual by ZSI and online insect identification app (iNaturalist) [16,17].

2.3 Data Analysis

The data was subjected to Simpson [18] and Shannon-Weiner index calculation [19] to measure species diversity.

2.4 Seasonal Variation

The seasonal data (temperature and rainfall) of the study location for 7 months (July 2021 to January 2022) was collected from Climate-Data.org website [20]. Correlation between Insect diversity and seasonal data was found using Pearson's correlation coefficient. All statistical work was done using MS Excel.

Fig. 1. Selected plantation sites

3. RESULTS AND DISCUSSION

Insects from 13 different orders were recorded (Fig. 2). A total of 87 insect species, spanning 50 families, were observed within these orders (Fig. 2). The order Hymenoptera had the highest number of identified insects, accounting for 29.7% of the total. In contrast, the orders Dermaptera, Mecoptera, and Neuroptera had the lowest number of insects collected.

The highest species richness was observed in Lepidopterans. A total of 21 Lepidopteran species from 9 families were recorded, with most sightings occurring in Plantation 1 (Table 1). Hymenoptera was the most abundant insect order observed, with a total of 942 individuals recorded during the study period. The highest number of insects was recorded in August (Table 2).

Plantation 1 exhibited higher diversity, with a Shannon diversity index of 1.81 and a Simpson's index of 0.79, attributed to its dense understory vegetation. This plantation had a greater number of Hymenopterans and Dipterans, with ants being particularly abundant. Both arboreal and terrestrial nesting ant species were recorded. Arboreal ants, such as weaver ants (*Oecophylla smaragdina*), built their nests on rubber trees in the plantation. Weaver ants (Fig. 3) were found across all three plantations, demonstrating resilience to disturbances in these environments. The closed canopy and thick litter layer in Plantation 1 supported various ant species, with groups of weaver ants observed building nests and foraging (Fig. 3). Among the Diptera, mosquitoes were notably abundant, especially during the monsoon season due to the availability of breeding water. Mosquito larvae were frequently found in rubber latex collecting cups and plastic bottles filled with rainwater in the plantation (Fig. 3).

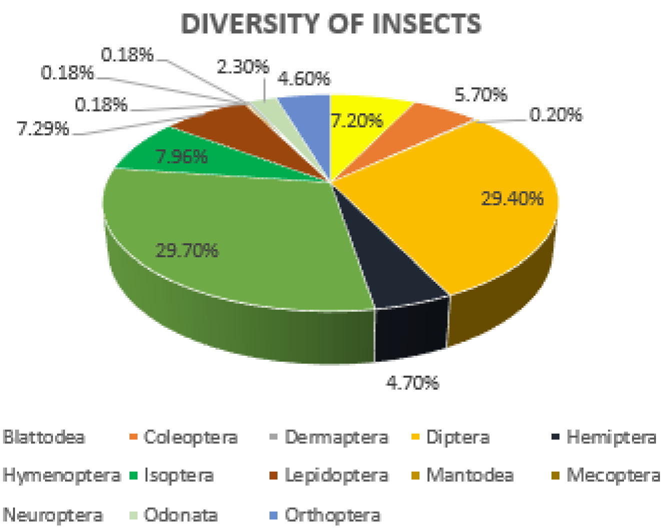

Fig. 2. Diversity of Insects in the rubber plantations

Fig. 3. Mosquito larva in latex collection cup and *Oecophylla smaragdina* on rubber tree

Fig. 4. Luprops tristis and gesonula punctifrons on basket grass

Fig. 5. Termite mounds, basket grass and *Leptocorisa oratoria*

Plantation 2 had minimal understory vegetation and a thin litter layer. Insects from 9 orders were collected from this plantation, which showed lower diversity with a Shannon diversity index of 1.53 and a Simpson's index of 0.71. Litter-dwelling beetles and ants were absent, and only two coleopteran species were found during the study period. Plantation 2 features two natural springs, which provide a consistent water source except during the dry summer months. The presence of water supported Odonates (Fig. 8). Weaver ants were also abundant in this plantation, and Hymenopterans were the most frequently collected insects. In contrast, Coleoptera numbers were the lowest, likely due to the lack of understory vegetation, which may have contributed to the reduced richness and diversity of coleopterans. No individuals from the orders Mecoptera, Mantodea, Neuroptera, or Dermaptera were recorded.

