Ecological Dynamics of Understory Vegetation in Managed Malaysian Oil Palm Ecosystems

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Abstract. Understory vegetation in oil palm plantations plays a crucial role in sustaining biodiversity, ecosystem health, and agricultural resilience; however, its diversity and distribution remain poorly understood. This study examined understory vegetation composition across the fringe, middle, and inner zones of oil palm plantations in the Banting, Selangor, using systematic quadrat sampling. A total of 1,630 individuals were identified, representing 31 species from five genera. The most dominant species were *Nephrolepis acutifolia*, *Paspalum conjugatum*, *Ageratum conyzoides*, and *Nephrolepis cordifolia*. Vegetation abundance was highest at the fringe (596 individuals), followed by the middle zone (557) and the inner zone (477). Diversity indices revealed that the middle zone supported the highest Shannon–Wiener Diversity Index (H' = 2.43) and Margalef Richness Index (R' = 4.11), while the inner zone exhibited the highest evenness (E' = 0.60) but the lowest diversity (H' = 1.97). Generalised Linear Models indicated significant differences in species distribution, particularly between fringe and inner zones ($p < 0.001$). Light availability and canopy cover were key drivers of vegetation patterns, with higher light penetration supporting greater diversity. These findings underscore the ecological significance of understory vegetation in managed oil palm systems and offer valuable insights for biodiversity conservation in agricultural landscapes.

Keywords. Habitat heterogeneity, monoculture, sustainable, plantation landscapes

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1 Introduction

In Malaysia, the oil palm plantation industry holds historical and economic significance. The region has remained pivotal to oil palm cultivation, helping Malaysia become the world's second-largest producer [1]. The growth and expansion of oil palm plantations in Selangor have been key to the prosperity of the area and the nation. The industry creates jobs, boosts exports, and supports small-scale farmers, playing a vital role in the region's and the country's economy. The oil palm plantations have the potential to support a diverse range of vegetation, including herbs, herbaceous climbers, shrubs, climbing shrubs, trees, small trees, ground and epiphytic ferns, angiosperms, and other plant species. Some vegetation species are even advantageous to oil palm trees and to biodiversity in the plantations [2].

Vegetation that grows below the canopy is called understory vegetation and supports biodiversity, provides various services, and ensures nutrient cycling and the balance of the entire ecosystem [3]. The understory comprises various species of vegetation, such as shrubs, herbs, bryophytes, and lichens, which can usually tolerate low light interception by having larger leaves to capture more light or by possessing specialised roots for nutrient absorption [4]. The diverse species of understory vegetation therefore provide numerous habitats and food resources to different types of fauna [2, 3]. Understory plants can also influence the regulation of microclimatic conditions in forests by affecting temperature, humidity, and soil moisture [4, 5].

To date, no studies have been conducted on the distribution and diversity of understory vegetation in oil palm plantations in the Banting area of Selangor. The types of understory vegetation species present and their distribution patterns within the oil palm plantations are unknown. Monoculture practices have threatened biodiversity in oil palm plantations. The presence of other vegetation can help mitigate this adverse effect. Understory vegetation plays an important role in providing food and shelter for local wildlife and in contributing to soil health [3]. Therefore, it is essential to study the diversity of understory plants. This knowledge will enable us to create effective action plans that conserve biodiversity in oil palm plantations and enhance the positive impacts of oil palm production.

From this research, we sought to understand the diversity and abundance of understory vegetation at selected sampling sites in the oil palm plantation in Banting, as well as the distribution of understory vegetation across the plantation's zones, from the fringe to the inner zones. The research questions guiding this study are as follows: (1) What species of understory vegetation are present within oil palm plantations located in Banting? (2) How does the distribution of understory vegetation species vary across different landscape gradients, specifically from the plantation fringe to the inner areas? This study aims to enhance the understanding of the diversity and abundance of vegetation species within the oil palm plantations of Banting. It will systematically document the distribution, classification, species composition, and ecological roles of understory vegetation in these agroecosystems. The findings of this research will provide critical insights into the functional significance of understory flora in relation to oil palm cultivation. Additionally, the results will serve as a foundational dataset for future ecological studies in similar settings, thereby contributing to a broader understanding of plant community dynamics in agricultural landscapes.

