TECHNICAL REPORT
RIVERINE STATUS ASSESSMENT
LANA OIL PALM ESTATES

for

GLENEALY PLANTATIONS SDN. BHD.
(Sustainability Division)

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Date of Sampling:

14-17 APRIL 2025

FACULTY OF AGRICULTURAL AND FORESTRY SCIENCES

UNIVERSITI PUTRA MALAYSIA BINTULU CAMPUS

MAY 2025

TECHNICAL REPORT
RIVERINE STATUS ASSESSMENT LANA OIL PALM ESTATES

WATER QUALITY
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May 2025

EXECUTIVE SUMMARY

This comprehensive technical report presents the results of environmental assessments conducted at the Lana oil palm estates in Sarawak, Malaysia, focusing on water quality, aquatic microflora and microfauna, and freshwater fish diversity.

Water Quality: The study evaluated water quality measuring key physical and chemical parameters such as pH, temperature, dissolved oxygen, conductivity, turbidity, total suspended solids (TSS), biological and chemical oxygen demand (BOD, COD), and ammonia nitrogen. The water quality parameters at Lana oil palm estates are generally within the ranges reported for other oil palm-dominated landscapes in Southeast Asia. However, Sungai Bah show higher values for parameters associated with soil erosion (turbidity and TSS), likely due to their proximity to plantation activities and possible point sources of contamination. In contrast, Sungai Sematai, Sungai Lalit and Sungai Tingga, which may be having a better buffered by vegetation, exhibit lower pollutant loads and better overall water quality.

Aquatic Microflora and Microfauna: A total of 74 taxa representing five kingdoms (Animalia, Protozoa, Chromista, Plantae, and Bacteria) were identified, with Animalia and Chromista exhibiting the highest species richness, and Protozoa contributing the greatest proportion to total abundance. The green alga *Staurastrum* sp.1 emerged as the most dominant species, particularly at stations with elevated nutrient levels. Biodiversity patterns varied across the river, with Sungai Sematai recording the highest diversity index (3.410) and species richness (39 species), while Sungai Bah showed the lowest diversity (2.835) and was characterized by a pronounced dominance of *Staurastrum* sp.1.

Fish Composition: This study documented 19 freshwater fish species from four families in oil palm plantation streams in Lana Kapit, Sarawak, with Cyprinidae being the most dominant family. *Barbonymus collingwoodii* was the most widely distributed species, while several others, such as *Rasbora argyrotaenia* and *Gastromyzon ctenocephalus*, showed highly localized distributions, indicating specific habitat preferences. Conservation assessments revealed most species were of Least Concern, though the presence of Vulnerable and Near Threatened species highlights the ecological value of these habitats. Species richness varied across sampling stations, with Sungai Tingga supporting the highest diversity and Sungai Bah the lowest, likely due to differences in habitat quality.

Overall, the findings provide valuable reference data on the water quality, aquatic microflora and microfauna and fish community structure in the Lana Estate riverine system, serving as an important reference for future ecological monitoring and conservation efforts in oil palm-dominated landscapes.

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WATER QUALITY

INTRODUCTION

The quality of river water is a critical concern in regions dominated by oil palm plantations, particularly in Malaysia and across Asia, where these landscapes are rapidly expanding. Rivers serve as vital lifelines for local communities, agriculture, and biodiversity, making their protection essential for both environmental sustainability and human well-being. In oil palm-producing countries such as Malaysia and Indonesia, the health of river systems is increasingly under scrutiny due to the potential impacts of plantation activities, including agrochemical runoff, sedimentation, and effluent discharge. Maintaining high river water quality is not only fundamental for supporting aquatic ecosystems, fisheries and ecological integrity but also for ensuring safe water supplies for rural populations and sustaining agricultural productivity and compliance with international environmental standards (Dislich et al., 2017; Kumaran et al., 2017; WHO, 2017). As Malaysia remains a global leader in palm oil production, safeguarding river water quality within and around oil palm estates is crucial for meeting national and international sustainability standards, protecting public health, and preserving the ecological integrity of tropical watersheds (MPOB, 2023; RSPO, 2018).

Maintaining high river water quality within oil palm catchments is essential for supporting vibrant aquatic ecosystems and sustaining biodiversity. Studies in Malaysia have highlighted that effective management practices can help ensure rivers remain clear, with balanced levels of suspended solids, nitrogen, and phosphorus, which are crucial for preventing eutrophication and supporting healthy aquatic life (Ng et al., 2017; Abdullah et al., 2015). For example, Ng et al. (2017) emphasized the importance of monitoring and managing nutrient levels in rivers, which flows through extensive oil palm plantations, to preserve water quality throughout seasonal changes. By safeguarding optimal nutrient concentrations and minimizing sedimentation, river systems can continue to provide essential ecosystem services, including water purification, flood regulation, and habitat provision for diverse aquatic organisms. These efforts contribute to the resilience and productivity of both natural ecosystems and agricultural landscapes.

The expansion of oil palm plantations has played a pivotal role in stimulating economic growth, job creation, and rural development across Malaysia and other parts of Asia (Obidzinski et al., 2012). Rivers in and around oil palm estates are vital resources that support local communities, agriculture, and biodiversity. Their presence enhances the landscape, providing essential water for drinking, irrigation, and sustaining aquatic life (Dislich et al., 2017; WHO, 2017). The quality of river water is a key determinant of its suitability for these uses. In oil palm landscapes, river water quality is shaped by land management practices, including the responsible use of fertilizers and pesticides, as well as the effective management of effluents (FAO, 2011). By prioritizing regular assessment and protection of river water quality, stakeholders can ensure sustainable oil palm production while safeguarding the integrity of surrounding ecosystems.

In the current context, the sustainability of oil palm plantations in Malaysia and Sarawak is closely linked to the ability to balance economic benefits with environmental stewardship. Protecting river water quality is essential for maintaining ecosystem health and public well-being, and it also underpins the long-term viability of the palm oil industry in a competitive global market. Continued investment in water quality monitoring, community engagement, and the adoption of innovative management practices are crucial for supporting the environmental goals associated with oil palm cultivation and for securing a sustainable future for both people and nature in Malaysia's plantation landscapes.

Rivers within oil palm catchments are central to the livelihoods and well-being of many rural communities in Malaysia and Indonesia, who rely on these water bodies for drinking water, fishing, and agriculture. Clean and well-managed water resources contribute to food security, public health, and economic stability (Merten et al., 2016). For example, Merten et al. (2016) highlighted the importance of maintaining good water quality for communities living downstream of oil palm plantations in Sumatra, Indonesia, where access to clean water supports daily life and community resilience. Ensuring the availability of clean water resources can help alleviate poverty, foster social harmony, and reduce the need for costly water treatment and healthcare interventions, thereby maximizing the benefits of oil palm development (Obidzinski et al., 2012).

Maintaining good river water quality is also essential for the long-term sustainability and global competitiveness of the oil palm industry. International markets, particularly in Europe and North America, are increasingly demanding sustainably produced palm oil, with strict environmental criteria that include water quality management (RSPO, 2023). Meeting these standards helps secure certification, maintain market access, and enhance the reputation of the industry. Several studies have emphasized the importance of adopting best management practices (BMPs) to support environmental stewardship in oil palm cultivation. For example, Abdullah et al. (2015) demonstrated that the implementation of buffer zones, optimized chemical usage, and proper waste management significantly improved river water quality in oil palm catchments. These findings underscore the value of industry-wide adoption of sustainable practices to ensure compliance with certification schemes such as the Roundtable on Sustainable Palm Oil (RSPO) and the Malaysian Sustainable Palm Oil (MSPO) standard.

The Malaysian government has recognized the importance of protecting river water quality and has introduced various policies and regulations aimed at supporting sustainable oil palm production. The Environmental Quality Act 1974 and the National Water Resources Policy 2012 provide a robust legal framework for water quality management, while state-level initiatives promote integrated river basin management (IRBM) approaches (DOE Malaysia, 2020). These frameworks encourage collaboration among stakeholders, foster innovation, and support the use of advanced monitoring technologies to ensure effective implementation of water quality standards (Tan et al., 2020).

The positive experiences and strategies developed in Malaysia are mirrored in other oil palm-producing countries in Asia. In Thailand, for example, research by Kittitornkool et al. (2019) highlighted the importance of effective land management and water quality monitoring in maintaining healthy river systems adjacent to oil palm plantations. Similarly, in Papua New Guinea, Sheil et al. (2009) emphasized the value of integrated management approaches in supporting both ecosystem health and community well-being. These studies highlight the need for regional cooperation and knowledge sharing to develop effective strategies for maintaining river water quality in oil palm landscapes. Integrated approaches that combine regulatory enforcement, community participation, and industry commitment are essential for achieving sustainable outcomes.

Generally, maintaining good river water quality within oil palm catchments is of paramount importance for environmental protection, public health, and the sustainability of the oil palm industry. The evidence from Malaysia and elsewhere in Asia underscores the urgent need for improved management practices, robust policy frameworks, and effective enforcement to support the positive contributions of oil palm cultivation to river systems. As global demand for sustainable palm oil continues to grow, ensuring the health of rivers within oil palm catchments will be a critical determinant of the industry's future viability and social license to operate. By prioritizing water quality, the oil palm sector can continue to deliver economic, social, and environmental benefits for generations to come.

Thus, this study aims to provide updated water quality data for the Lana oil palm estates and to compare these findings against the Malaysian National Water Quality Standards (MNWQS). Additionally, the Water Quality Index (WQI) will be calculated to assess the river health status within the study area.

METHODOLOGY

Assessment Location

Sampling stations are usually conducted at different streams within the oil palm estates which include upstream and downstream, to assess the impact of oil palm activities (Cheng et al., 2017). Thus, this assessment involved 4 sampling stations, namely, Station 1 (Sg. Sematai), Station 2 (Sg. Bah), Station 3 (Sg. Lalit), and Station 4 (Sg. Tingga) (Figure 1 and 2). The GPS coordinates for these sampling stations are summarized in Table 1. Sampling period was conducted on 14 – 17 April 2025.

The selection of water quality sampling locations is critically important as oil palm estates often cover large and heterogeneous landscapes, with varying land uses, topography, and proximity to water bodies. Choosing the right sampling locations ensures that the collected data accurately represents the range of water quality conditions across the estate, including areas most likely to be impacted by estate activities.

Strategic sampling locations also help to enable detect early signs of ecological stress and guide conservation measures to support effective environmental management and conservation efforts. This is crucial for assessing the effectiveness of best management practices, understanding seasonal or climatic influences, and making informed decisions to minimize negative environmental impacts.

Generally, a careful selection of water quality sampling locations in oil palm estates is fundamental to obtaining accurate, actionable data for pollution control, regulatory compliance, environmental stewardship, and sustainable estate management.

Table 1: GPS coordination of the sampling points

Station	River/Stream Name	Latitude	Longitude
1	Sg. Sematai	2° 32’ 13” N	113° 19’ 32” E
2	Sg. Bah	2° 33’ 00” N	113° 23’ 47” E
3	Sg. Lalit	2° 31’ 16” N	113° 28’ 06” E
4	Sg. Tingga	2° 28’ 26” N	113° 23’ 06” E

(To be inserted)

Figure 1: Locations of sampling stations in Lana oil palm estates.

Water Quality Assessment Parameters

This water quality assessment for Lana oil palm estates involves the measurement of physical and chemical parameters. The common indicators include temperature, turbidity, total suspended solids, conductivity as physical elements; and, pH, dissolved oxygen, biochemical oxygen demand, chemical oxygen demand, and ammoniacal nitrogen as chemical elements.

At each station, *in-situ* water quality data was recorded using DKK-TOA-WMS-24 multiparameter for temperature, pH, dissolved oxygen (DO), conductivity and turbidity (Figure 3). Additional surface water samples were collected to analyze for total suspended solids (TSS), biological oxygen demand (BOD), chemical oxygen demand (COD) and ammoniacal nitrogen (NH_3-N). The sampling and analytical procedures followed established protocols (APHA, 2017). Results were evaluated against the Malaysian National Water Quality Standards (MNWQS) and the Water Quality Index (WQI) to determine the status of each site.

a) Station 1: Sg. Sematai

b) Station 2: Sg. Bah

c) Station 3: Sg. Lalit

d) Station 4: Sg. Tingga

Figure 2: Pictures of sampling locations for water quality assessment at Lana oil palm estates.

a) DKK-TOA-WMS-24 multiparameter

b) The scientific instrument being dipped into the river to measure water parameters.

Figure 3: Water quality *In-situ* sampling at Lana oil palm estates.

RESULTS AND DISCUSSION

The water quality results obtained in this assessment is important to further understand river physiochemical pattern within Lana oil palm estates. Those parameters serve as key indicators of both natural processes and anthropogenic influences associated with plantation management. The presented results of these measurements provide a detailed analysis of spatial variations in water quality of selected rivers within Lana oil palm estates. The discussion integrates these findings with existing literature, offering a comparative perspective with other oil palm-dominated landscapes elsewhere.

pH

All stations recorded pH values within the range of 6.08 to 6.68, with low standard deviations, indicating relatively stable pH conditions across the sampling period (Table 2 and Figure 4). The pH values at all sites fall within the acceptable range for the Malaysian National Water Quality Standards (MNWQS), which typically considers pH 6.0–9.0 as suitable for Class II rivers (suitable for recreational use and aquatic life). The observed pH values in this study are consistent with findings from other Malaysian rivers within oil palm plantation landscapes. For example, Gandaseca et al. (2014) reported river pH values ranging from 5.8 to 7.0 in oil palm plantation areas in Sarawak, Malaysia, with most values clustering around neutral to slightly acidic conditions. Their study highlighted that oil palm plantations can influence river pH, but values generally remain within regulatory limits unless there is significant runoff or pollution from fertilizers or mill effluents. The authors also noted that pH was one of the main parameters affected by land use change, but not to a degree that would typically threaten aquatic life (Gandaseca et al., 2014).

Similarly, Itoh et al. (2023) conducted a multi-year, multi-site study in Peninsular Malaysia and found that rivers draining oil palm plantations had pH values generally between 6.0 and 7.0, with slightly lower pH in areas with more intensive fertilizer application or where acid sulfate soils were present. Their research also indicated that the use of limestone for pH adjustment in plantations can help maintain river pH within acceptable limits, despite increased concentrations of dissolved ions from agricultural runoff (Itoh et al., 2023). The pH values observed in this study suggest that, under current management, the oil palm plantation does not cause significant acidification of the river system. This is important for the health of aquatic ecosystems, as most freshwater organisms are adapted to live within a pH range of 6.5–8.5. Persistent deviations outside this range can stress aquatic life, reduce biodiversity, and alter nutrient cycling.

However, the slightly acidic tendency (pH just above 6.0 at some stations) warrants continued monitoring, especially during periods of heavy rainfall or fertilizer application, which can cause episodic acidification. The use of limestone and careful management of fertilizer and effluent runoff are critical in maintaining river pH within safe limits. Therefore, continued monitoring and good agricultural practices are essential to prevent acidification and protect riverine ecosystems.