Plantation 3 was the second most diverse of the three plantations, with a Shannon diversity index of 1.73 and a Simpson's index of 0.78. Insects from 8 orders were observed. Although the total number of individuals was lower than in Plantation 2, the distribution of species was more even. Dipteran insects were the most abundant, followed by Hymenoptera, while Blattodea had the fewest individuals. No insects from the orders Dermaptera, Mecoptera, Mantodea, or Neuroptera were recorded. Mosquitoes were particularly dominant in this plantation, likely due to the presence of nearby residents and associated anthropogenic activities, which may have contributed to their increased diversity and abundance. The leaf litter was sparse, and moderate understory vegetation was present.

Table 1. Insect species recorded from Monoculture Rubber plantations in Kanyakumari

S No	Order	Family	Organism	Observed in
1.	Blattodea	Blattidae	*Periplaneta fuliginosa*	Plantation 1, 2 and 3
		Ectobiidae	*Blattella asahinai*	Plantation 1
			Supella longipalpa	Plantation 3
			Ectobius vittiventris	Plantation1 and 3
2.	Coleoptera	Coccinellidae	*Delphastus pusillus*	Plantation1
			Coccinella septempunctata	Plantation 1 and 3
		Chrysomelidae	*Aulacophora foveicollis*	Plantation 1, 2 and 3
			Luperus flavipes	Plantation 1
			Mordella marginata	Plantation 1
			Heteronychus arator	Plantation 1
			Hydnobius punctasus	Plantation 1
			Litargus connexus	Plantation 1
			Luprops tristis	Plantation 1, 2 and 3
			Luciola lateralis	Plantation 1, 2 and 3
			Hydaticus aruspex	Plantation 2
3.	Dermaptera	Forficulidae	*Forficula auricularia*	Plantation 1
4.	Diptera	Bombyliidae	*Poecilanthrax apache*	Plantation 1
		Micropezidae	*Rainiera antennaepes*	Plantation 1, 2 and 3
		Chironomidae	*Chironomus plumosus*	Plantation 1, 2 and 3
		Culicidae	*Aedes aegypti*	Plantation 1, 2 and 3
		Muscidae	*Musca domestica*	Plantation 1, 2 and 3
		Calliphoridae	*Lucilia sericata*	Plantation 1
		Tephritidae	*Tephritis conura*	Plantation 1
			Anomoia purmunda	Plantation 1
		Tipulidae	*Dolichopeza walleyi*	Plantation 1
5.	Hemiptera	Alydidae	*Leptocorisa oratoria*	Plantation 1
		Lygaeidae	*Oncopeltus fasciatus*	Plantation 1 and 3
		Miridae	*Lygocoris pabulinus*	Plantation 1, 2 and 3
		Cercopidae	*Cercopis saguinolenta*	Plantation 1 and 2
		Cicadellidae	*Aphrodes bicintus*	Plantation 1, 2 and 3
6.	Hymenoptera	Sphecidae	*Chalybion californicum*	Plantation 1
		Apidae	*Apis mellifera*	Plantation 1 and 3
			Amegilla cingulata	Plantation 1
		Halictidae	*Halictus farinosus*	Plantation 1 and 3
			Augochlora pura	Plantation 1, 2 and 3
		Formicidae	*Oecophylla smaragdina*	Plantation 1, 2 and 3
			Odontomachus bauri	Plantation 1
			Pogonomyrmex bicolor	Plantation 1
			Camponotus radiates	Plantation 1, 2 and 3
			Tetraponera allaborans	Plantation 1
			Anoplolepis gracileps	Plantation 1
			Monomorium pharaonic	Plantation 1, 2 and 3
			Paratrechina longicornis	Plantation 1, 2 and 3
		Pompilidae	*Auplopus carbonarius*	Plantation 1
7.	Isoptera	Rhinotermitidae	*Coptotermes formosanus*	Plantation 1, 2 and 3
8.	Lepidoptera	Uraniidae	*Micronia aculeate*	Plantation 1
		Crambidae	*Achyra ranatlis*	Plantation 1
			Nausinoe geometralis	Plantation 1
			Patania ruralis	Plantation 1
		Erebidae	*Sphragedius similis*	Plantation 1
			Syntomoides imaon	Plantation 1
		Pterophoridae	*Hellinsia pectodactylus*	Plantation 1
		Nymphalidae	*Ypthima huebneri*	Plantation 1 and 3