2 Materials and methods

2.1 Study sites

The site for this study was in Banting, Selangor (2°51'59.9"N 101°33'41.3" E) (Fig. 1). The Banting area is known by locals as an agricultural hub, with oil palm plantations and vegetable farms. The plantation here is owned by a smallholder company. The area of this oil palm plantation was managed with less intense monoculture and vegetation removal. In the study area, the diversity and abundance of understory vegetation were investigated in three different areas: the fringe, middle, and inner. The areas designated for the plantation were characterised by several factors relevant to this research. The fringe area was the closest area with higher human activities, such as the suburban area, in which case the roadway is used by vehicles passing over. The middle area has limited development, with only a small passageway for oil palm plantation workers to access it, which is reachable only by motorcycle or on foot. The least populated area is the inner one, which is accessible only on foot.

Fig. 1. Map view of the sampling site.

2.2 Sampling method

In this research, understory vegetation was identified in three different zones along different landscape gradients: fringe, middle, and inner. In the fringe, middle, and inner zones, transect lines were set up at each zone as guidance for quadrat placement (Fig. 2). Quadrats with optimal sizes of 1 meter x 1 meter ($1m^2$) were used suitably to identify the most occupied herbaceous vegetation in the study site area and were placed randomly to ensure more accurate and reliable results were obtained. Ten quadrats of 1 m2 were randomly placed along the transect lines in each area to identify and record vegetation diversity and abundance. Woody plants and herbaceous species were counted directly, as it was easier to differentiate them as distinct entities. For more distinct vegetation, such as grass, creepers, and shrubs, it was counted individually by clumps or tussocks. Tussocks are dense clumps or any rounded shape vegetation with a maximum of 0.2 meters away from each other. Photos of the vegetation were taken as references for identification. Further identification of understory vegetation was conducted by using journals, Malaysia Biodiversity Information System (MyBIS), and iNaturalist Malaysia as references.

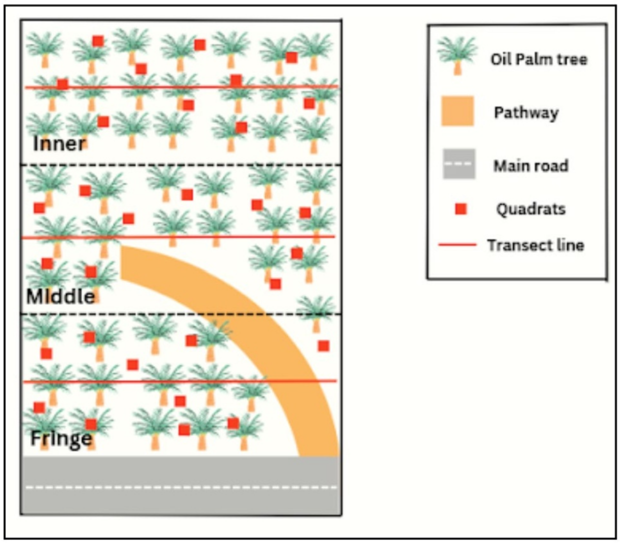

Fig. 2. Area division and spatial layout of the plantation.

3 Results and discussion

3.1 Abundance of Understory Vegetation in Bating oil palm plantation

In this study, a total of 1,630 understory vegetation samples were recorded from three different zones in Banting oil palm plantations. The fringe zone recorded the largest number of understory vegetation with a total of 596, followed by the middle zone with 557 individuals, and the inner zone recorded the smallest number with 477 (Table 1). The most dominant species in the plantation were *Nephrolepis acutifolia,* followed by *Paspalum conjugatum, Ageratum conyzoides*, *and Nephrolepis cordifolia,* which covered more than 10% of the total individuals identified. Some vegetation species were found in fewer than 10 individuals and covered 5% of the total area. These species included *Cyclosorus interruptus, Diplazium cordifolium, Stenochlaena palustris, Phyllanthus urinaria, Desmodium incanum, Populus heterophylla, Toddalia asiatica, Cleome rutidosperma, Lygodium palmatum, Brillantaisia lamium, Mallotus paniculatus, Dysoxylum spectabile, Magnolia scortechinii, Aegle marmelos, Asplenium pinnatifidum, Asplenium platyneuron, Cryptolepis buchananii, Fallopia convolvulus, Melicope* sp., and *Strobilanthes cusia*.