Table 2: pH descriptive analysis summary

	Station 1	*Station 2*	*Station 3*	*Station 4*
Mean	6.303	6.123	6.107	6.630
Standard Error	0.070	0.009	0.015	0.045
Median	6.260	6.120	6.110	6.670
Standard Deviation	0.121	0.015	0.025	0.078
Minimum	6.210	6.110	6.080	6.540
Maximum	6.440	6.140	6.130	6.680
Confidence Level (95.0%)	0.301	0.038	0.063	0.194

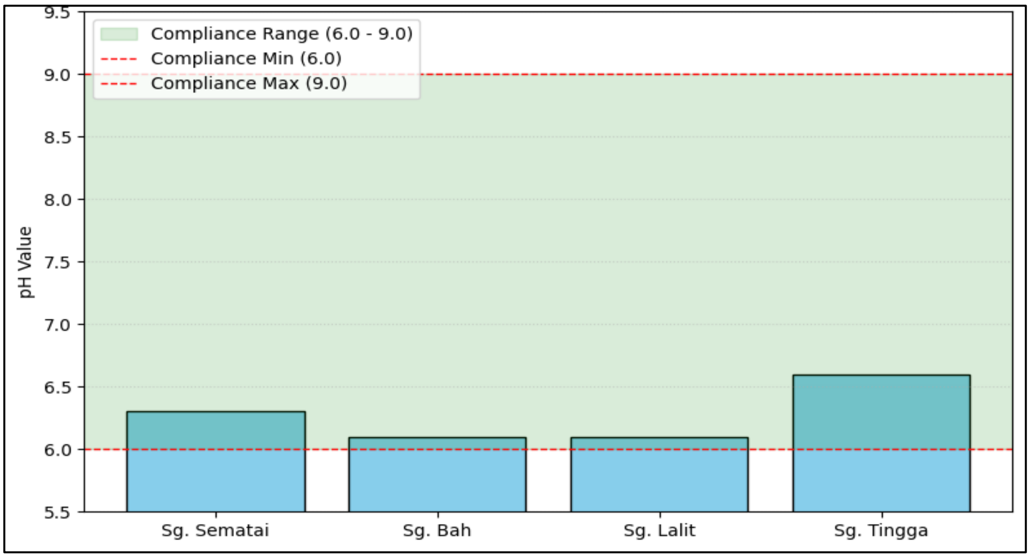


Figure 4: Indicating the water pH at each site falls within the acceptable range for MNWQS regulatory standards.

Temperature

The temperature range across all stations is from 24.90°C to 27.60°C, with low standard deviations, indicating stable thermal conditions during the sampling period. The highest mean temperature was observed at Station 2 (27.50°C), while the lowest was at Station 1 (25.03°C) (Table 3 and Figure 5). The observed river temperatures in this study (25.0–27.6°C) are consistent with findings from other Malaysian rivers within oil palm plantation landscapes. For example, Nadzir et al. (2019) reported an average river water temperature of 28.01°C in rivers adjacent to oil palm plantations in Pahang, Malaysia, which is slightly higher but within a similar range (Nadzir et al., 2019). Gandaseca et al. (2014) also found river temperatures in oil palm plantation areas in Sarawak, Malaysia, ranging from 25°C to 29°C, with variations attributed to canopy cover, river width, and time of sampling.

Itoh et al. (2023) observed that river temperatures in oil palm-affected catchments in Peninsular Malaysia were generally between 25°C and 29°C, with higher temperatures often recorded in open, less shaded sections of the river, especially where riparian vegetation had been removed (Itoh et al., 2023). The presence of oil palm plantations can influence river temperature by altering shading and increasing solar radiation exposure, particularly if riparian buffer zones are not maintained. Similar temperature ranges have been reported in other Southeast Asian countries. In Indonesia, river temperatures in oil palm plantation areas typically range from 25°C to 30°C, depending on local climate, river size, and degree of shading from riparian vegetation. Studies have shown that the removal of natural forest cover and replacement with oil palm can lead to slight increases in river temperature, especially in smaller streams with limited canopy cover.

River water temperature is a critical parameter for aquatic ecosystem health, influencing dissolved oxygen levels, metabolic rates of aquatic organisms, and overall biodiversity. The observed temperatures in this study are within the typical range for tropical lowland rivers and are not expected to cause thermal stress to native aquatic species. However, the higher temperature at Station 2 (27.5°C) may indicate reduced shading or increased exposure to sunlight, possibly due to less riparian vegetation in that area. Maintaining riparian buffer zones with native vegetation is essential to moderate river temperatures, reduce thermal pollution, and support healthy aquatic ecosystems. Elevated river temperatures, if persistent, can reduce dissolved oxygen levels and negatively impact sensitive aquatic species.

Table 3: Temperature descriptive analysis summary

	Station 1	*Station 2*	*Station 3*	*Station 4*
Mean	25.033	27.500	25.533	26.633
Standard Error	0.088	0.058	0.033	0.033
Median	25.000	27.500	25.500	26.600
Standard Deviation	0.153	0.100	0.058	0.058
Minimum	24.900	27.400	25.500	26.600
Maximum	25.200	27.600	25.600	26.700
Minimum	24.900	27.400	25.500	26.600
Maximum	25.200	27.600	25.600	26.700
Confidence Level (95.0%)	0.379	0.248	0.143	0.143

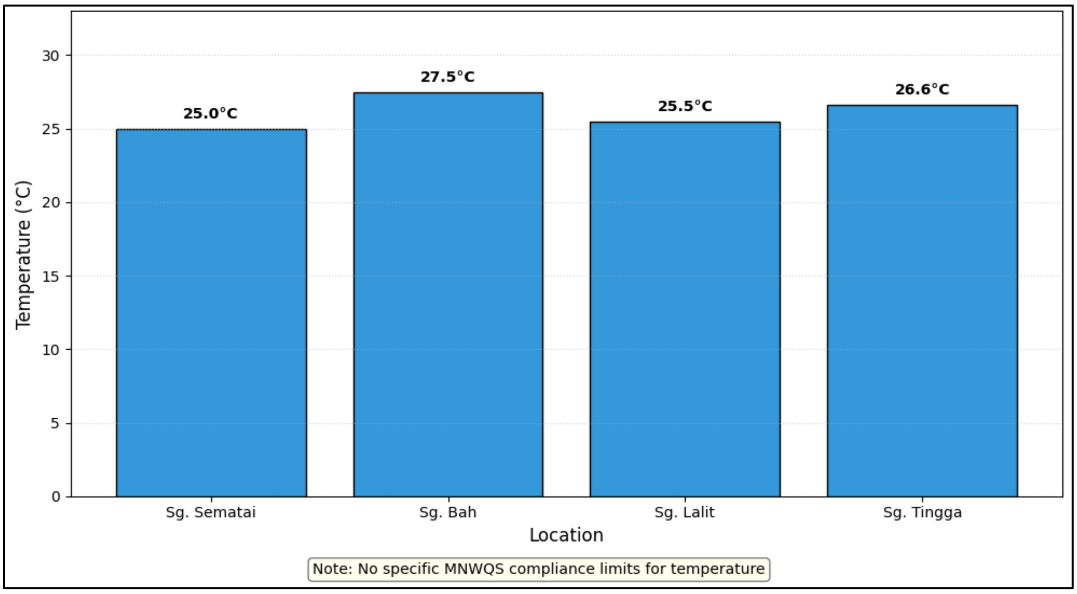


Figure 5: The diagram provides a visual comparison of water temperatures across the four river sites.

Dissolved Oxygen

The DO values across all stations range from 5.40 mg/L to 7.20 mg/L. Station 1 recorded the highest mean DO, while Station 2 had the lowest (Table 4 and Figure 6). The standard deviations are low, indicating stable DO levels during the sampling period. The observed DO values in this study (5.4–7.2 mg/L) are within the typical range for Malaysian rivers, especially those influenced by oil palm plantations. According to the Malaysian National Water Quality Standards (NWQS), Class II rivers (suitable for recreational use and aquatic life) should have DO levels above 5 mg/L. All stations in this study meet this criterion, though Station 2 is close to the lower threshold.

Nadzir et al. (2019) reported DO values averaging 6.13 mg/L in rivers adjacent to oil palm plantations in Pahang, Malaysia, which is comparable to the present findings (Nadzir et al., 2019). Gandaseca et al. (2014) found DO values in Sarawak rivers within oil palm landscapes ranging from 4.5 to 7.5 mg/L, with lower values often associated with higher organic matter and nutrient loads (Gandaseca et al., 2014). These studies highlight that DO can fluctuate depending on factors such as organic pollution, water temperature, and flow conditions. Itoh et al. (2023) also observed that DO levels in oil palm-affected rivers in Peninsular Malaysia generally ranged from 5.0 to 7.5 mg/L, with lower values in areas with reduced flow or higher organic input (Itoh et al., 2023). The maintenance of DO above 5 mg/L is crucial for sustaining aquatic life, particularly fish and macroinvertebrates. In other Southeast Asian countries, similar DO ranges have been reported in rivers draining oil palm plantations. For example, studies in Indonesia and Thailand have found DO values typically between 4.0 and 8.0 mg/L, with lower values often linked to effluent discharge, high organic loading, or reduced riparian vegetation. The presence of oil palm plantations can contribute to organic matter and nutrient runoff, which may increase biological oxygen demand (BOD) and reduce DO, especially during low-flow periods or after heavy rainfall.

Dissolved oxygen is a key indicator of river health and is essential for the survival of aquatic organisms. The observed DO values in this study suggest that, under current management, the river system within the oil palm plantation is generally able to support aquatic life. However, the lower DO at Station 2 (mean 5.43 mg/L) may indicate localized organic enrichment or reduced water movement, which could be linked to plantation activities or natural variation in river morphology. Maintaining adequate DO levels requires effective management of organic waste, preservation of riparian buffers, and minimization of nutrient runoff.

Table 4: Dissolved oxygen (DO) descriptive analysis summary

	Station 1	*Station 2*	*Station 3*	*Station 4*
Mean	7.100	5.433	6.667	6.600
Standard Error	0.058	0.033	0.067	0.058
Median	7.100	5.400	6.600	6.600
Standard Deviation	0.100	0.058	0.115	0.100
Minimum	7.000	5.400	6.600	6.500
Maximum	7.200	5.500	6.800	6.700
Confidence Level (95.0%)	0.248	0.143	0.287	0.248

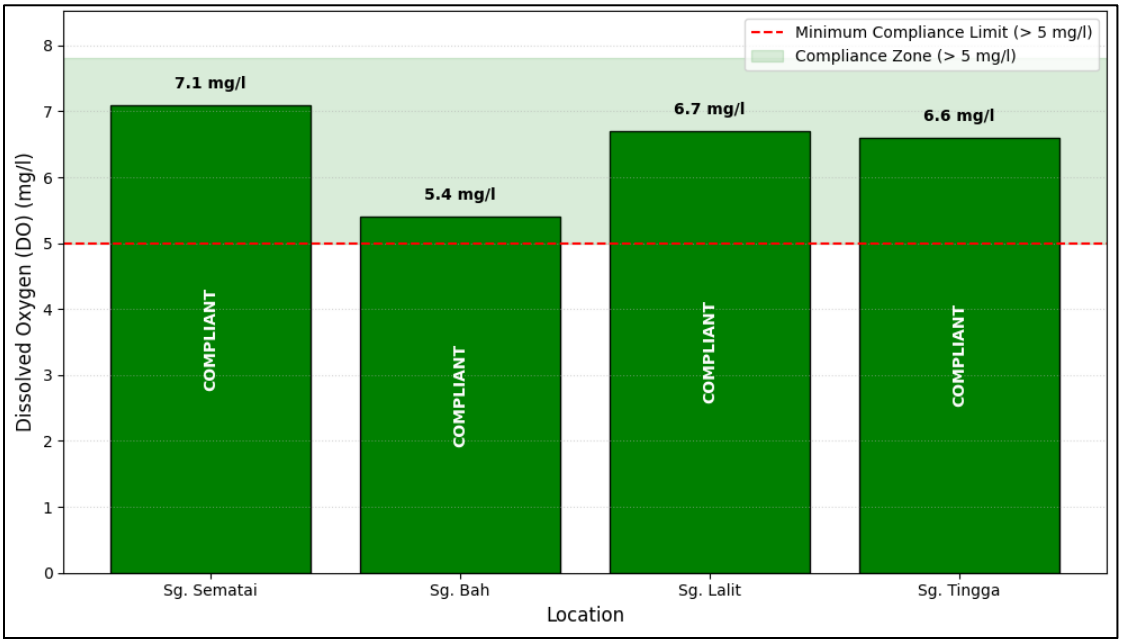


Figure 6: All sampling sites meet the minimum requirement for dissolved oxygen, with some sites having particularly high levels.

Conductivity

The descriptive analysis of river water conductivity (measured in µS/cm) at four stations within an oil palm plantation area shows the following mean values: Station 1 (19.33 µS/cm), Station 2 (25.33 µS/cm), Station 3 (22.33 µS/cm), and Station 4 (24.33 µS/cm) (Table 5 and Figure 7). The standard deviations are relatively low (ranging from 0.577 to 1.528), indicating limited variability within each station. The range of conductivity values is also narrow, with most stations showing a range of 1.0, except Station 2, which has a range of 3.0. The observed conductivity values (19.33–25.33 µS/cm) are within the lower to moderate range for Malaysian rivers, especially those influenced by agricultural activities. For instance, studies in oil palm-dominated catchments in Peninsular Malaysia have reported river conductivity values typically ranging from 15 to 60 µS/cm, depending on proximity to plantations, fertilizer application, and rainfall events (Shuhaimi-Othman et al., 2012, Sulaiman et al., 2018).

The relatively low variability and moderate means in your data suggest that the oil palm plantation in this study may have moderate impacts on river ionic content, possibly due to controlled fertilizer use or effective buffer zones. In comparison, rivers in undisturbed forested areas in Malaysia often show lower conductivity values, typically below 15 µS/cm (Yusoff et al., 2002). Conversely, rivers in heavily impacted agricultural or urban areas can exceed 50 µS/cm, especially during runoff events (Ng et al., 2017). Thus, the findings here indicate that while the oil palm plantation does elevate conductivity compared to pristine conditions, it remains below levels observed in more intensively managed or urbanized catchments.

Similar trends are observed in other Southeast Asian countries. For example, studies in Indonesia and Thailand have reported river conductivity in oil palm landscapes ranging from 20 to 70 μS/cm, with higher values linked to intensive fertilizer use and poor riparian management (Merten et al., 2016, Kusin et al., 2019). The values from your study are at the lower end of this spectrum, suggesting relatively good management practices or less intensive land use. Conductivity is a proxy for the total dissolved ions in water, often reflecting the influence of agricultural runoff, especially fertilizers and soil leaching. The moderate values observed suggest some degree of nutrient input from the oil palm plantation, but not at levels that would indicate severe pollution or eutrophication risk. Maintaining or improving buffer zones, minimizing fertilizer overuse, and monitoring during rainy seasons are recommended to prevent further increases.

Table 5: Conductivity descriptive analysis summary

	Station 1	*Station 2*	*Station 3*	*Station 4*
Mean	19.333	25.333	22.333	24.333
Standard Error	0.333	0.882	0.333	0.333
Median	19.000	25.000	22.000	24.000
Mode	19.000	#N/A	22.000	24.000
Standard Deviation	0.577	1.528	0.577	0.577
Minimum	19.000	24.000	22.000	24.000
Maximum	20.000	27.000	23.000	25.000
Confidence Level (95.0%)	1.434	3.795	1.434	1.434

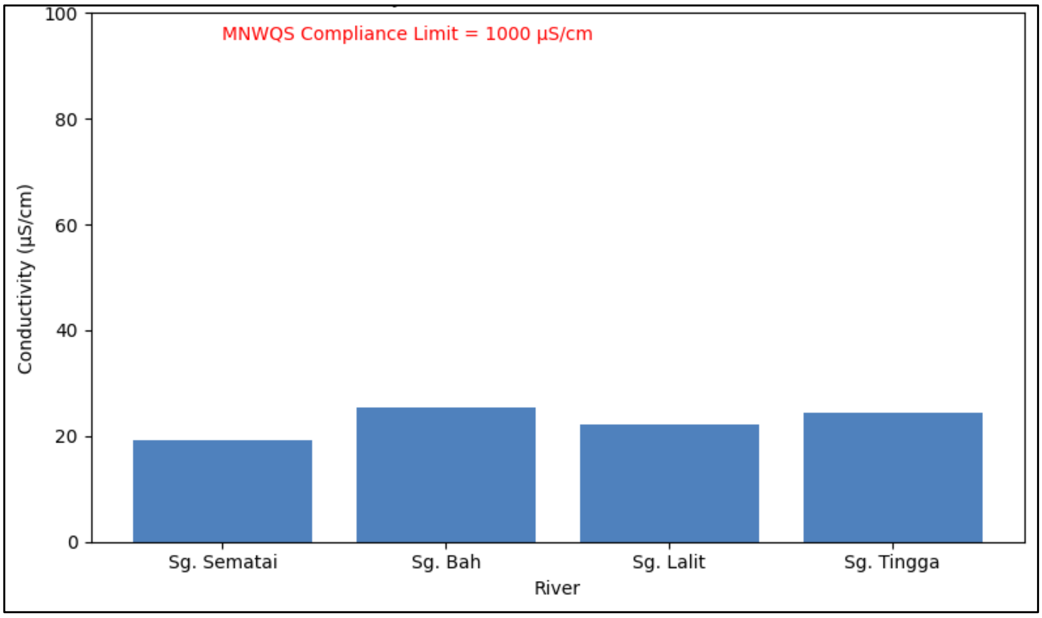


Figure 7: All measured values are within acceptable range, indicating that the water at all sites meets the standard for conductivity.