S No	Order	Family	Organism	Observed in
			Junio lemonias	Plantation 1
			Mycalesis perseus	Plantation 2 and 3
		Papillionidae	*Troides minos*	Plantation 1
			Battus polydamus	Plantation 1
			Papilio polytes	Plantation 1
		Lycaenidae	*Talicada nyseus*	Plantation 1
			Zizula hylax	Plantation 1
			Euchrysops cnejus	Plantation 1
			Jamides celeno	Plantation 1
			Castalius rosimon	Plantation 1
		Hesperiidae	*Lambrix salsa*	Plantation 1
			Arnetta vindhiana	Plantation 1
		Pieridae	*Eurema blanda*	Plantation 1, 2 and 3
9.	Mantodea	Liturgusidae	*Litergusa maya*	Plantation 1
		Mantidae	*Hierodula patellifera*	Plantation 1
			Ameles decolor	Plantation 1
10.	Mecoptera	Panorpidae	*Panorpa nuptialis*	Plantation 1
11.	Neuroptera	Myrmeleontidae	*Distoleon tetragammicus*	Plantation 1
12.	Odonata	Coenagrionidae	*Ceriagrion cerinorubellum*	Plantation 1
			Pesudagrion microcephalum	Plantation 1
		Platycnemididae	*Copera marginipes*	Plantation 1
		Libellulidae	*Rhyothemis variegate*	Plantation 1
			Neurothemis tullia	Plantation 1 and 2
			Trithemis aurora	Plantation 1, 2 and 3
			Tholymis tillarga	Plantation 1 and 2
			Orthetrum glaucum	Plantation 2
			Orthetrum chrysis	Plantation 2
			Diplacodes trivalis	Plantation 1
13.	Orthoptera	Acrididae	*Gesonula punctifronsI*	Plantation 1
		Gryllidae	*Xenogryllus marmortus*	Plantation 1
			Xenogryllus sp	Plantation 1
			Telogryllus emma	Plantation 1
		Tetrigidae	*Tetrix tenuicornis*	Plantation 1
			Paratettix curtipennis	Plantation 2 and 3