Table 1. The abundance of understory vegetation from different areas

Order	Family	Species	Fringe	Middle	Inner	Total
Asterales	Asteraceae	*Ageratum conyzoides*	75	72	69	216
Brassicales	Cleomaceae	*Cleome rutidosperma*	0	5	0	5
Caryophyllales	Polygonaceae	*Fallopia scandens*	0	0	1	1
Fabales	Fabaceae	*Desmodium incanum*	0	6	0	6
Gentianales	Apocynaceae	*Cryptolepis buchananii*	0	1	0	1

	Rubiaceae	*Spermacoce alata*	93	15	61	169
		Spermacoce latifolia	63	0	0	63
Lamiales	Acanthaceae	*Asystasia gangetica*	61	53	0	114
		Brillantaisia lamium	0	3	0	3
		Strobilanthes cusia	1	0	0	1
	Lamiaceae	*Mentha* sp.	23	11	0	34
Lycopodiales	Lycopodiaceae	*Palhinhaea cernua*	21	7	0	28
Magnoliales	Magnoliaceae	*Magnolia scortechinii*	1	1	0	2
Malpighiales	Euphorbiaceae	*Mallotus paniculatus*	3	0	0	3
	Phyllanthaceae	*Phyllanthus urinaria*	0	0	7	7
	Salicaceae	*Populus* sp.	1	5	0	6
Myrtales	Melastomataceae	*Melastoma candidum*	4	6	0	10
		Miconia crenata	8	31	0	39
Ophioglossales	Ophioglossaceae	*Sceptridium dissectum*	9	9	0	18
Poales	Poaceae	*Oplismenus undulatifolius*	0	0	25	25
		Panicum repens	23	9	28	60
		Paspalum conjugatum	95	86	41	222
Polypodiales	Aspleniaceae	*Asplenium pinnatifidum*	1	0	0	1
		Asplenium platyneuron	0	1	0	1
	Athyriaceae	*Diplazium cordifolium*	7	1	0	8
	Blechnaceae	*Stenochlaena palustris*	0	3	5	8
	Davalliaceae	*Davallia* sp.	0	21	0	21
	Nephrolepidaceae	*Nephrolepis acutifolia*	83	115	125	323
		Nephrolepis cordifolia	11	84	106	201
	Onocleaceae	*Onoclea sensibilis*	10	0	0	10
	Thelypteridaceae	*Cyclosorus interruptus*	3	3	3	9
Sapindales	Meliaceae	*Didymocheton spectabilis*	0	2	0	2
	Rutaceae	*Aegle marmelos*	0	1	0	1
		Melicope sp.	0	1	0	1
		Toddalia asiatica	0	0	6	6
Schizaeales	Lygodiaceae	*Lygodium* sp.	0	5	0	5
		Total	596	557	477	1630

Most species found in large quantities for this research exhibit traits of high adaptability and resilience. *Nephrolepis acutifolia* and *Nephrolepis cordifolia* were the two *Nephrolepis* species that spread widely in this oil palm plantation. The high number of individuals found for this species is reasonable, given its high reproductive and adaptive features. Hovenkamp and Miyamoto [6] stated that *Nephrolepis* (Nephrolepidaceae) can grow in various soil types, utilising its downward-growing runners, which are notably thin and have roots at their tips or wherever they encounter a suitable surface. They are also capable of reproducing vast quantities of spores, which allows a higher success rate for germination that results in the wide distribution of the ferns [6].