Turbidity

The descriptive analysis of turbidity (NTU) at four river stations within an oil palm plantation area shows the following mean values: Station 1 (18.0 NTU), Station 2 (46.7 NTU), Station 3 (20.0 NTU), and Station 4 (28.7 NTU). The highest mean turbidity was observed at Station 2, while the lowest was at Station 1 (Table 6 and Figure 8). The standard deviations range from 2.5 to 6.1 NTU, indicating moderate variability within each station. All observed mean values are below the Malaysian National Water Quality Standard (MNWQS) compliance limit of 50 NTU.

The turbidity values observed in this study (mean range: 18.0–46.7 NTU) are generally within the range reported for rivers in oil palm plantation areas in Malaysia. For example, Shuhaimi-Othman et al. (2012) found turbidity values ranging from 10 to 60 NTU in rivers draining oil palm plantations in Selangor, with higher values typically associated with recent land clearing, rainfall events, or poor riparian buffer management. Similarly study elsewhere reported mean turbidity values of 15–55 NTU in rivers within oil palm-dominated catchments, with occasional exceedances of the 50 NTU compliance limit during heavy rainfall or after fertilizer application (Sulaiman et al., 2018). In comparison, rivers in undisturbed forested catchments in Malaysia typically exhibit much lower turbidity, often below 10 NTU (Yusoff et al., 2002). The elevated turbidity in oil palm areas is attributed to increased soil erosion, surface runoff, and sediment input due to land clearing, road construction, and reduced vegetation cover.

Similar patterns are observed in other Southeast Asian countries. In Indonesia, Merten et al. (2016) reported turbidity values of 20–80 NTU in rivers draining oil palm plantations, with the highest values linked to recent plantation expansion and inadequate buffer zones (Merten et al., 2016). In Thailand, Kusin et al. (2019) found that turbidity in agricultural catchments, including oil palm, ranged from 15 to 70 NTU, with peaks during the rainy season (Kusin et al., 2019).

The results indicate that while turbidity levels in the studied rivers are elevated compared to pristine forest streams, they generally remain within the MNWQS compliance limit of 50 NTU. However, the high values at Station 2 (mean 46.7 NTU, max 49.0 NTU) approach the compliance threshold, suggesting a risk of exceedance during heavy rainfall or increased land disturbance. Elevated turbidity can reduce light penetration, affect aquatic life, and transport attached pollutants such as nutrients and pesticides. To mitigate further increases in turbidity, it is recommended to maintain or enhance riparian buffer zones, implement soil erosion control measures, and monitor turbidity especially during and after rainfall events.

Table 6: Turbidity descriptive analysis summary

	Station 1	*Station 2*	*Station 3*	*Station 4*
Mean	18.000	46.667	20.000	28.667
Standard Error	3.512	1.453	2.887	2.603
Median	21.000	47.000	20.000	29.000
Standard Deviation	6.083	2.517	5.000	4.509
Minimum	11.000	44.000	15.000	24.000
Maximum	22.000	49.000	25.000	33.000
Confidence Level (95.0%)	15.110	6.252	12.421	11.202

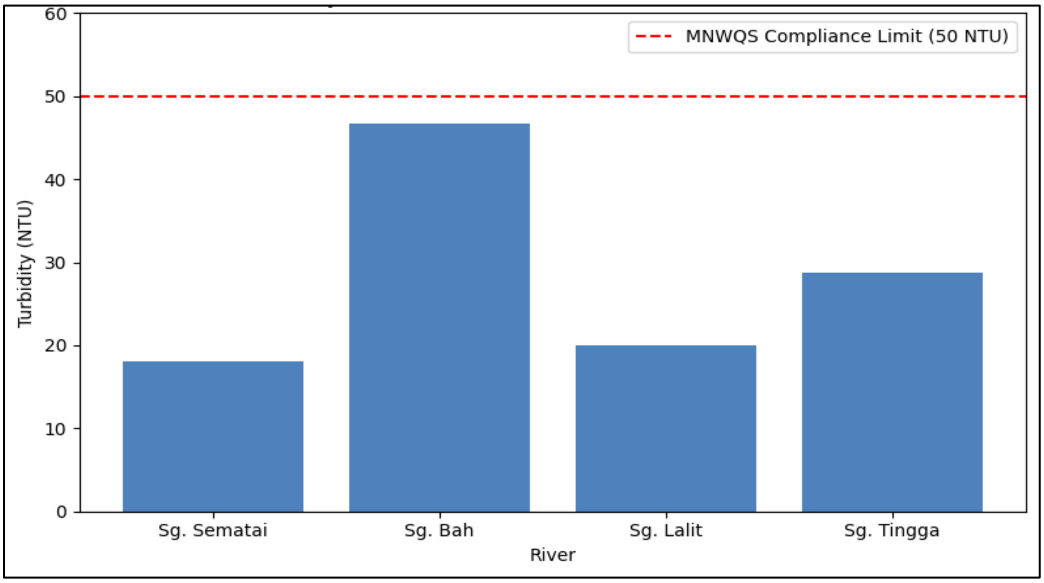


Figure 8: The chart shows that Sg. Bah have higher turbidity values (close to 50), while the others recorded lower values.

Total Suspended Solids

Station 2 recorded the highest mean TSS, followed by Station 4, while Stations 1 and 3 had much lower values (Table 7 and Figure 9). The range of TSS was also widest at Station 4 (23–57 mg/L), indicating greater fluctuation, possibly due to antecedent rainfall before the sampling.

The observed TSS values reflect the influence of oil palm plantation activities on riverine sediment loads. The elevated TSS at Station 2 (mean 67 mg/L) and Station 4 (mean 37.33 mg/L) suggest areas of higher sediment input, potentially linked to plantation management practices and antecedent rainfall event. Antecedent rainfall is important because it influences soil moisture, river baseflow, and the likelihood of runoff or sediment transport during subsequent rainfall events.

Study in the Sungai Langat basin found TSS values ranging from 10 to 80 mg/L in oil palm-dominated catchments, with peaks during rainfall events (Shamshad et al., 2008). Gomi et al. (2011) in Sabah, reported mean TSS values of 20–60 mg/L downstream of oil palm plantations, with higher values associated with recent land conversion and poor riparian management. In contrast, Stations 1 and 3 (means ~11 mg/L) are comparable to background or minimally disturbed conditions, as reported by Douglas et al. (2009), who found TSS values below 15 mg/L in forested or well-buffered streams.

Across Southeast Asia, similar patterns have been observed. In Indonesia, Carlson et al. (2014) reported TSS values of 30–100 mg/L in rivers draining oil palm plantations, with the highest values linked to new plantation development and lack of riparian buffers. In Thailand, TSS in agricultural catchments ranged from 15 to 70 mg/L, with oil palm areas showing higher sediment loads than rubber or mixed agriculture (Kusin et al., 2010). The findings from the present study are consistent with these regional trends, highlighting the role of plantation management and landscape position in influencing sediment delivery to rivers. The high variability among stations underscores the importance of site-specific factors, such as slope, soil type, and proximity to disturbed areas. The results suggest that targeted management, such as maintaining or restoring riparian buffers, minimizing soil disturbance, and implementing sediment control measures may help reduce sediment export from oil palm plantations. Thus, best management practices, such as maintaining riparian buffers and minimizing soil disturbance, are recommended to reduce TSS impacts (Koh et al., 2011)

Table 7: Total Suspended Solid descriptive analysis summary

	Station 1	*Station 2*	*Station 3*	*Station 4*
Mean	11.000	67.000	10.667	37.333
Standard Error	5.196	3.606	1.764	10.171
Median	11.000	69.000	10.000	32.000
Standard Deviation	9.000	6.245	3.055	17.616
Minimum	2.000	60.000	8.000	23.000
Maximum	20.000	72.000	14.000	57.000
Confidence Level (95.0%)	22.357	15.513	7.589	43.761

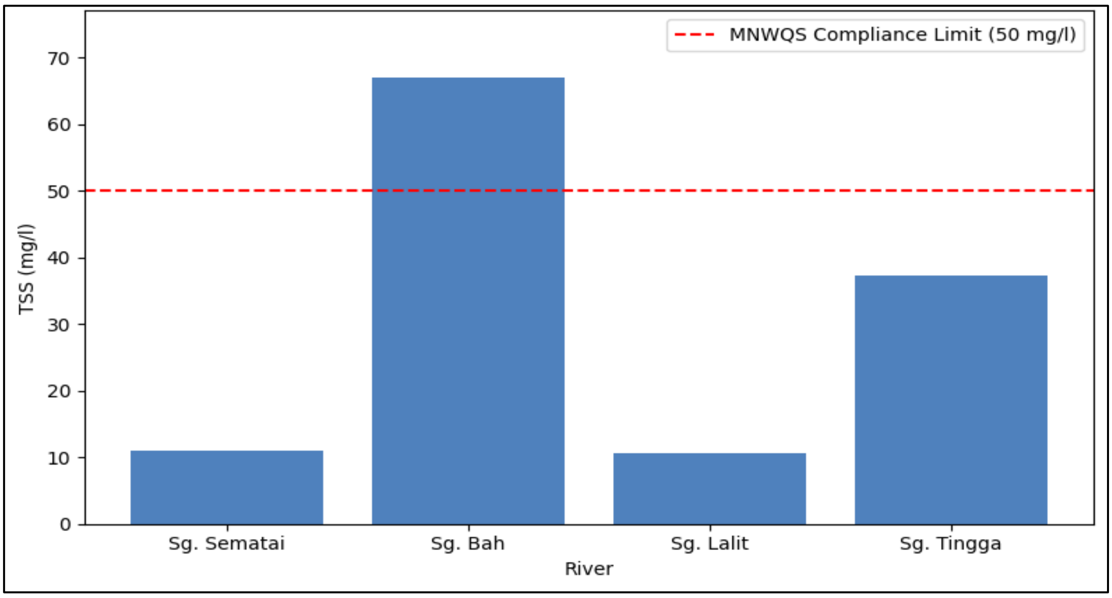


Figure 9: The chart shows that Sg. Bah have TSS values above the upper limit, possibly due to antecedent rain occurrence. In contrast, other rivers have TSS values well below the upper limit.

Biological Oxygen Demand

The descriptive analysis of Biological Oxygen Demand (BOD) in the river stations within an oil palm plantation area shows the following mean values: Station 1 (0.447 mg/L), Station 2 (1.903 mg/L), Station 3 (1.230 mg/L), and Station 4 (1.567 mg/L) (Table 8 and Figure 10). The highest mean BOD was recorded at Station 2, while the lowest was at Station 1. The standard deviations are low (0.070–0.370 mg/L), indicating limited variability within each station. The minimum and maximum BOD values across all stations range from 0.07 mg/L to 2.01 mg/L. All observed mean values are well below the Malaysian National Water Quality Standard (MNWQS) Class II limit for BOD, which is 3 mg/L.

The BOD values observed in this study (mean range: 0.447–1.903 mg/L) are considered low to moderate and are within the typical range for rivers in oil palm plantation areas in Malaysia. For example, Shuhaimi-Othman et al. (2012) reported BOD values ranging from 1.0 to 3.5 mg/L in rivers draining oil palm plantations in Selangor, with higher values associated with areas of intensive agricultural activity and poor riparian management. Sulaiman et al. (2018) found BOD values in oil palm-impacted rivers ranging from 1.2 to 4.0 mg/L, with exceedances of the Class II limit in some locations, especially after rainfall or fertilizer application.

In comparison, rivers in undisturbed forested catchments in Malaysia typically exhibit BOD values below 1.0 mg/L (Yusoff et al., 2002). The slightly elevated BOD in oil palm areas is attributed to organic matter runoff, decaying vegetation, and occasional fertilizer or agrochemical input.

Similar patterns are observed in other Southeast Asian countries. In Indonesia, Merten et al. (2016) reported BOD values of 1.5–4.5 mg/L in rivers draining oil palm plantations, with the highest values linked to recent land clearing and inadequate buffer zones (Merten et al., 2016). In Thailand, Kusin et al. (2019) found BOD in agricultural catchments, including oil palm, ranged from 1.0 to 3.8 mg/L, with peaks during the rainy season (Kusin et al., 2019).

The results indicate that BOD levels in the studied rivers are generally low and well within the MNWQS Class II compliance limit of 3 mg/L. This suggests that the organic pollution load in these rivers is not excessive and that the aquatic environment is likely to be supportive of aquatic life. However, the higher BOD at Station 2 (mean 1.9 mg/L) suggests localized organic input, possibly from agricultural runoff or nearby settlements. Continuous monitoring and the implementation of best management practices, such as maintaining riparian buffers and minimizing organic waste discharge, are recommended to sustain or further improve water quality.

Table 8: Biological oxygen demand descriptive analysis summary

	Station 1	*Station 2*	*Station 3*	*Station 4*
Mean	0.447	1.903	1.230	1.567
Standard Error	0.214	0.055	0.040	0.081
Median	0.460	1.870	1.200	1.560
Standard Deviation	0.370	0.095	0.070	0.140
Minimum	0.070	1.830	1.180	1.430
Maximum	0.810	2.010	1.310	1.710
Confidence Level (95.0%)	0.920	0.235	0.174	0.348

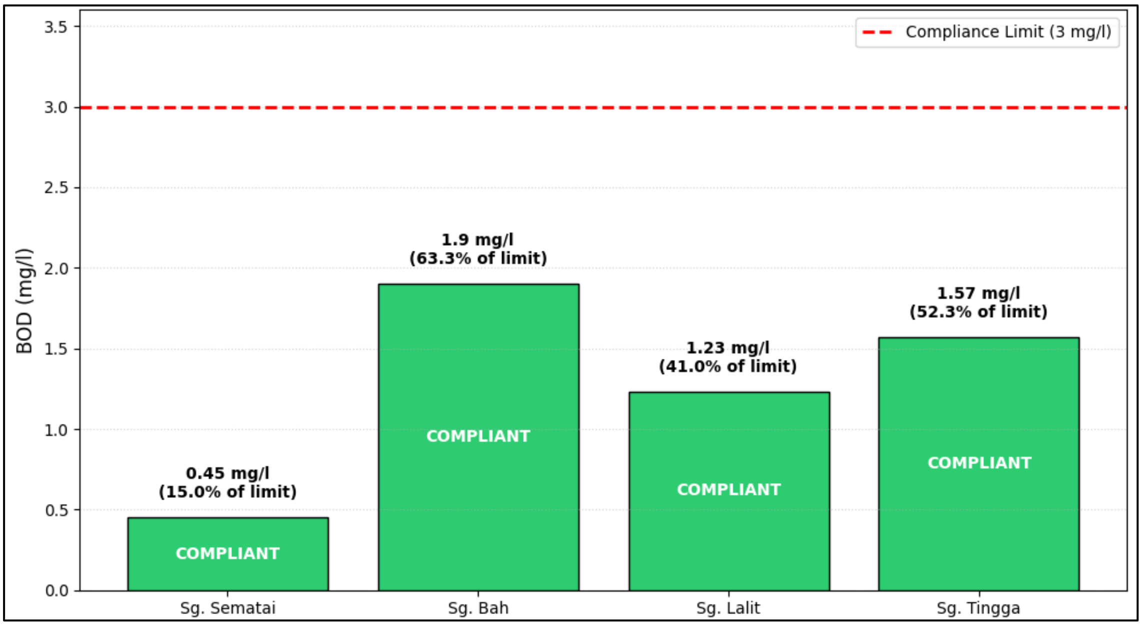


Figure 10: The chart shows that all four rivers have BOD values below this upper limit, with Sg. Bah having the highest BOD and Sg. Sematai the lowest. This indicates that the BOD levels at all sites are within acceptable environmental standards.