Fig. 6. Papilio polytes and *Jamides celeno*

Fig. 7. *Teleogryllus emma*

Fig. 8. Odonates from Plantation 2, Neurothemis tullia and Tholymis tillarga

Table 2. Number of Insects recorded in each insect order

Months	July			August			September			October			November			December			January		
Insects	**P-1**	**P-2**	**P-3**	**P-1**	**P-2**	**P-3**	**P-1**	**P-2**	**P-3**	**P-1**	**P-2**	**P-3**	**P-1**	**P-2**	**P-3**	**P-1**	**P-2**	**P-3**	**P-1**	**P-2**	**P-3**
Blattodea	5	7	3	12	NO	NO	11	NO	1	1	1	NO	1	NO	NO	2	4	NO	NO	3	1
Coleoptera	21	NO	5	21	NO	7	35	NO	11	22	2	9	29	NO	4	11	NO	2	6	NO	NO
Dermaptera	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	1	NO	NO	2	NO	NO
Diptera	86	32	10	123	30	8	103	45	29	56	31	18	144	57	25	69	10	14	17	15	11
Hemiptera	7	NO	NO	2	NO	NO	6	1	NO	1	2	5	58	4	9	29	25	NO	2	NO	NO
Hymenoptera	102	37	9	170	78	13	173	44	7	48	34	9	66	33	3	7	10	4	52	26	17
Isoptera	NO	10	5	152	NO	NO	18	NO	8	NO	NO	NO	NO	NO	NO	NO	4	NO	25	20	10
Lepidoptera	24	4	4	48	3	2	56	2	2	14	2	1	20	1	NO	6	2	2	24	5	9
Mantodea	NO	NO	NO	1	NO	NO	1	NO	NO	NO	NO	NO	0	NO	NO	NO	NO	NO	1	NO	NO
Mecoptera	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	2	NO	NO	NO	NO	NO	NO	NO	NO
Neuroptera	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	2	NO	NO
Odonata	6	1	NO	8	2	NO	7	2	NO	2	3	NO	1	4	NO	NO	4	NO	2	3	NO
Orthoptera	16	2	NO	14	5	NO	15	7	3	3	9	7	17	14	5	11	6	6	5	2	NO
Total	**267**	**93**	**36**	**551**	**118**	**30**	**425**	**101**	**61**	**147**	**84**	**49**	**338**	**113**	**46**	**136**	**65**	**28**	**138**	**74**	**48**

Fig. 9. Seasonal variation in vegetation, Canopy and litter during January in Plantation -1