Paspalum conjugatum is also widely distributed as a grass species with an above-ground stem that grows laterally, spreading horizontally to quickly cover the ground and form dense mats [7]. *Paspalum* can reproduce both sexually and asexually and can grow year-round in low soil moisture, contributing to high yields [7]. Another species with a high number of individuals is *Ageratum conyzoides,* which can rapidly establish in new environments through rapid growth, early maturity, high seed production (up to 95,000 lightweight seeds), 50% germination, and vegetative spread by stolons [8]. Moreover, *Ageratum conyzoides* seeds exhibit high thermal and water-stress tolerance, enabling this species to grow in diverse environments and promoting its widespread distribution across various habitats [8].

From all the understory vegetation recorded from this study, most species are considered beneficial for the plantation's soil. For example, past research has shown that Cleome rutidosperma can fix atmospheric nitrogen, enriching the soil with various forms of organic nitrogen, thereby stimulating plant growth and increasing overall soil fertility [9]. Beroni et al. [10] also made similar observations, noting that Desmodium incanum has the potential to improve soil health through symbiosis with rhizobia, and that further investigation is needed. Understory vegetation can generally enhance soil biodiversity and health by improving nutrient cycling through the addition of organic matter, preventing erosion, and preserving soil moisture and temperature, thereby fostering microbial activity [5, 6].

Pollinators in a plantation are crucial for economic and agricultural value [2]. They are significant contributors to global agricultural production, securing high yields and good-quality crops [3]. Pollinators also drive the reproduction of many plants, which is crucial to life and essential for maintaining the genetic diversity needed to withstand various environmental and pest pressures, while simultaneously supporting pest-preying species [1]. Some species ascertained from this research are known to be attracting pollinators, which are beneficial for the plantation's business. *Mentha* sp., as discovered in this study, is a good attractant for pollinators, especially during the flowering period [11]. The *Magnolia* species are also recognised for attracting their pollinators with large, conspicuous flowers and a powerful, sweet fragrance.

Some vegetation found in this oil palm plantation also uniquely exhibits pharmaceutical traits. *Spermacoce* species of the family Rubiaceae are known for their anti-inflammatory, antitumor, and antimicrobial larvicidal antioxidant activities, alongside many other biological properties [12]. The incorporation of medicinal plants into plantations will enhance biodiversity, support sustainable resource management, and reduce pressure on wild populations, thereby conserving them [2]. Agroforestry practices within oil palm plantations could be implemented by maintaining medicinal plants, which could be further developed into other business products through further research [3].

3.2 Abundance of understory vegetation across all zones

A total of 36 species were enumerated from this study, of which 21 species (58%) were found in the fringe zone, 27 species (75%) were found in the middle zone, and 12 species (33%) were found in the inner zone. Many individuals were found in the fringe zone, possibly due to the more open area, with wider spacing between oil palm trees [1]. This condition allowed for greater light penetration, which probably explains the dominance in this zone. Higher light availability promotes the growth of light-dependent understory plants, leading to increased species richness and greater diversity in this zone [5]. Variation in canopy cover across areas can also influence the distribution of understory vegetation. With oil palm trees in the fringe zone of this plantation, which are far apart and provide less canopy cover, more light reaches the lower vegetation and the soil [1]. A study by Ou et al. [13] proved that differences in canopy structure can regulate understory species composition by altering light availability.

Despite a slight difference in understory vegetation abundance between zones, the inner zone had the fewest individuals. Several factors might contribute to this outcome, and competition for resources could be one of them. Based on the data collected, Nephrolepis spp. in the inner zone is generally dominant. They are recognised for their resilient traits, allowing them to form large colonies with a rapid growth rate and for their seeds to remain viable in the soil for over a decade [6]. High competition from this species may diminish the fitness and survival of less dominant species, potentially causing a decline in biodiversity within the inner zone [1]. Fast-growing species can dominate and outcompete other vegetation for light, leading to a situation where a few dominant species flourish while a more diverse plant community declines [2]. Some species of *Nephrolepis* were also known to possess allelopathic potential, which can prevent the growth of other vegetation. A study from Boonmee et al. [14] ascertained that *Nephrolepis cordifolia* specifically releases inhibitory allelochemicals that hinder the flourishing of dicotyledonous and monocotyledonous plant species. These biochemical traits in *Nephrolepis* species further provide an advantageous environment for this species to dominate the inner area of this plantation.