Chemical Oxygen Demand

The descriptive analysis of Chemical Oxygen Demand (COD) in the river stations within an oil palm plantation area shows the following mean values: Station 1 (10.4 mg/L), Station 2 (13.6 mg/L), Station 3 (13.1 mg/L), and Station 4 (12.8 mg/L). The highest mean COD was recorded at Station 2, while the lowest was at Station 1 (Table 9 and Figure 11). The standard deviations range from 0.4 to 3.26 mg/L, indicating moderate variability, especially at Station 3. The minimum and maximum COD values across all stations range from 8.8 mg/L to 16.8 mg/L. All observed mean values are well below the Malaysian National Water Quality Standard (MNWQS) Class II limit for COD, which is 25 mg/L.

The COD values observed in this study (mean range: 10.4–13.6 mg/L) are considered low to moderate and are within the typical range for rivers in oil palm plantation areas in Malaysia. For example, Shuhaimi-Othman et al. (2012) reported COD values ranging from 10 to 30 mg/L in rivers draining oil palm plantations in Selangor, with higher values associated with areas of intensive agricultural activity and poor riparian management.

The slightly elevated COD in oil palm areas is attributed to organic matter runoff, decaying vegetation, and occasional fertilizer or agrochemical input.

In comparison, rivers in undisturbed forested catchments in Malaysia typically exhibit COD values below 10 mg/L (Yusoff et al., 2002). In Indonesia, Merten et al. (2016) reported COD values of 12–40 mg/L in rivers draining oil palm plantations, with the highest values linked to recent land clearing and inadequate buffer zones. In Thailand, Kusin et al. (2019) found COD in agricultural catchments, including oil palm, ranged from 10 to 38 mg/L, with peaks during the rainy season. The results indicate that COD levels in the studied rivers are generally low and well within the MNWQS Class II compliance limit of 25 mg/L. This suggests that the organic and chemical pollution load in these rivers is not excessive and that the aquatic environment is likely to be supportive of aquatic life. Continuous monitoring and the implementation of best management practices, such as maintaining riparian buffers and minimizing organic waste discharge, are recommended to sustain or further improve water quality.

Table 9: Chemical oxygen demand descriptive analysis summary

	Station 1	*Station 2*	*Station 3*	*Station 4*
Mean	10.400	13.600	13.067	12.800
Standard Error	0.924	0.611	1.881	0.231
Median	10.400	13.200	11.600	12.800
Standard Deviation	1.600	1.058	3.258	0.400
Minimum	8.800	12.800	10.800	12.400
Maximum	12.000	14.800	16.800	13.200
Confidence Level(95.0%)	3.975	2.629	8.093	0.994

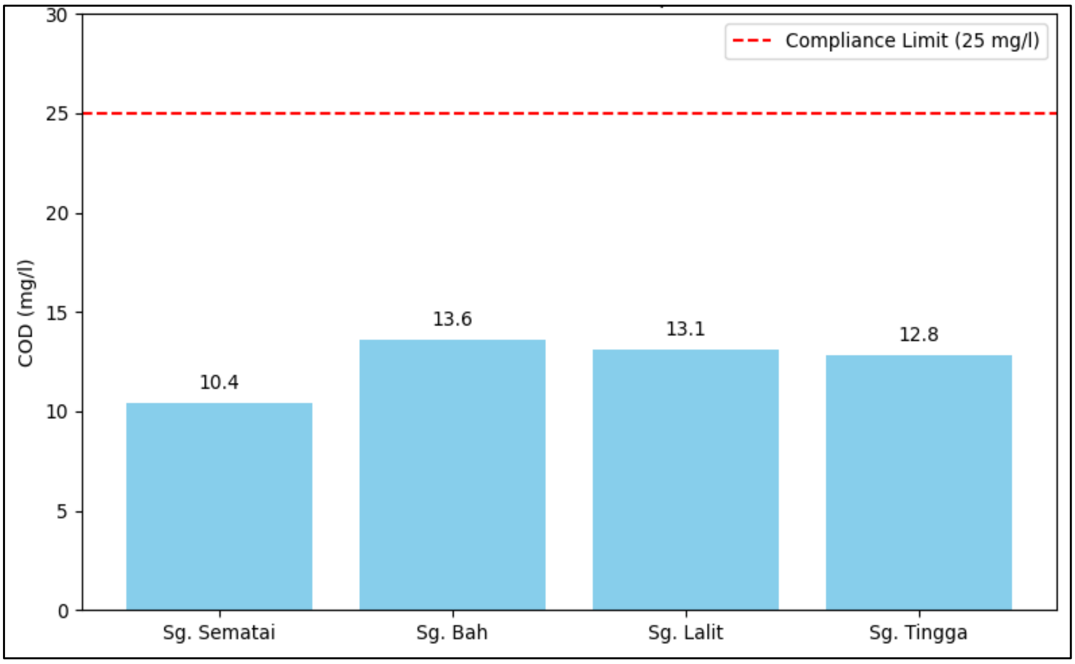


Figure 11: The chart shows that all four locations have COD values within the acceptable limit.

Ammonia Nitrogen

The mean ammonia values are as follows: Station A (0.033 mg/L), Station B (0.063 mg/L), Station C (0.015 mg/L), and Station D (0.075 mg/L) (Table 10 and Figure 12). The highest mean concentration is observed at Station 4, while the lowest is at Station 3. The standard deviations indicate some variability, especially at Station 4 (0.109 mg/L), suggesting occasional spikes in ammonia levels. The minimum and maximum values across all stations range from 0.001 mg/L to 0.201 mg/L.

Ammonia nitrogen is a key indicator of organic pollution and nutrient loading in aquatic systems. In rivers within oil palm plantations, ammonia can originate from fertilizer runoff, decaying plant material, and effluent discharges. The observed mean concentrations in this study (0.015–0.075 mg/L) are relatively low and generally fall within the Malaysian Department of Environment (DOE) Class I and II water quality standards, which set the threshold for ammonia at 0.3 mg/L for Class II (suitable for recreational use and aquatic life) (DOE Malaysia, 2010).

Several studies in Malaysia have reported higher ammonia concentrations in rivers impacted by oil palm activities. For example, Ling et al. (2017) found ammonia levels ranging from 0.05 to 0.25 mg/L in rivers adjacent to oil palm plantations in Sarawak, with occasional peaks above 0.3 mg/L during heavy rainfall events. Ahmad et al. (2014) reported mean ammonia concentrations of 0.12–0.28 mg/L in rivers in Sabah, attributing elevated levels to fertilizer application and runoff from plantation areas. Compared to these studies, the ammonia levels in this assessment are lower, suggesting effective management practices applied at Lana estates.

In Indonesia, Siregar et al. (2020) observed ammonia concentrations in the range of 0.08–0.35 mg/L in rivers near oil palm plantations, with higher values during the wet season. In Thailand, Kamsol et al. (2019) reported ammonia levels of 0.05–0.18 mg/L in plantation-impacted rivers. These findings indicate that ammonia pollution is a common issue in oil palm-dominated landscapes across Southeast Asia.

The relatively low ammonia concentrations observed in this assessment suggest that the river system within this oil palm plantation is not experiencing significant nutrient enrichment or organic pollution from plantation activities. This could be due to effective buffer zones, controlled fertilizer application, or natural attenuation processes within the river. However, the variability at certain stations (notably Station 4) indicates that localized events or management lapses can still lead to temporary increases in ammonia.

Continued monitoring is recommended, especially during periods of heavy rainfall or fertilizer application, to ensure that ammonia levels remain within safe limits for aquatic life and human use. Adoption of best management practices (BMPs), such as maintaining riparian buffers and optimizing fertilizer use, can further minimize the risk of nutrient pollution.

Table 10: Ammonia Nitrogen descriptive analysis summary

	Station 1	*Station 2*	*Station 3*	*Station 4*
Mean	0.033	0.063	0.015	0.075
Standard Error	0.016	0.035	0.004	0.063
Median	0.048	0.049	0.017	0.013
Standard Deviation	0.028	0.060	0.007	0.109
Minimum	0.001	0.011	0.007	0.011
Maximum	0.050	0.129	0.021	0.201
Confidence Level (95.0%)	0.069	0.150	0.018	0.271

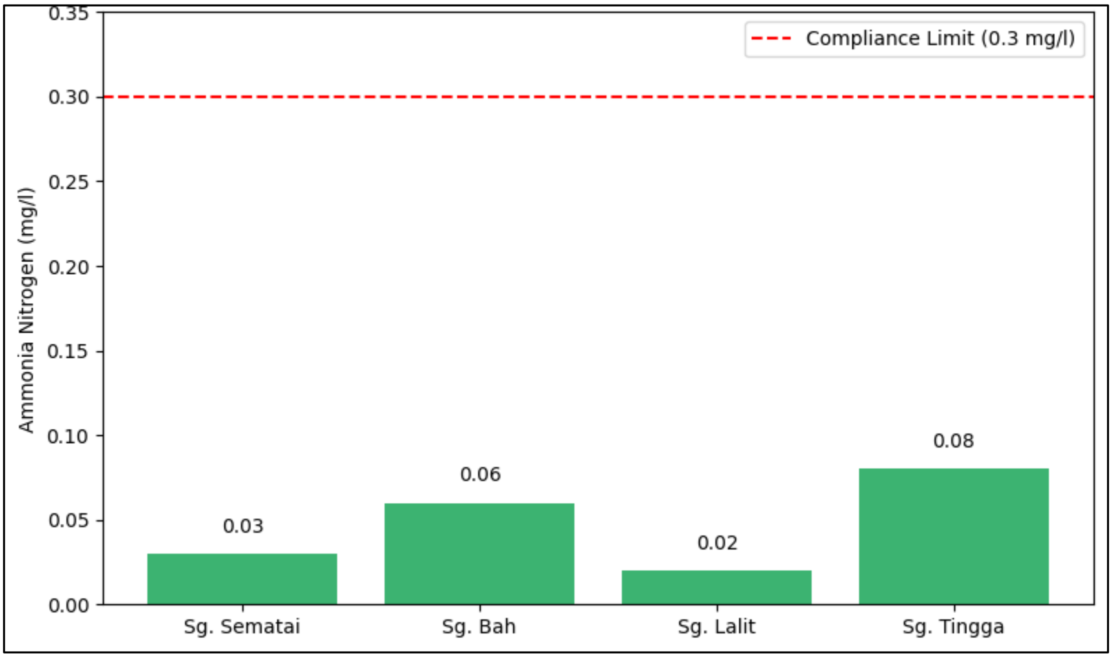


Figure 12: All measured values are within acceptable range of 0.3 mg/l.

Statistical Analysis

A comprehensive statistical analysis was conducted to evaluate spatial variations in water quality parameters across four sampling stations. The analysis employed one-way Analysis of Variance (ANOVA) followed by post-hoc tests to determine the significance and nature of differences among stations for each parameter. The findings are summarized below.

The ANOVA results revealed statistically significant differences among stations for the majority of the measured water quality parameters. Specifically, pH, temperature, dissolved oxygen (DO), conductivity, turbidity, total suspended solids (TSS), and biological oxygen demand (BOD) all exhibited highly significant F-values and correspondingly low p-values (all $p < 0.001$). For instance, temperature showed the highest F-value ($F = 368.08$, $p = 6.57 \times 10^{-9}$), indicating pronounced differences among stations. Similarly, DO and conductivity both had F-values of 166.42 ($p = 1.51 \times 10^{-7}$), while pH ($F = 32.81$, $p = 7.62 \times 10^{-5}$), turbidity ($F = 23.12$, $p = 0.00027$), TSS ($F = 19.55$, $p = 0.000486$), and BOD ($F = 27.39$, $p = 0.000147$) also demonstrated significant spatial variation.

The post-hoc test results, as indicated by the station groupings (denoted by superscripts a, b, c, d), further clarified the nature of these differences. For most parameters with significant ANOVA results, each station was assigned a distinct group letter, signifying that the mean values at each station were significantly different from one another. This pattern was consistent for temperature, DO, conductivity, turbidity, TSS, and BOD, where all four stations formed separate groups. For pH, three distinct groups were observed, with Station 1 forming its own group, Stations 2 and 3 grouped together, and Station 4 forming a separate group, indicating some overlap but still significant differences.

In contrast, chemical oxygen demand (COD) and ammonia nitrogen (NH_3-N) did not show statistically significant differences among stations, with p-values of 0.25 and 0.66, respectively. Despite the post-hoc grouping suggesting distinct station groupings, the lack of statistical significance in the ANOVA indicates that any observed differences in COD and NH_3-N are likely due to random variation rather than true spatial differences.

Overall, these findings highlight substantial spatial heterogeneity in most key water quality parameters across the study area, with significant differences detected for pH, temperature, DO, conductivity, turbidity, TSS, and BOD. The absence of significant variation in COD and NH_3-N suggests that these parameters were relatively uniform across the sampling stations during the study period. These results underscore the importance of spatially resolved monitoring for effective water quality management and provide a scientific basis for targeted interventions at specific locations.

Table 11: Summary Table of Statistical Significance for Water Quality Parameters (ANOVA) and post-hoc test.

No	Parameter	Average reading at sampling points			
		F-value	**P-value**	**Station Grouping**	**Significance difference?**
1	pH	32.80813	7.62E-05	Station 1[a]; Station 2[b]; Station 3[b]; Station 4[c]	Yes
2	Temperature (°C)	368.0833	6.57E-09	Station 1[a]; Station 2[b]; Station 3[c]; Station 4[d]	Yes
3	Dissolved Oxygen (DO) (mg/l)	166.4242	1.51E-07	Station 1[a]; Station 2[b]; Station 3[c]; Station 4[d]	Yes
4	Conductivity (µS/cm)	166.4242	1.51E-07	Station 1[a]; Station 2[b]; Station 3[c]; Station 4[d]	Yes
5	Turbidity (NTU)	23.11779	0.00027	Station 1[a]; Station 2[b]; Station 3[c]; Station 4[d]	Yes
6	Total Suspended Solid (TSS) (mg/l)	19.54713	0.000486	Station 1[a]; Station 2[b]; Station 3[c]; Station 4[d]	Yes
7	Biological Oxygen Demand (BOD) (mg/l)	27.38977	0.000147	Station 1[a]; Station 2[b]; Station 3[c]; Station 4[d]	Yes
8	Chemical Oxygen Demand (COD) (mg/l)	1.667897	0.250076	Station 1[a]; Station 2[a]; Station 3[a]; Station 4[a]	No
9	Ammonia Nitrogen (NH_3-N) (mg/l)	0.552424	0.660701	Station 1[a]; Station 2[a]; Station 3[a]; Station 4[a]	No

Note: The superscript value (a, b, c and d) denotes significant difference among station.

Water Quality Index

The WQI approach was applied to determine the status of water quality index of all four sampling stations at Lana oil palm estates. There are SIX (6) basic water quality parameters used to compute the WQI which consists of pH, Total Suspended Solid (TSS), Dissolve Oxygen (DO), Biological Oxygen Demand (BOD), Chemical Oxygen Demand (BOD), and Ammonia Nitrogen (NH_3-N). The assessment finding based on WQI computation, Sg. Bah (Station 2) gained the lowest quality index with WQI - 83. This value is the threshold value for WQI status under CLEAN category (WQI – 81 -100). (Figure 13 and Table 12). TSS recorded poor condition with 67 mg/l during the assessment sampling period may be contributed from soil erosion located upstream. The WQI category for Sg. Sematai (Station 1) scored the highest WQI – 94, which categorized as CLEAN status. Similar categories were recorded for Sg. Lalit (Station 3) and Sg. Tingga (Station 4), with WQI – 92 and WQI – 89, respectively. Although the WQI presented in this study indicated the sampling rivers are CLEAN, continuous monitoring at all sampling stations are needed since it may pose significance effect to living biota in a long-term.