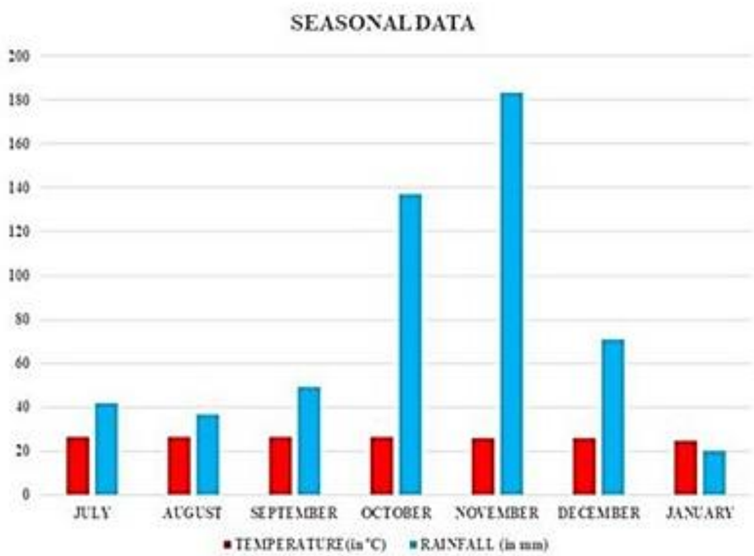

Fig. 10. Temperature and rainfall data

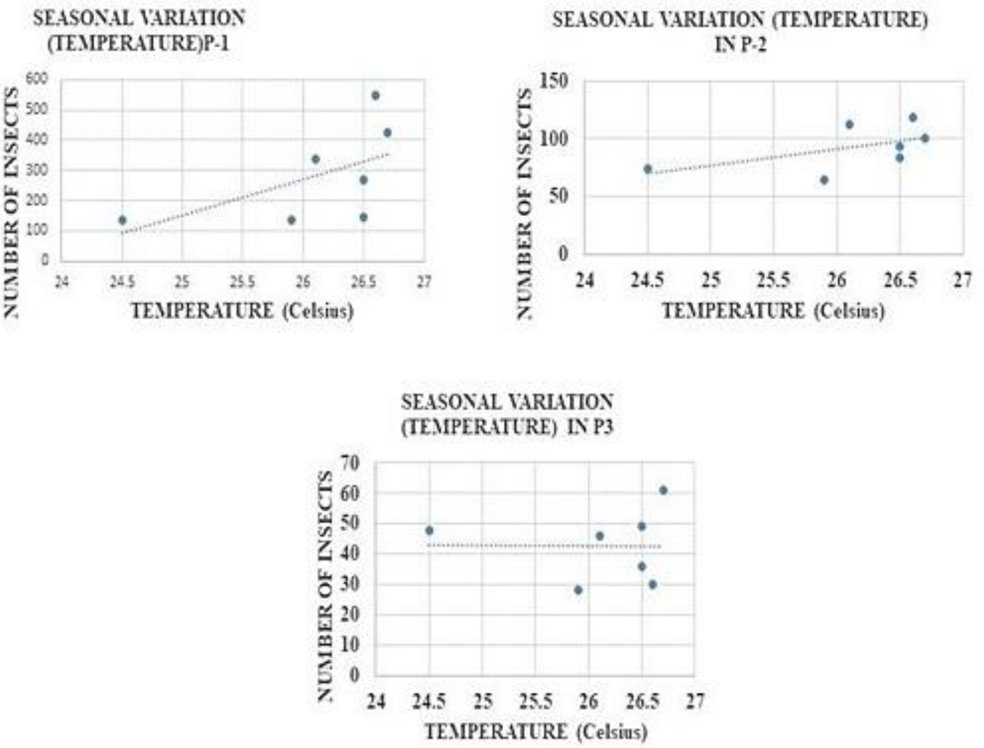

Fig. 11. Correlation between Insect diversity and Temperature

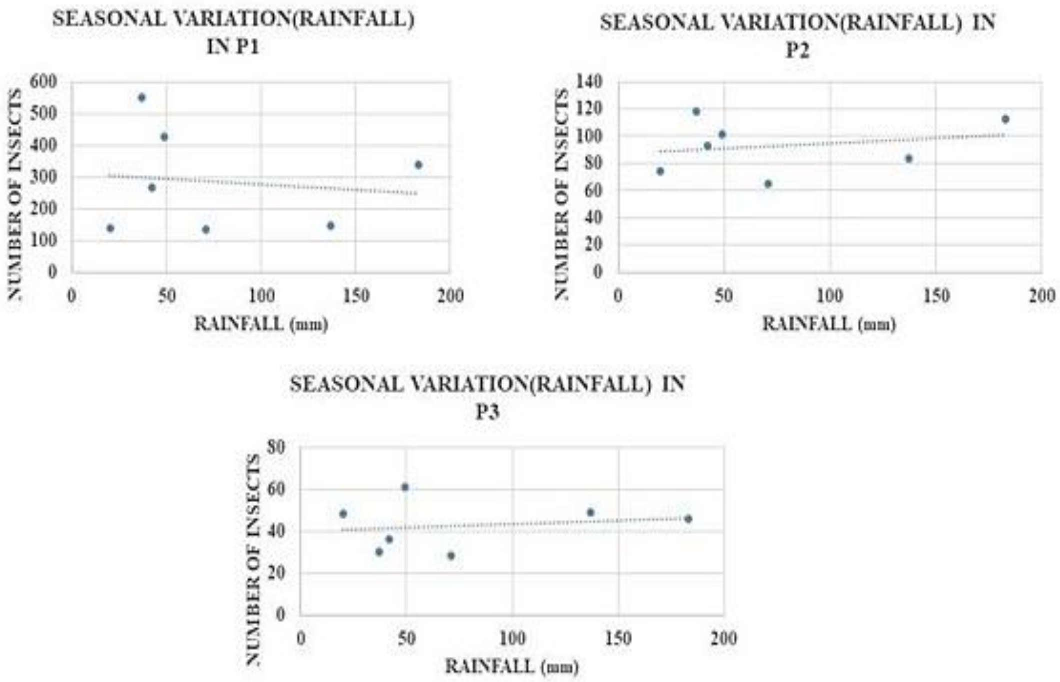

Fig. 12. Correlation between insect diversity and temperature

Table 3. Pearson's correlation coefficient

Plantations	Temperature (in C)	Rainfall (in MM)
1	0.56481	-0.12557
2	0.550524	0.226639
3	-0.01947	0.174588