The inner zone between the palm trees has closer spacing, resulting in greater canopy coverage than the fringe. This shaded area could prevent vegetation from growing, retaining only species that favour the environment [5]. Areas with highly shaded canopies will be deprived of sunlight, making understory plants struggle with photosynthesis and growth. However, some studies have found that Nephrolepis spp. can tolerate low-light environments, allowing them to grow and flourish, which explains the high density of *Nephrolepis* spp. phenomenon in the inner area [6].

With closer adjacency between oil palm trees, the density of oil palm trees in the inner zone is higher, which may also affect the ecological relationships with understory vegetation. Canopy trees were known to be capable of monopolising soil moisture and nutrients, aiding the survival struggles of lower vegetation [4]. This also applies to the oil palm, as they also have extensive root systems and high nutrient requirements, which makes it challenging for understory vegetation's survival [1]. There was also a discovery that oil palm trees have the potential to release allelochemicals that inhibit the growth of other plants [15]. Areas with more oil palm trees would have higher oil palm leaf litter, which would impede vegetation growth. Inquiries have found that leaf litter can act as a barrier to the seedling emergence, thereby inhibiting their germination [15]. To improve the ecological environment and biodiversity, dominant and invasive species need to be controlled, while maintaining healthy conditions for diverse lower vegetation development in the oil palm plantation.

A Generalised Linear Model test was used to determine significant differences in distribution for all understory vegetation species among the fringe, middle, and inner areas. There was a significant difference (GLM, $\chi 2 = 8581.319$, df = 1, $p < 0.001$) in the understory vegetation species distribution among the areas comprehensively, and pairwise comparisons showed that a significant difference occurred ($p < 0.05$) between the Fringe–Inner and Middle-Inner pairs.

3.3 Diversity of understory vegetation across all zones

The diversity of understory vegetation collected from the three zones, which are fringe, middle, and inner, was analysed using PAST version 4 software. The obtained values for the Shannon–Wiener Diversity Index (H′), Evenness Index (E′), and Margalef Richness Index (R′) are tabulated in Table 2. The values obtained from this study analysis showed that the middle zone had the highest diversity, H′ = 2.43, followed closely by the fringe zone, H′ = 2.40. The inner zone is observed to be considerably less diverse, with H′ = 1.97, suggesting that a few species dominate this area. This trend aligns with past studies, which have consistently shown that environmental conditions are highly important for species diversity in managed ecosystems, such as oil palm plantations. 45

Table 2. Shannon-Wiener Diversity Index (H'), Evenness Index (E'), and Margalef Richness Index (R').

Area	H′	E′	R′
Fringe	2.40	0.53	3.13
Middle	2.43	0.42	4.11
Inner	1.97	0.60	1.78

The inner zone has the highest evenness value (E′ = 0.60), indicating that species were more evenly distributed than in the fringe and middle zones, which have evenness values of 0.53 and 0.42, respectively. Hence, this analysis indicates that while the inner zone may have lower overall diversity, it is more evenly distributed among the species. For species richness, the Margalef Richness Index (R′) in the middle zone obtained the highest richness with a value of R′ = 4.11, while the fringe zone follows with R′ = 3.13. The inner zone had the lowest richness at R′ = 1.78, which supported the notion that plant species diversity might be lower than in the fringe and middle zones.

Conclusion

The results of this research revealed that the oil palm plantation in Banting had a high understory vegetation density within agroecosystems, with the fringe area recording the highest number of individuals, possibly due to higher light intensity and lower canopy cover. The retention of the understory vegetation within the oil palm plantation can improve the biodiversity of species in the agricultural area that is always known to house little biodiversity, thus countering the negative perceptions of the expansion oil the oil palm industry in Malaysia is the major driver of biodiversity loss and saves the market of the palm oil industry.

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