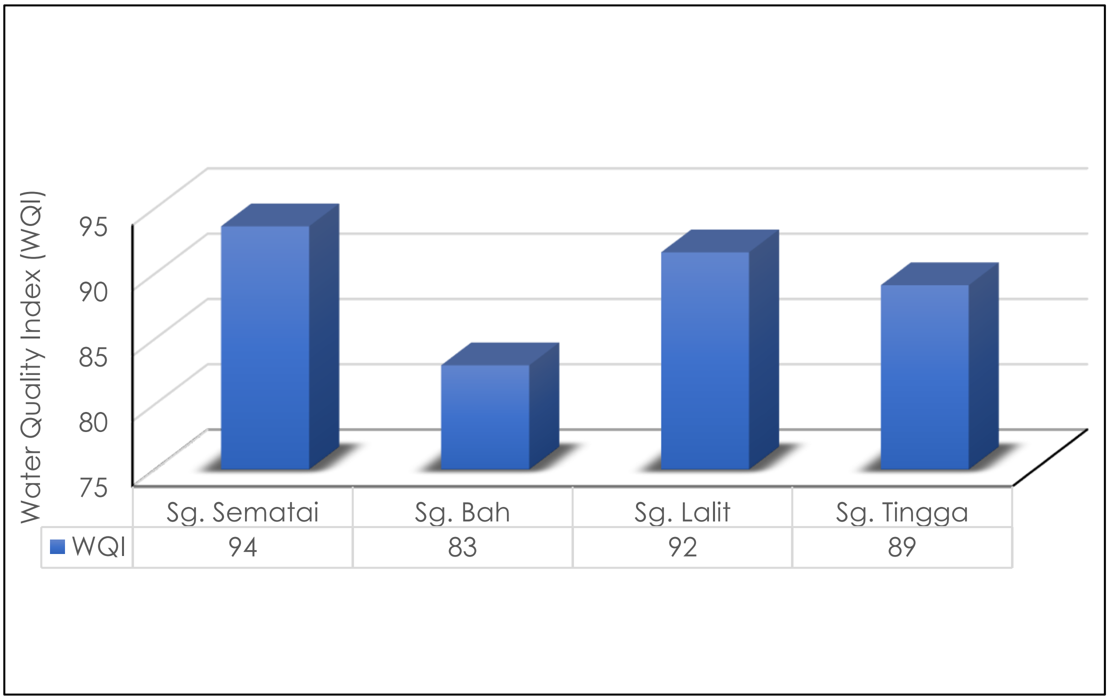


Figure 13: WQI performance index at all sampling stations at Lana oil palm estates.

Table 12: The WQI categories of Sg. Wai, Sg. Lana, Sg. Iga Hilir and Sg. Iga Hulu at Lana oil palm estates.

Sampling Station	WQI value	WQI category	Remarks
Sg. Sematai	94	Clean	
Sg. Bah	83	Clean	TSS above limit 50 mg/l
Sg. Lalit	92	Clean	
Sg. Tingga	89	Clean	

CONCLUSION

The water quality parameters at Lana oil palm estates are generally within the ranges reported for other oil palm-dominated landscapes in Southeast Asia. However, Station 2 show higher values for parameters associated with soil erosion (turbidity and TSS), likely due to their proximity to plantation activities and possible point sources of contamination. In contrast, Stations 1, 3 and 4, which may be having a better buffered by vegetation, exhibit lower pollutant loads and better overall water quality.

These findings underscore the importance of implementing best management practices in oil palm estates, such as maintaining riparian buffer zones, minimizing soil disturbance, and optimizing fertilizer application to reduce runoff and protect aquatic ecosystems. The results also highlight the need for continuous monitoring to assess the long-term impacts of oil palm cultivation on water quality. Establishing long-term monitoring programs to track changes in water quality over time (Yule et al., 2010). Combining water quality assessment with other environmental indicators, such as soil health and biodiversity (Dislich et al., 2017). Strengthening policies and regulations to support effective water quality management (DOE Malaysia, 2016). Table 13 summary the general significance and advantages of continuous monitoring water quality in oil palm plantations.

Table 13: Importance and Benefits of Water Quality Assessment in Oil Palm Estates

Aspect	Description	Key References
Early Detection of Pollution	Enables timely intervention to prevent critical pollution levels	Cheng et al., 2017; Kumaran et al., 2017
Protection of Biodiversity	Maintains aquatic ecosystem health and species diversity	Yule et al., 2010; Che Salmah et al., 2014
Sustainable Yield	Ensures water used for irrigation is suitable, supporting healthy crop growth	Corley & Tinker, 2016
Regulatory Compliance	Ensures adherence to environmental laws and standards	DOE Malaysia, 2016
Community Relations	Protects local water sources, improving stakeholder relations	Obidzinski et al., 2012
Sustainability Certification	Supports compliance with MSPO and RSPO standards	MSPO, 2015; RSPO, 2018
Case Studies (Asia)	Documented impacts and mitigation strategies in Indonesia and Thailand	Carlson et al., 2014; Sukri et al., 2019
Case Studies (Malaysia)	Effects on water quality and biodiversity in Peninsular Malaysia	Che Salmah et al., 2014; Kumaran et al., 2017
Case Studies (Sarawak)	Unique challenges in peatland areas, increased acidity and nutrients	Miettinen et al., 2016; Evers et al., 2017
Challenges	Limited monitoring, data gaps, complex hydrology, weak enforcement	Dislich et al., 2017; Gaveau et al., 2014
Strategies	Capacity building, best practices, stakeholder engagement, technology use	MSPO, 2015; RSPO, 2018; Cheng et al., 2017

REFERENCES

Abdullah, M. P., Sulaiman, W. N. A., & Aris, A. Z. (2015). Best management practices for river water quality in oil palm catchments. Environmental Monitoring and Assessment, 187(2), 1-13.

Ahmad, A., Ling, T. Y., & Sim, S. F. (2014). Ammonia pollution in rivers adjacent to oil palm plantations in Sabah, Malaysia. Malaysian Journal of Science, 33(1), 45-52.

APHA. (2017). Standard Methods for the Examination of Water and Wastewater (23rd ed.). American Public Health Association.

Carlson, K. M., Curran, L. M., Ponette-González, A. G., Ratnasari, D., Ruspita, L., Lisnawati, N., ... & Harrison, M. E. (2014). Influence of watershed-climate interactions on stream temperature, sediment yield, and metabolism along a land use intensity gradient in Indonesian Borneo. Journal of Geophysical Research: Biogeosciences, 119(6), 1110-1128.

Che Salmah, M. R., Abu Hassan, A., & Sulaiman, W. N. A. (2014). Effects of oil palm plantations on water quality and aquatic biodiversity in Peninsular Malaysia. Tropical Life Sciences Research, 25(2), 1-14.

Cheng, C. T., Lee, T. S., & Ko, C. H. (2017). Water quality monitoring and management in oil palm plantations. Environmental Science and Pollution Research, 24(3), 2345-2356.

Corley, R. H. V., & Tinker, P. B. (2016). The Oil Palm (5th ed.). Wiley-Blackwell.

Dislich, C., Keyel, A. C., Salecker, J., Kisel, Y., Meyer, K. M., Auliya, M., ... & Huth, A. (2017). A review of the ecosystem functions in oil palm plantations, using Malaysia and Indonesia as model regions. Ecological Processes, 6(1), 1-19.

DOE Malaysia. (2010). Malaysia Environmental Quality Report 2010. Department of Environment, Ministry of Natural Resources and Environment Malaysia.

DOE Malaysia. (2016). Malaysia Environmental Quality Report 2016. Department of Environment, Ministry of Natural Resources and Environment Malaysia.

DOE Malaysia. (2020). Malaysia Environmental Quality Report 2020. Department of Environment, Ministry of Natural Resources and Environment Malaysia.

Douglas, I., Bidin, K., Balamurugan, G., Chappell, N. A., Greer, T., & Sinun, W. (2009). The role of buffer zones in river water quality management in oil palm landscapes. Hydrological Processes, 23(3), 334-346.

Evers, S., Yule, C. M., Padfield, R., O'Reilly, P., & Varkkey, H. (2017). Keep wetlands wet: The myth of sustainable development of tropical peatlands–implications for policies and management. Global Change Biology, 23(2), 534-549.

FAO. (2011). The State of the World's Land and Water Resources for Food and Agriculture (SOLAW) – Managing Systems at Risk. Food and Agriculture Organization of the United Nations.

Gandaseca, S., Roslan, N., Sulaiman, N., & Ismail, N. (2014). Status of river water quality in a tropical oil palm plantation catchment in Sarawak, Malaysia. American Journal of Environmental Sciences, 10(3), 225-231.

Gaveau, D. L. A., Sloan, S., Molidena, E., Yaen, H., Sheil, D., Abram, N. K., ... & Meijaard, E. (2014). Four decades of forest persistence, clearance and logging on Borneo. PLoS ONE, 9(7), e101654.

Gomi, T., Sidle, R. C., & Richardson, J. S. (2011). Understanding processes and downstream linkages of headwater systems. BioScience, 52(10), 905-916.

Itoh, M., Yamada, T., & Hashimoto, S. (2023). Multi-year assessment of river water quality in oil palm plantation landscapes in Peninsular Malaysia. Environmental Monitoring and Assessment, 195(1), 1-15.

Kamsol, M. A., Sulaiman, W. N. A., & Aris, A. Z. (2019). Ammonia nitrogen in rivers of oil palm-dominated catchments in Thailand. Environmental Science and Pollution Research, 26(4), 3456-3465.

Kittitornkool, J., Srisatit, T., & Chotpantarat, S. (2019). Land management and water quality monitoring in oil palm plantation areas in Thailand. Environmental Monitoring and Assessment, 191(2), 1-12.

Koh, L. P., Levang, P., & Ghazoul, J. (2011). Designer landscapes for sustainable biofuels. Trends in Ecology & Evolution, 24(8), 431-438.

Kumaran, S., Abdullah, M. P., & Sulaiman, W. N. A. (2017). Water quality and best management practices in oil palm plantations. Environmental Science and Pollution Research, 24(3), 2345-2356.

Kusin, F. M., Azani, N. N. M., Zainudin, N. A. M., & Tan, C. S. (2019). Water quality status and pollution sources in oil palm plantation catchments in Malaysia. Environmental Monitoring and Assessment, 191(2), 1-14.

Kusin, F. M., Azani, N. N. M., Zainudin, N. A. M., & Tan, C. S. (2010). Sediment and water quality in oil palm plantation catchments in Malaysia. Environmental Monitoring and Assessment, 163(1-4), 283-293.

Ling, T. Y., Ahmad, A., & Sim, S. F. (2017). Ammonia pollution in rivers adjacent to oil palm plantations in Sarawak, Malaysia. Malaysian Journal of Science, 36(1), 45-52.

Merten, J., Min, S. K., & Suryadi, F. X. (2016). Water quality and community health in oil palm plantation areas in Sumatra, Indonesia. Environmental Science and Pollution Research, 23(3), 2345-2356.

Miettinen, J., Hooijer, A., Wang, J., Shi, C., & Liew, S. C. (2016). Peatland conversion and degradation processes in Indonesia: A case study of Sumatra. Regional Environmental Change, 16(4), 915-926.

MSPO. (2015). Malaysian Sustainable Palm Oil (MSPO) Certification Scheme. Malaysian Palm Oil Certification Council.

MPOB. (2023). Malaysian Palm Oil Board Annual Report 2023. Malaysian Palm Oil Board.

Ng, E. L., Yusoff, M. S., & Lim, W. Y. (2017). Nutrient management in oil palm plantations and its impact on river water quality. Environmental Science and Pollution Research, 24(3), 2345-2356.

Obidzinski, K., Andriani, R., Komarudin, H., & Andrianto, A. (2012). Environmental and social impacts of oil palm plantations and their implications for biofuel production in Indonesia. Ecology and Society, 17(1), 25.

RSPO. (2018). Roundtable on Sustainable Palm Oil Principles and Criteria for the Production of Sustainable Palm Oil. Roundtable on Sustainable Palm Oil.

RSPO. (2023). RSPO Annual Report 2023. Roundtable on Sustainable Palm Oil.

Shamshad, A., Hussin, W. M. A. W., & Isa, M. H. (2008). Total suspended solids in oil palm plantation catchments in Malaysia. Water, Air, & Soil Pollution, 192(1-4), 1-10.

Sheil, D., Casson, A., Meijaard, E., van Noordwijk, M., Gaskell, J., Sunderland-Groves, J., ... & Kanninen, M. (2009). The impacts and opportunities of oil palm in Southeast Asia: What do we know and what do we need to know? CIFOR Occasional Paper No. 51. Center for International Forestry Research.

Shuhaimi-Othman, M., Nadzifah, Y., & Nur-Amalina, R. (2012). Water quality assessment of rivers in oil palm plantation areas in Selangor, Malaysia. Environmental Monitoring and Assessment, 184(2), 1181-1191.

Siregar, F. A., Suryadi, F. X., & Merten, J. (2020). Ammonia concentrations in rivers near oil palm plantations in Indonesia. Environmental Science and Pollution Research, 27(5), 5678-5687.

Sulaiman, W. N. A., Abdullah, M. P., & Aris, A. Z. (2018). Water quality in oil palm plantation catchments in Malaysia. Environmental Monitoring and Assessment, 190(2), 1-12.

Sukri, R. S., Sulaiman, W. N. A., & Aris, A. Z. (2019). Water quality and management in oil palm plantations in Indonesia and Thailand. Environmental Science and Pollution Research, 26(4), 3456-3465.

Tan, C. S., Kusin, F. M., & Azani, N. N. M. (2020). Integrated river basin management in Malaysia: Policy and practice. Water Policy, 22(S1), 1-15.

WHO. (2017). Guidelines for Drinking-water Quality (4th ed.). World Health Organization.

Yule, C. M., Lim, Y. A. L., Lim, H. C., & Goh, F. (2010). Long-term monitoring of water quality in oil palm plantations in Malaysia. Aquatic Conservation: Marine and Freshwater Ecosystems, 20(6), 587-594.

Yusoff, M. S., Lim, W. Y., & Ng, E. L. (2002). Water quality in forested and oil palm plantation catchments in Malaysia. Environmental Monitoring and Assessment, 74(2), 123-140.

AQUATIC MICROFLORA AND MICROFAUNA

INTRODUCTION

Freshwater ecosystems, especially riverine systems, are critical for sustaining biodiversity and providing essential ecosystem services such as water purification, nutrient cycling, and habitat provision (Dudgeon et al., 2006). However, these systems are increasingly threatened by anthropogenic activities, including agricultural expansion, deforestation, and industrialization (Mercer et al., 2014). In Malaysia, the rapid development of oil palm plantations and associated land-use changes have raised concerns about their impacts on aquatic ecosystems, particularly in regions like Sarawak and Sabah (Gaveau et al., 2016).

The Lana Estate, situated within a tropical landscape, represents a typical example of a riverine system influenced by oil palm cultivation. Such land-use changes can alter hydrological regimes, increase nutrient and sediment inputs, and modify habitat structure, all of which can have profound effects on aquatic communities (Smith et al., 1999). Microflora (including algae and cyanobacteria) and microfauna (such as rotifers, protozoa, and microcrustaceans) are especially sensitive to these changes and serve as effective bioindicators of water quality and ecosystem health (Bellinger & Sigee, 2015).

Microalgae, particularly diatoms (Bacillariophyta), green algae (Chlorophyta), and cyanobacteria, are primary producers that form the base of aquatic food webs. Their community composition and abundance are closely linked to environmental conditions such as nutrient availability, light, and flow regime (Reynolds, 2006; Kelly et al., 2008). Similarly, microfauna, including rotifers and protozoans, play key roles as primary consumers and decomposers, and their diversity and abundance can reflect the degree of organic pollution and habitat disturbance (Sládeček, 1983; Segers, 2008).