3.1 Seasonal Variation

The understory vegetation and canopy density varied throughout the year. From June to November, the canopy was dense, while both the understory and canopy were less dense in December and January, though the litter layer increased in thickness (Fig. 9). The highest temperature was recorded in September, and the lowest in January 2022. Rainfall peaked in November 2021, with 183 mm recorded, whereas January 2022 saw the lowest rainfall (Fig. 10). Temperature positively influenced insect diversity in Plantations 1 and 2, but Plantation 3 exhibited a negative correlation with temperature (Fig. 11, Table 3). This is supported by the study conducted on the litter insects and their relationship with rainfall in Western Ghats which states, seasonal variation was not seen on the whole. But, orthopteran numbers increased during monsoon [21].

Rainfall positively affected insect diversity in Plantations 2 and 3, whereas Plantation 1 showed a negative correlation with rainfall (Fig. 12, Table 3). However, the diversity of some insect groups remained relatively stable despite seasonal changes. This finding aligns with a study on litter insects in the Western Ghats, which reported minimal overall seasonal variation but noted an increase in orthopteran numbers during the monsoon.

The study's data and analyses reveal insights into insect diversity across three plantations, highlighting seasonal variations and the impact of temperature and rainfall. Temperature remains relatively stable from July to January, while rainfall peaks in October and November. The correlation between temperature and insect numbers shows a moderate positive relationship in Plantations 1 and 2, with coefficients of 0.56481 and 0.550524, respectively, indicating that higher temperatures are associated with more insects. Plantation 3 shows no significant correlation (-0.01947). Conversely, rainfall exhibits weaker and more variable correlations with insect numbers. In Plantation 1, there is a weak negative correlation (-0.12557), while Plantations 2 and 3 show weak positive correlations (0.226639 and 0.174588, respectively). These findings suggest that temperature is a more consistent factor influencing insect diversity, particularly in Plantations 1 and 2, whereas the impact of rainfall is less clear and more variable across the plantations.

4. CONCLUSION

Of the 81 insects recorded, 47 were found exclusively in Plantation 1, highlighting that understory vegetation with natural flora can significantly enhance insect biodiversity, even in monoculture rubber plantations. Specific plants attracted various insects; for instance, *Clerodendrum infortunatum* was prevalent in Plantation 1, attracting species such as the *Troides minos* (southern birdwing butterfly), *Tephritis conura* and *Anomoia purmunda* (fruit flies), and *Oecophylla smaragdina* (weaver ants) which were observed collecting nectar from its flowers. Similarly, plants like basket grass supported several insects, including *Tetraponera allaborans* (slender ants) and *Leptocorisa oratoria* (rice ear bug). This indicates that native plants can enhance insect diversity within rubber plantations.

Maintaining healthy understory vegetation with a mix of native shrubs and grasses positively impacts insect diversity. Effective understory management practices, such as limiting the collection of twigs and litter and avoiding excessive weeding of native grasses, can support ground-dwelling and leaf-eating insects. Currently, many local rubber plantation workers and owners are unaware of the impact of their practices on biodiversity. Educating them about the benefits of these practices could lead to improved overall insect biodiversity.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that generative AI technologies such as Large Language Models, etc have been used during writing or editing of manuscripts. This explanation will include the name, version, model, and source of the generative AI technology and as well as all input prompts provided to the generative AI technology

Details of the AI usage are given below:

1. https://app.grammarly.com/ - Grammarly to check for spelling and grammatical error.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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