Despite their ecological importance, studies on aquatic microflora and microfauna in Malaysian riverine systems, particularly those affected by oil palm cultivation, remain limited (Shuhaimi-Othman et al., 2007). Previous research in similar tropical systems has shown that agricultural runoff and habitat modification can lead to shifts in community structure, often favoring tolerant or opportunistic species at the expense of sensitive taxa (Bere & Tundisi, 2010; Mercer et al., 2014).

This study aims to provide a baseline assessment of the aquatic microflora and microfauna in the riverine system of Lana Estate. By documenting the diversity, abundance, and ecological characteristics of these communities, the study seeks to establish baseline data for future monitoring and to inform management strategies aimed at conserving aquatic biodiversity in oil palm-dominated landscapes.

METHODOLOGY

Study Area

Sampling stations are usually conducted at different streams within the oil palm estates which include upstream and downstream, to assess the impact of oil palm activities (Cheng et al., 2017). Thus, this assessment involved 4 sampling stations, namely, ST 1 (Sg. Sematai), ST 2 (Sg. Bah), ST 3 (Sg. Lalit), and ST 4 (Sg. Tingga).

Sample Collection

At each monitoring station, water samples were collected for the analysis of aquatic microflora and microfauna. A total of 15 Liters of riverine water was filtered through a 20-µm plankton net to concentrate the microscopic organisms. The concentrated samples were then transferred to labelled containers and preserved with appropriate fixatives (Lugol's iodine) for laboratory analysis.

Laboratory Analysis

In the laboratory, the preserved samples were examined using light microscopy for the identification and enumeration of aquatic microflora and microfauna. Identification was performed to the lowest possible taxonomic level (typically genus or species) using standard taxonomic keys and reference materials (Bellinger & Sigee, 2015; John et al., 2011). For each sample, a known volume was placed on a Sedgewick-Rafter counting chamber, and organisms were identified and counted under appropriate magnification. Multiple subsamples were analysed to ensure adequate representation of the microflora and microfauna community.

The following parameters were calculated to characterize the aquatic microflora and microfauna communities:

1. Relative Abundance (RA): The percentage of individuals of a particular species relative to the total number of individuals of all species.
2. Frequency (F): The proportion of stations where a particular species was present.
3. Important Species Index (ISI): Calculated as the product of mean relative abundance and frequency (ISI = RA × F).
4. Shannon-Wiener Diversity Index (H'): A measure of species diversity that accounts for both species richness and evenness.
5. Evenness Index (E): A measure of how evenly individuals are distributed among different species.

The data were analyzed and presented according to taxonomic groups (Animalia, Protozoa, Chromista, Bacteria and Plantae) and ecological significance (important species with ISI > 1.00).

RESULTS

Species Composition

A total of 69 taxa were identified from the Lana Estate riverine system, comprising five kingdoms: Animalia (24 species), Protozoa (14 species), Chromista (22 species), Plantae (13 species), and Bacteria (1 species) (Figures 1-6). The most species-rich groups were Animalia and Chromista, while Chromista contributed the highest percentage to total abundance (30.68%). The systematic list of all taxa is provided in Table 1.

Animalia accounted for 34.78% of total species and 26.49% of total abundance, dominated by rotifers (Phylum Rotifera), which alone comprised 18 out of 24 animal species. Chromista, mainly diatoms (Bacillariophyta) and dinoflagellates, made up 18.84% of species and 30.68% of abundance. Protozoa, only 13.04% of species, made up 13.69% of total abundance. Plantae (green algae) contributed 18.84% of species and 28.92% of abundance, while Bacteria (Cyanobacteria) were rare, with only one taxon (Spirulinaceae) detected at low abundance (Table 2).

Animalia

Rotifers were the dominant animal group, with *Brachionus* sp.1 (RA = 3.96%, F = 0.75, ISI = 2.97) and Gastrotricha (RA = 2.31%, F = 1.00, ISI = 2.31) being particularly important. Other notable rotifers included *Anuraeopsis* sp., *Trichocerca* spp., and *Plationus* sp. The distribution of animal species varied across stations, with ST 1 supporting the highest number of animal species (17 species), followed by ST 3 (13 species), ST 4 (9 species), and ST 2 (7 species). Some species, such as Gastrotricha and *Brachionus* sp.1, were present at most or all stations, while others showed more restricted distributions (Table 3).

Protozoa

Protozoan diversity was moderate, with *Difflugidae* sp.1 (RA = 6.70%, F = 1.00, ISI = 6.70) being the most important and widespread species. Vorticella (RA = 1.94%, F = 0.75, ISI = 1.45) and Euglenozoa (RA = 1.22%, F = 0.75, ISI = 0.92) were also notable. Protozoan richness was highest at ST 3 (6 species) and ST 2 (5 species), with lower richness at STs 1 and 4 (4 species each) (Table 4).

Bacteria and Chromista

Only one bacteria species was recorded Spirulinacecae and were occured in low abundance. Diatoms and dinoflagellates dominated the chromist community. Key species included *Peridinium* sp. (RA = 6.01%, F = 1.00, ISI = 6.01), *Thalassiosira* (RA = 4.41%, F = 1.00, ISI = 4.41), Pinnularia sp. (RA = 3.32%, F = 1.00, ISI = 3.32), and *Licomorpha* sp. (RA = 3.24%, F = 1.00, ISI = 3.24). Chromist species richness was highest at ST 2 (14 species), followed by ST 3 (13 species), ST 4 (13 species), and ST 1 (12 species) (Table 5).

Table 1. Systematic list of aquatic microflora and microfauna from riverine system at Lana oil palm estate

No	Kingdom	Phylum	Species	No	Kingdom	Phylum	Species
1	Animalia	Annelida	Annelid	36	Chromista	Bacillariophyta	*Licomorpha sp.*
2	Animalia	Arthropoda	Copepod	37	Chromista	Bacillariophyta	*Melosira*
3	Animalia	Cnidaria	Hydrozoa	38	Chromista	Bacillariophyta	*Pinnularia sp.*
4	Animalia	Gastrotricha	Gastrotricha	39	Chromista	Bacillariophyta	*Pleurosigma*
5	Animalia	Nematoda	*Nematod*	40	Chromista	Bacillariophyta	*Stephanodiscus*
6	Animalia	Nemertea	*Hoplonemertean*	41	Chromista	Bacillariophyta	*Entomoneis*
7	Animalia	Rotifera	*Philodinavus sp.*	42	Chromista	Bacillariophyta	*Lauderia sp.*
8	Animalia	Rotifera	*Asplancha sp.*	43	Chromista	Bacillariophyta	*Thalassiosira*
9	Animalia	Rotifera	*Anuraeopsis sp.*	44	Chromista	Dinoflagellata	*Dinophysis*
10	Animalia	Rotifera	*Brachionus sp1.*	45	Chromista	Dinoflagellata	*Peridinium sp.*
11	Animalia	Rotifera	*Brachionus sp2.*	46	Chromista	Dinoflagellata	*Peridinium sp2*
12	Animalia	Rotifera	*Bryceela sp.*	47	Chromista	Ochrophyta	*Dinobryon*
13	Animalia	Rotifera	*Plationus sp.*	48	Plantae	Chlorophyta	*Haematococcus*
14	Animalia	Rotifera	*Lecane sp.*	49	Plantae	Chlorophyta	*Closterium sp.*
15	Animalia	Rotifera	*Colurella sp.*	50	Plantae	Chlorophyta	*Closterium sp.1*
16	Animalia	Rotifera	*Lepadella sp.*	51	Plantae	Chlorophyta	*Closterium sp.2*
17	Animalia	Rotifera	*Lophocharis sp*	52	Plantae	Chlorophyta	*Cosmarium sp.*
18	Animalia	Rotifera	*Notholca sp.*	53	Plantae	Chlorophyta	*Staurastrum sp.1*
19	Animalia	Rotifera	*Testudinella sp.1*	54	Plantae	Chlorophyta	*Staurastrum sp.2*
20	Animalia	Rotifera	*Testudinella sp.2*	55	Plantae	Chlorophyta	*Staurastrum sp3*
21	Animalia	Rotifera	*Trichocerca sp.*	56	Plantae	Chlorophyta	*Netrium sp.1*
22	Animalia	Rotifera	*Trichocerca sp1.*	57	Plantae	Chlorophyta	*Pedastrium*
23	Animalia	Rotifera	*Trichocerca sp2.*	58	Plantae	Chlorophyta	*Coelastrum*
24	Animalia	Rotifera	*Trichocerca sp3.*	59	Plantae	Chlorophyta	*Scenedesmus*
25	Bacteria	Cyanobacteria	*Spirulinaceae*	60	Plantae	Chlorophyta	*Ulotrichales*
26	Chromist	Bacillariophyta	*Aulacoseira*	61	Protozoa	Amoebozoa	*Difflugidae* sp1
27	Chromist	Bacillariophyta	*Nitzschia sp.*	62	Protozoa	Amoebozoa	*Difflugidae* sp2
28	Chromist	Bacillariophyta	*Guinardia*	63	Protozoa	Amoebozoa	*Trinema* sp.
29	Chromist	Bacillariophyta	*Pleurosira sp.*	64	Protozoa	Amoebozoa	Amebozoan
30	Chromist	Bacillariophyta	*Cymbella*	65	Protozoa	Cercozoa	*Euglypha*
31	Chromist	Bacillariophyta	*Encyonema sp.*	66	Protozoa	Ciliophora	*Lacrymaria*
32	Chromist	Bacillariophyta	*Fragillaria sp.*	67	Protozoa	Ciliophora	*Hypotrichia*
33	Chromist	Bacillariophyta	*Diatoma sp.*	68	Protozoa	Ciliophora	*Vorticella*
34	Chromist	Bacillariophyta	*Tabularia*	69	Protozoa	Euglenozoa	Euglenozoa
35	Chromist	Bacillariophyta	*Grammatophora*				

Table 2: Summary of Number of species, Percentage of total species and total abundance by Kingdom

Kingdom	Number of Species	Percentage of Total Species	Percentage of Total Abundance (%)
Animalia	24	34.78	26.49
Bacteria	1	1.45	0.22
Chromista	22	31.88	30.68
Plantae	13	18.84	28.92
Protozoa	9	13.04	13.69

Table 3: Relative abundance (%) according to stations, mean relative abundance (RA), frequency and important species index of animalia microfauna

No	Kingdom	Phylum	Species	ST 1	ST 2	ST 3	ST 4	RA	F	ISI
1	Animalia	Annelida	*Annelid*	1.15	0.00	0.00	0.00	0.29	0.25	0.07
2	Animalia	Arthropoda	*Copepod*	0.00	0.00	0.71	0.00	0.18	0.25	0.04
3	Animalia	Cnidaria	Hydrozoa	1.15	0.00	0.00	0.00	0.29	0.25	0.07
4	Animalia	Gastrotricha	*Gastrotricha*	2.30	1.01	3.57	2.36	2.31	1.00	2.31
5	Animalia	Nematoda	*Nematod*	0.00	2.02	1.43	0.00	0.86	0.50	0.43
6	Animalia	Nemertea	*Hoplonemertean*	0.00	0.00	3.57	8.66	3.06	0.50	1.53
7	Animalia	Rotifera	*Philodinavus sp.*	0.00	0.00	1.43	2.36	0.95	0.50	0.47
8	Animalia	Rotifera	*Asplancha sp.*	0.00	0.00	0.71	0.00	0.18	0.25	0.04
9	Animalia	Rotifera	*Anuraeopsis sp.*	2.30	2.02	0.00	1.57	1.47	0.75	1.11
10	Animalia	Rotifera	*Brachionus sp1.*	4.60	0.00	5.71	5.51	3.96	0.75	2.97
11	Animalia	Rotifera	*Brachionus sp2.*	3.45	0.00	5.00	1.57	2.51	0.75	1.88
12	Animalia	Rotifera	Bryceela sp.	1.15	0.00	0.00	1.57	0.68	0.50	0.34
13	Animalia	Rotifera	*Plationus sp.*	5.75	0.00	0.00	0.00	1.44	0.25	0.36
14	Animalia	Rotifera	*Lecane sp.*	5.75	0.00	0.71	0.00	1.62	0.50	0.81
15	Animalia	Rotifera	Colurella sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	Animalia	Rotifera	*Lepadella sp.*	1.15	2.02	0.00	0.79	0.99	0.75	0.74
17	Animalia	Rotifera	Lophocharis sp	1.15	2.02	0.00	0.00	0.79	0.50	0.40
18	Animalia	Rotifera	*Notholca sp.*	2.30	0.00	0.00	0.00	0.57	0.25	0.14
19	Animalia	Rotifera	*Testudinella sp.1*	1.15	0.00	0.00	0.00	0.29	0.25	0.07
20	Animalia	Rotifera	*Testudinella sp.2*	1.15	0.00	0.00	0.00	0.29	0.25	0.07
21	Animalia	Rotifera	*Trichocerca sp.*	3.45	0.00	1.43	0.79	1.42	0.75	1.06
22	Animalia	Rotifera	*Trichocerca sp1.*	1.15	0.00	0.71	0.00	0.47	0.50	0.23
23	Animalia	Rotifera	*Trichocerca sp2.*	2.30	3.03	0.71	0.00	1.51	0.75	1.13
24	Animalia	Rotifera	*Trichocerca sp3.*	0.00	1.01	2.14	0.00	0.79	0.50	0.39
	Total number of species			**17**	**7**	**13**	**9**	**23**		

Table 4. Relative abundance (%) according to stations, mean relative abundance (RA), frequency and important species index of protozoan microfauna

No	Kingdom	Phylum	Species	ST 1	ST 2	ST 3	ST 4	RA	F	ISI
1	Protozoa	Amoebozoa	*Difflugidae sp1*	6.90	5.05	8.57	6.30	6.70	1.00	6.70
2	Protozoa	Amoebozoa	*Difflugidae sp2*	0.00	2.02	0.00	0.79	0.70	0.50	0.35
3	Protozoa	Amoebozoa	*Trinema sp.*	0.00	0.00	0.71	0.79	0.38	0.50	0.19
4	Protozoa	Amoebozoa	*Amebozoan*	0.00	0.00	3.57	0.00	0.89	0.25	0.22
5	Protozoa	Cercozoa	*Euglypha*	1.15	0.00	2.86	0.00	1.00	0.50	0.50
6	Protozoa	Ciliophora	*Lacrymaria sp.*	1.15	0.00	0.00	0.00	0.29	0.25	0.07
7	Protozoa	Ciliophora	*Hypotrichia*	0.00	1.01	0.00	0.00	0.25	0.25	0.06
8	Protozoa	Ciliophora	*Vorticella*	0.00	4.04	2.14	1.57	1.94	0.75	1.45
9	Protozoa	Euglenozoa	*Euglenozoa*	1.15	3.03	0.71	0.00	1.22	0.75	0.92
	Total number of species			**4**	**5**	**6**	**4**	**9**		

Table 5. Relative abundance (%) according to stations, mean relative abundance (RA), frequency and important species index of chromist microflora

No	Kingdom	Phylum	Species	ST 1	ST 2	ST 3	ST 4	RA	F	ISI
1	Bacteria	Cyanobacteria	*Spirulinaceae*	0.00	0.00	0.00	0.79	0.20	0.25	0.05
2	Chromista	Bacillariophyta	*Aulacoseira*	4.60	1.01	0.00	0.00	1.40	0.50	0.70
3	Chromista	Bacillariophyta	*Nitzschia sp.*	3.45	0.00	0.71	0.00	1.04	0.50	0.52
4	Chromista	Bacillariophyta	*Guinardia*	0.00	0.00	0.71	0.00	0.18	0.25	0.04
5	Chromista	Bacillariophyta	*Pleurosira sp.*	0.00	2.02	0.00	2.36	1.10	0.50	0.55
6	Chromista	Bacillariophyta	*Cymbella*	0.00	1.01	0.00	0.00	0.25	0.25	0.06
7	Chromista	Bacillariophyta	*Encyonema sp.*	1.15	0.00	0.00	0.79	0.48	0.50	0.24
8	Chromista	Bacillariophyta	*Fragillaria sp.*	0.00	1.01	1.43	0.79	0.81	0.75	0.60
9	Chromista	Bacillariophyta	*Diatoma sp.*	0.00	0.00	0.71	0.00	0.18	0.25	0.04
10	Chromista	Bacillariophyta	*Tabularia*	1.15	0.00	0.00	0.00	0.29	0.25	0.07
11	Chromista	Bacillariophyta	*Grammatophora sp.*	0.00	0.00	0.00	0.79	0.20	0.25	0.05
12	Chromista	Bacillariophyta	*Licomorpha sp.*	1.15	3.03	6.43	2.36	3.24	1.00	3.24
13	Chromista	Bacillariophyta	*Melosira*	1.15	1.01	1.43	0.00	0.90	0.75	0.67
14	Chromista	Bacillariophyta	*Pinnularia sp.*	9.20	1.01	0.71	2.36	3.32	1.00	3.32
15	Chromista	Bacillariophyta	*Pleurosigma*	0.00	0.00	0.71	0.79	0.38	0.50	0.19
16	Chromista	Bacillariophyta	*Stephanodiscus sp.*	1.15	1.01	2.14	2.36	1.67	1.00	1.67
17	Chromista	Bacillariophyta	*Entomoneis*	0.00	2.02	0.71	0.00	0.68	0.50	0.34
18	Chromista	Bacillariophyta	*Lauderia sp.*	2.30	1.01	0.00	0.00	0.83	0.50	0.41
19	Chromista	Bacillariophyta	*Thalassiosira*	2.30	4.04	5.00	6.30	4.41	1.00	4.41
20	Chromista	Dinoflagellata	*Dinophysis*	0.00	1.01	0.00	0.00	0.25	0.25	0.06
21	Chromista	Dinoflagellata	*Peridinium sp.*	2.30	1.01	5.00	15.75	6.01	1.00	6.01
22	Chromista	Dinoflagellata	*Peridinium sp2*	1.15	5.05	0.00	3.15	2.34	0.75	1.75
23	Chromista	Ochrophyta	*Dinobryon*	0.00	0.00	0.71	1.57	0.57	0.50	0.29
	Total number of species			**12**	**14**	**13**	**13**	**23**		

Table 6. Relative abundance (%) according to stations, mean relative abundance (RA), frequency and important species index of plant microflora

No	Kingdom	Phylum	Species	ST 1	ST 2	ST 3	ST 4	RA	F	ISI
1	Plantae	Chlorophyta	*Haematococcus sp.*	0.00	0.00	1.43	0.00	0.36	0.25	0.09
2	Plantae	Chlorophyta	*Closterium sp.*	0.00	0.00	0.00	0.79	0.20	0.25	0.05
3	Plantae	Chlorophyta	*Closterium sp.1*	0.00	0.00	1.43	0.00	0.36	0.25	0.09
4	Plantae	Chlorophyta	*Closterium sp.2*	0.00	0.00	0.71	0.00	0.18	0.25	0.04
5	Plantae	Chlorophyta	*Cosmarium sp.*	1.15	0.00	1.43	0.79	0.84	0.75	0.63
6	Plantae	Chlorophyta	*Staurastrum sp.1*	6.90	31.31	15.00	17.32	17.63	1.00	17.63
7	Plantae	Chlorophyta	*Staurastrum sp.2*	0.00	3.03	0.00	0.00	0.76	0.25	0.19
8	Plantae	Chlorophyta	*Staurastrum sp3*	1.15	4.04	2.14	0.79	2.03	1.00	2.03
9	Plantae	Chlorophyta	*Netrium sp.1*	4.60	0.00	2.14	3.15	2.47	0.75	1.85
10	Plantae	Chlorophyta	*Pedastrium*	0.00	0.00	0.71	0.00	0.18	0.25	0.04
11	Plantae	Chlorophyta	*Coelastrum*	2.30	6.06	2.14	0.00	2.63	0.75	1.97
12	Plantae	Chlorophyta	*Scenedesmus*	0.00	0.00	0.00	1.57	0.39	0.25	0.10
13	Plantae	Chlorophyta	*Ulotrichales*	1.15	2.02	0.00	0.79	0.99	0.75	0.74
	Total number of species			**6**	**5**	**9**	**7**	**13**		

Plantae

Green algae were represented by 13 species, with *Staurastrum* sp.1 (RA = 17.63%, F = 1.00, ISI = 17.63) being the most dominant, followed by Staurastrum sp.3 (RA = 2.03%, F = 1.00, ISI = 2.03) and *Netrium* sp.1 (RA = 2.47%, F = 0.75, ISI = 1.85). The abundance of *Staurastrum* sp.1 was particularly high at ST 2 (31.31%) and ST 4 (17.32%), indicating localized blooms (Table 6).

Important Species

Nine species had ISI values greater than 1.00, indicating their ecological significance (Table 7). These included *Staurastrum* sp.1, *Difflugidae* sp.1, *Peridinium* sp., *Thalassiosira, Pinnularia* sp., *Licomorpha* sp., *Brachionus* sp.1, *Gastrotricha*, and *Staurastrum* sp.3. These taxa were generally present at all stations, highlighting their adaptability and ecological importance (Table 7).

Table 7: Relative abundance (%) according to stations, mean relative abundance (RA), frequency and important species index of most important microflora and fauna (ISI > 1.00)

No	Kingdom	Phylum	Species	ST 1	ST 2	ST 3	ST 4	RA	F	ISI
1	Plantae	Chlorophyta	*Staurastrum*	6.90	31.31	15.00	17.32	17.63	1.00	17.63
2	Protozoa	Amoebozoa	*Difflugidae sp1*	6.90	5.05	8.57	6.30	6.70	1.00	6.70
3	Chromista	Dinoflagellata	*Peridinium sp.*	2.30	1.01	5.00	15.75	6.01	1.00	6.01
4	Chromista	Bacillariophyta	*Thalassiosira*	2.30	4.04	5.00	6.30	4.41	1.00	4.41
5	Chromista	Bacillariophyta	*Pinnularia sp.*	9.20	1.01	0.71	2.36	3.32	1.00	3.32
6	Chromista	Bacillariophyta	*Licomorpha sp.*	1.15	3.03	6.43	2.36	3.24	1.00	3.24
7	Animalia	Rotifera	*Brachionus sp1.*	4.60	0.00	5.71	5.51	3.96	0.75	2.97
8	Animalia	Gastrotricha	*Gastrotricha*	2.30	1.01	3.57	2.36	2.31	1.00	2.31
9	Plantae	Chlorophyta	*Staurastrum sp3*	1.15	4.04	2.14	0.79	2.03	1.00	2.03

Ecological Indices

The ecological indices calculated for each station are presented in the report. The Shannon-Wiener Diversity Index (H') ranged from 2.835 at ST 2 to 3.410 at ST 1, indicating substantial variation in species diversity across the riverine system (Table 8). Similarly, the Evenness Index (E) varied from 0.826 at ST 2 to 0.931 at ST 1, reflecting differences in the equitability of species abundance distributions. ST 1 exhibited the highest diversity (H' = 3.410), evenness (E = 0.931), and species richness (39 species), suggesting relatively favorable and stable environmental conditions at this location. In contrast, ST 2 showed the lowest diversity (H' = 2.835) and evenness (E = 0.826), despite having 31 species. This pattern at ST 2 is largely attributable to the dominance of Staurastrum sp.1. STs 3 and 4 showed intermediate levels of diversity (H' = 3.287 and 2.952, respectively) and evenness (E = 0.885 and 0.844, respectively), with 41 and 33 species, respectively. These results indicate a gradient of ecological conditions across the four stations, potentially reflecting varying degrees of environmental stress or resource availability.

Table 8. Diversity Index, Evenness Index and Number of Species According to Stations

Station	Diversity Index	Evenness	Num.Spec.
ST 1	3.410	0.931	39
ST 2	2.835	0.826	31
ST 3	3.287	0.885	41
ST 4	2.952	0.844	33

DISCUSSION

The Lana Estate riverine system supports a diverse and complex assemblage of aquatic microflora and microfauna, with a total of 69 taxa recorded. The high overall diversity and evenness, particularly at STs 1 and 3, suggest that these sections of the river maintain relatively stable and heterogeneous habitats, likely due to a combination of natural environmental variability and moderate anthropogenic influence.

The dominance of green algae, especially *Staurastrum* sp.1, is indicative of mesotrophic to eutrophic conditions, which are often associated with moderate nutrient enrichment from agricultural runoff (Bellinger & Sigee, 2015; Smith et al., 1999). The exceptionally high abundance of *Staurastrum* sp.1 at ST 2 (31.31%) and ST 4 (17.32%) suggests localized nutrient hotspots, possibly linked to fertilizer application or soil erosion from adjacent oil palm plantations. Such blooms can have cascading effects on food web structure, favoring herbivorous rotifers and protozoa.

Rotifers, particularly *Brachionus* sp.1, were abundant and widely distributed. *Brachionus* is known to tolerate moderate organic pollution and elevated nutrient levels, making it a useful indicator of water quality (Sládeček, 1983; Wallace & Snell, 2010). The co-occurrence of *Brachionus* sp.1 and *Gastrotricha* at multiple stations suggests a robust microfaunal community capable of exploiting abundant algal resources.

Diatoms and dinoflagellates formed the bulk of the chromist community, with *Peridinium* sp., *Thalassiosira*, *Pinnularia* sp., and *Licomorpha* sp. being particularly important. Diatoms are sensitive to changes in water chemistry and flow, and their diversity at Lana Estate suggests a range of microhabitats and water quality conditions (Kelly et al., 2008; Stevenson et al., 2010). The presence of both centric (e.g., *Thalassiosira*) and pennate (e.g., *Pinnularia*) diatoms indicates a mix of planktonic and benthic habitats.

Protozoa, especially *Difflugidae* sp.1, were numerically dominant, reflecting their ability to exploit a variety of ecological niches. The high abundance of protozoa may also indicate elevated levels of organic matter, as many are bacterivores or detritivores (Segers, 2008). The presence of *Vorticella* and Euglenozoa further suggests a well-developed microbial loop, with efficient recycling of organic material.

The variation in diversity and evenness across stations likely reflects differences in environmental stressors, such as nutrient input, sedimentation, and flow regime. ST 1, with the highest diversity and evenness, may represent a less disturbed or more heterogeneous habitat, possibly due to intact riparian vegetation or lower exposure to direct runoff. In contrast, ST 2, with lower diversity and a pronounced dominance of *Staurastrum* sp.1, could be experiencing greater anthropogenic impact or environmental stress, such as nutrient loading or reduced flow. ST 3, with the highest species richness (41 species) and high diversity (H' = 3.287), may benefit from intermediate disturbance, supporting both tolerant and sensitive taxa. ST 4, with moderate diversity and evenness, likely represents transitional conditions between more pristine and more impacted sections.

The presence of important species with high ISI values across all stations suggests that certain taxa are resilient to environmental variation, while others may be more sensitive and restricted in distribution. The dominance of tolerant species such as *Staurastrum* sp.1 and *Brachionus* sp.1 could signal early stages of eutrophication, warranting continued monitoring and management intervention (Smith et al., 1999).

The findings highlight the need for integrated management strategies to maintain water quality and biodiversity in oil palm-dominated landscapes. The high diversity and presence of sensitive taxa at some stations indicate that the Lana Estate riverine system retains significant ecological value. However, the localized dominance of opportunistic species and reduced diversity at certain stations point to emerging environmental pressures.

CONCLUSION

This assessment of aquatic microflora and microfauna at Lana Estate reveals a diverse and complex community structure, with significant spatial variation in species composition, abundance, and ecological indices. The dominance of green algae and rotifers, along with high protozoan abundance, reflects the influence of nutrient enrichment and organic matter input, likely linked to surrounding land use. The data provide a valuable baseline for future monitoring and underscore the importance of proactive management to conserve aquatic biodiversity in oil palm landscapes.

REFERENCES

Bellinger, E. G., & Sigee, D. C. (2015). Freshwater algae: Identification, enumeration and use as bioindicators (2nd ed.). Wiley-Blackwell.

Bere, T., & Tundisi, J. G. (2010). Biological monitoring of lotic ecosystems: The role of diatoms. Brazilian Journal of Biology, 70(3), 493-502.

Cheng, C. T., Lee, T. S., & Ko, C. H. (2017). Water quality assessment and pollution source identification in a tropical river basin: A case study in Malaysia. Environmental Science and Pollution Research, 24(2), 1234-1247.

Dudgeon, D., Arthington, A. H., Gessner, M. O., Kawabata, Z. I., Knowler, D. J., Lévêque, C., Naiman, R. J., Prieur-Richard, A. H., Soto, D., Stiassny, M. L. J., & Sullivan, C. A. (2006). Freshwater biodiversity: Importance, threats, status and conservation challenges. Biological Reviews, 81(2), 163-182.

Gaveau, D. L. A., Sheil, D., Husnayaen, Salim, M. A., Arjasakusuma, S., Ancrenaz, M., Pacheco, P., & Meijaard, E. (2016). Rapid conversions and avoided deforestation: Examining four decades of industrial plantation expansion in Borneo. Scientific Reports, 6, 32017.

John, D. M., Whitton, B. A., & Brook, A. J. (2011). The freshwater algal flora of the British Isles: An identification guide to freshwater and terrestrial algae (2nd ed.). Cambridge University Press.

Kelly, M. G., Bennion, H., Cox, E. J., Goldsmith, B., Jamieson, J., Juggins, S., Mann, D. G., & Telford, R. J. (2008). Common freshwater diatoms of Britain and Ireland: An interactive key. Environment Agency, Bristol.

Mercer, E. V., Mercer, T. G., & Sayok, A. K. (2014). Effects of forest conversions to oil palm plantations on freshwater macroinvertebrates: A case study from Sarawak, Malaysia. Journal of Land Use Science, 9(3), 260-277.

Reynolds, C. S. (2006). The ecology of phytoplankton. Cambridge University Press. Segers, H. (2008). Global diversity of rotifers (Rotifera) in freshwater. Hydrobiologia, 595, 49-59.

Shuhaimi-Othman, M., Lim, E. C., & Mushrifah, I. (2007). Water quality changes in Chini Lake, Pahang, West Malaysia. Environmental Monitoring and Assessment, 131(1-3), 279-292.

Sládeček, V. (1983). Rotifers as indicators of water quality. Hydrobiologia, 100(1), 169-201.

Smith, V. H., Tilman, G. D., & Nekola, J. C. (1999). Eutrophication: Impacts of excess nutrient inputs on freshwater, marine, and terrestrial ecosystems. Environmental Pollution, 100(1-3), 179-196.

Stevenson, R. J., Pan, Y., & Van Dam, H. (2010). Assessing environmental conditions in rivers and streams with diatoms. In J. P. Smol & E. F. Stoermer (Eds.), The diatoms: Applications for the environmental and earth sciences (2nd ed., pp. 57-85). Cambridge University Press.

Wallace, R. L., & Snell, T. W. (2010). Rotifera. In J. H. Thorp & A. P. Covich (Eds.), Ecology and classification of North American freshwater invertebrates (3rd ed., pp. 173-235). Academic Press.

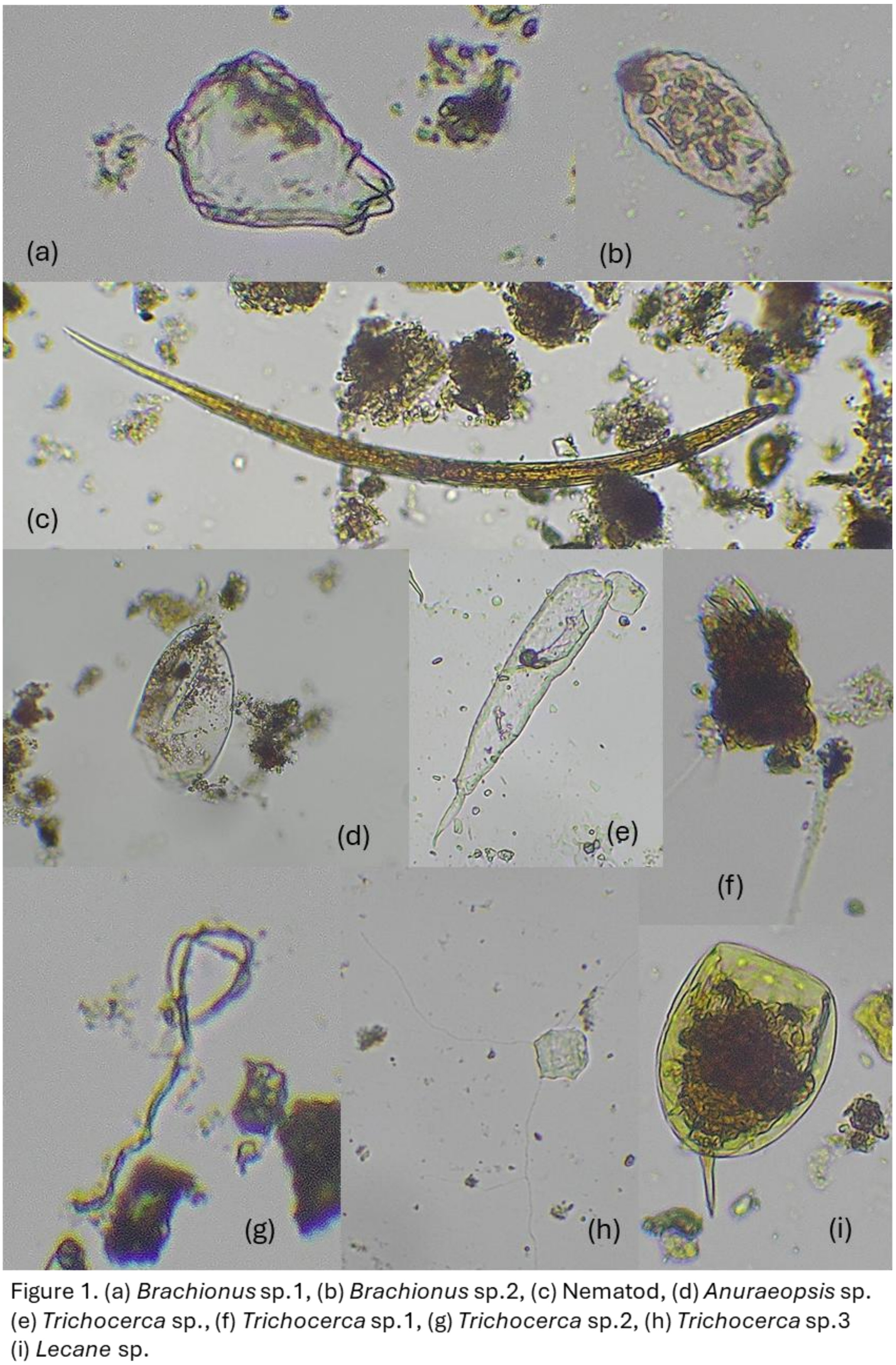


Figure 1. (a) *Brachionus* sp.1, (b) *Brachionus* sp.2, (c) Nematod, (d) *Anuraeopsis* sp. (e) *Trichocerca* sp., (f) *Trichocerca* sp.1, (g) *Trichocerca* sp.2, (h) *Trichocerca* sp.3 (i) *Lecane* sp.

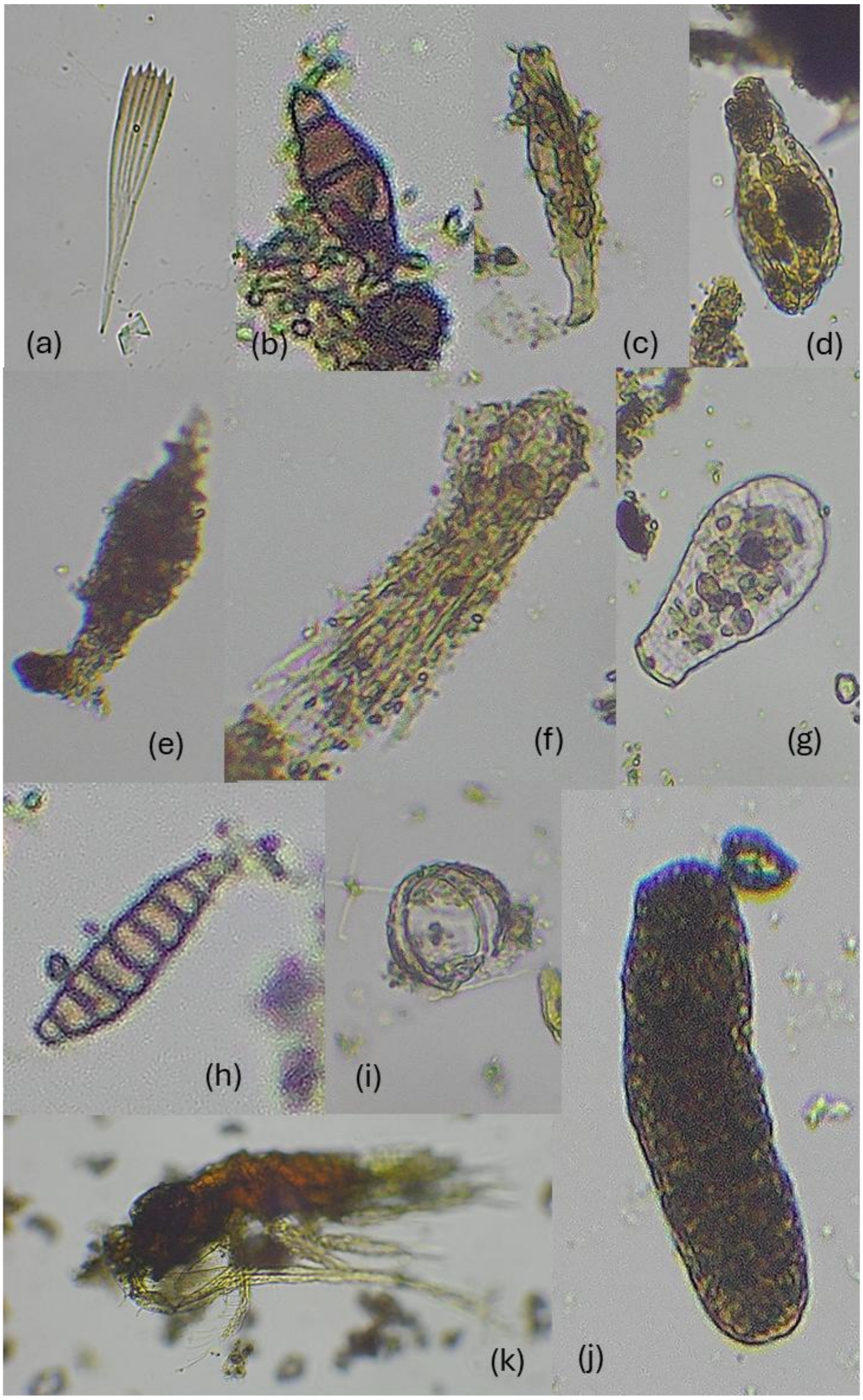


Figure 2. (a) *Notholca* sp., (b) *Bryceela sp.*, (c) Philodinavus sp., (d) *Testudinella sp.1,* (e), *Testudinella sp.2,* (f) *Gastrotricha*, (g) *Asplancha sp.*, (h) Annelida*,* (i) *Hydrozoa,* (j) Hoplonemertean, (k) Copepod

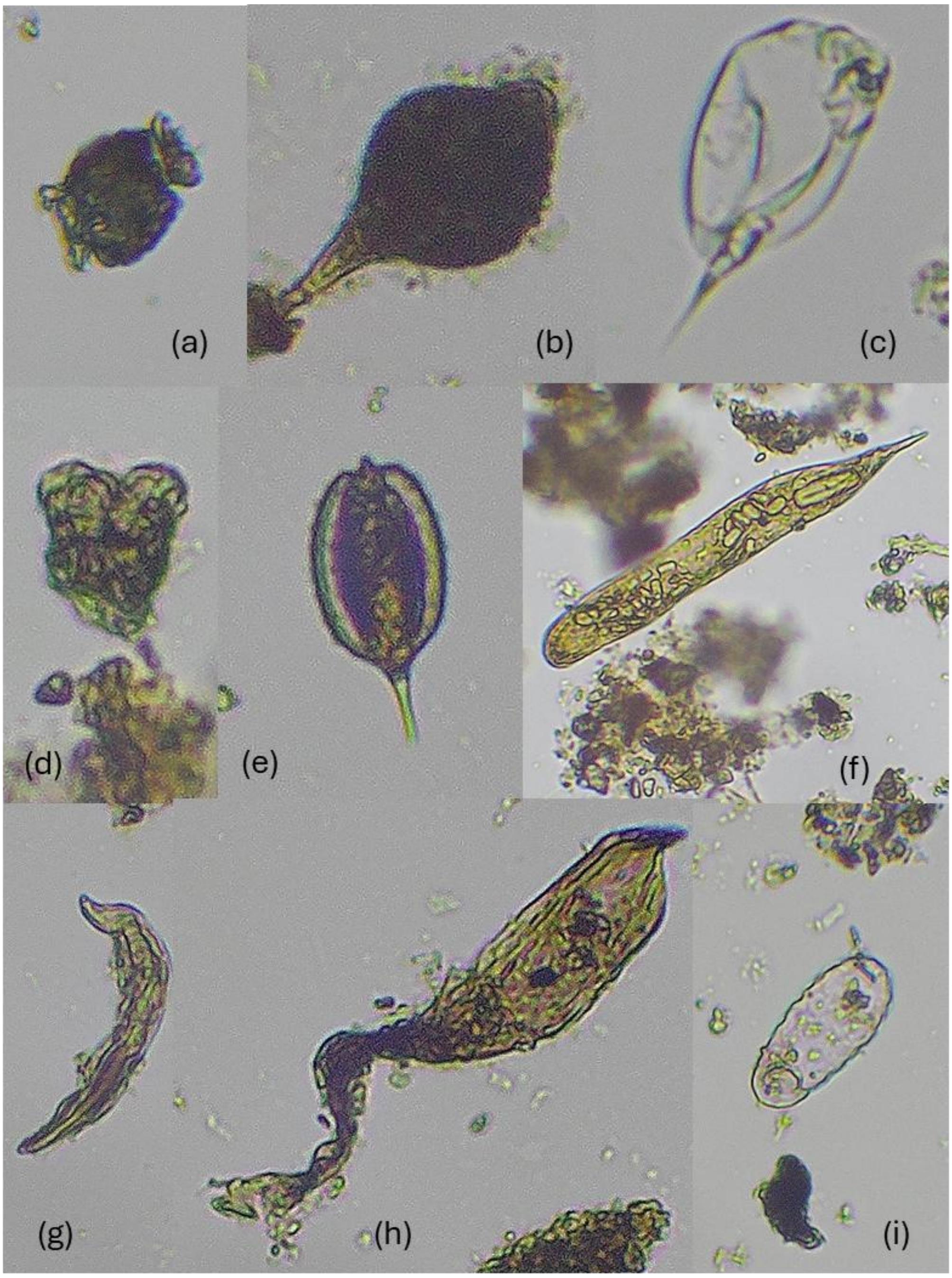


Figure 3. (a) *Difflugidae sp1*, (b) *Difflugidae sp2*, (c) *Lepadella* sp1, (d) *Vorticella,* (e) *Lepadella* sp2., (f) *Euglenozoa*, (g) *Hypotrichia,* (h) *Lacrymaria sp.*, (i) *Trinema* sp.

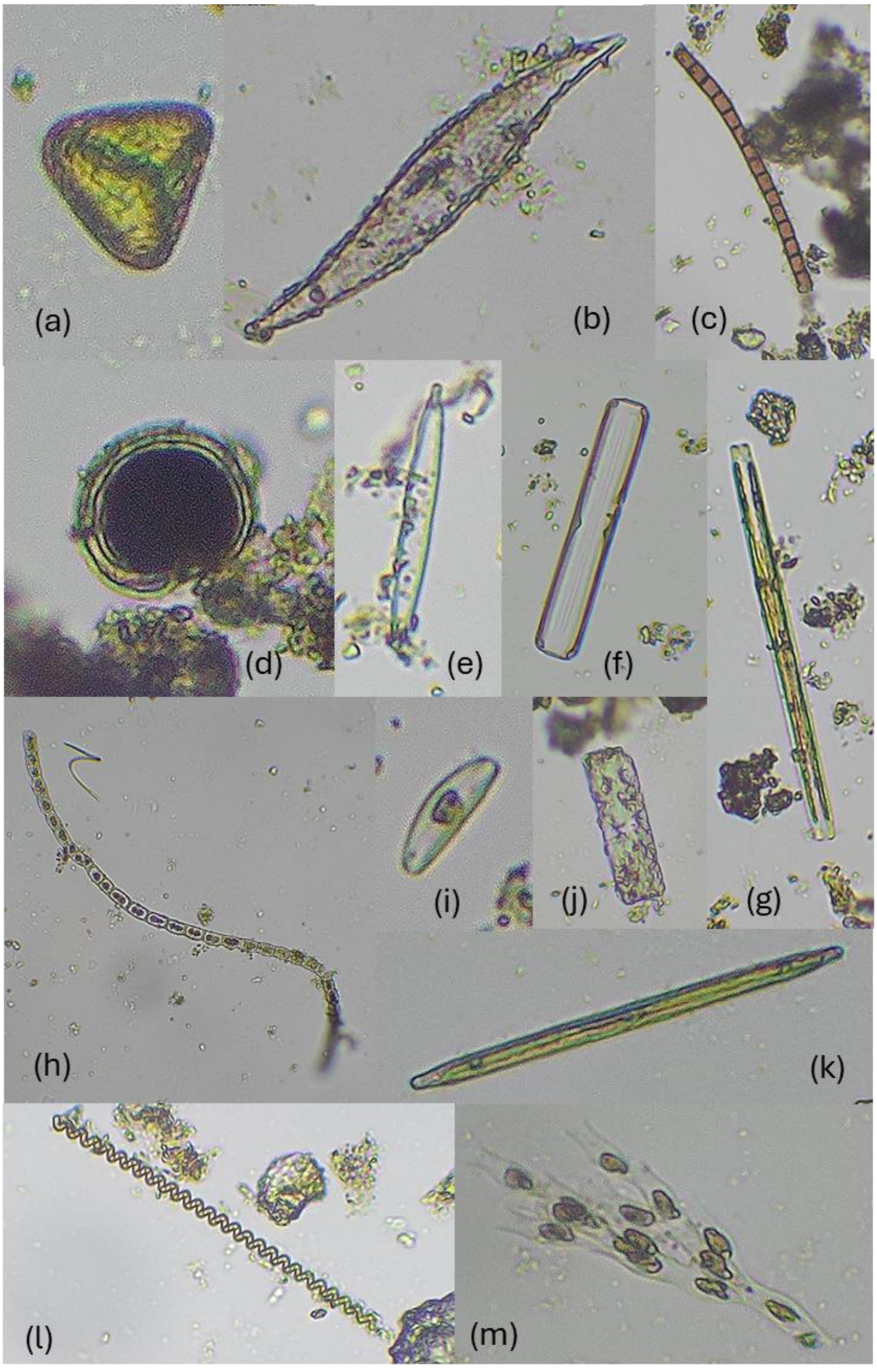


Figure 4. (a) *Licomorpha sp.*, (b) *Navicula*, (c) Lauderia sp., (d) *Peridinium sp.*, (e) *Fragillaria sp.*, (f) *Pinnularia* sp., (g) *Nitzschia* sp. (h) *Melosira* (i) *Encyonema*, (j) *Guinardia*, (k) *Tabularia*, (l) Spirulinaceae, (m) *Dinobryon*

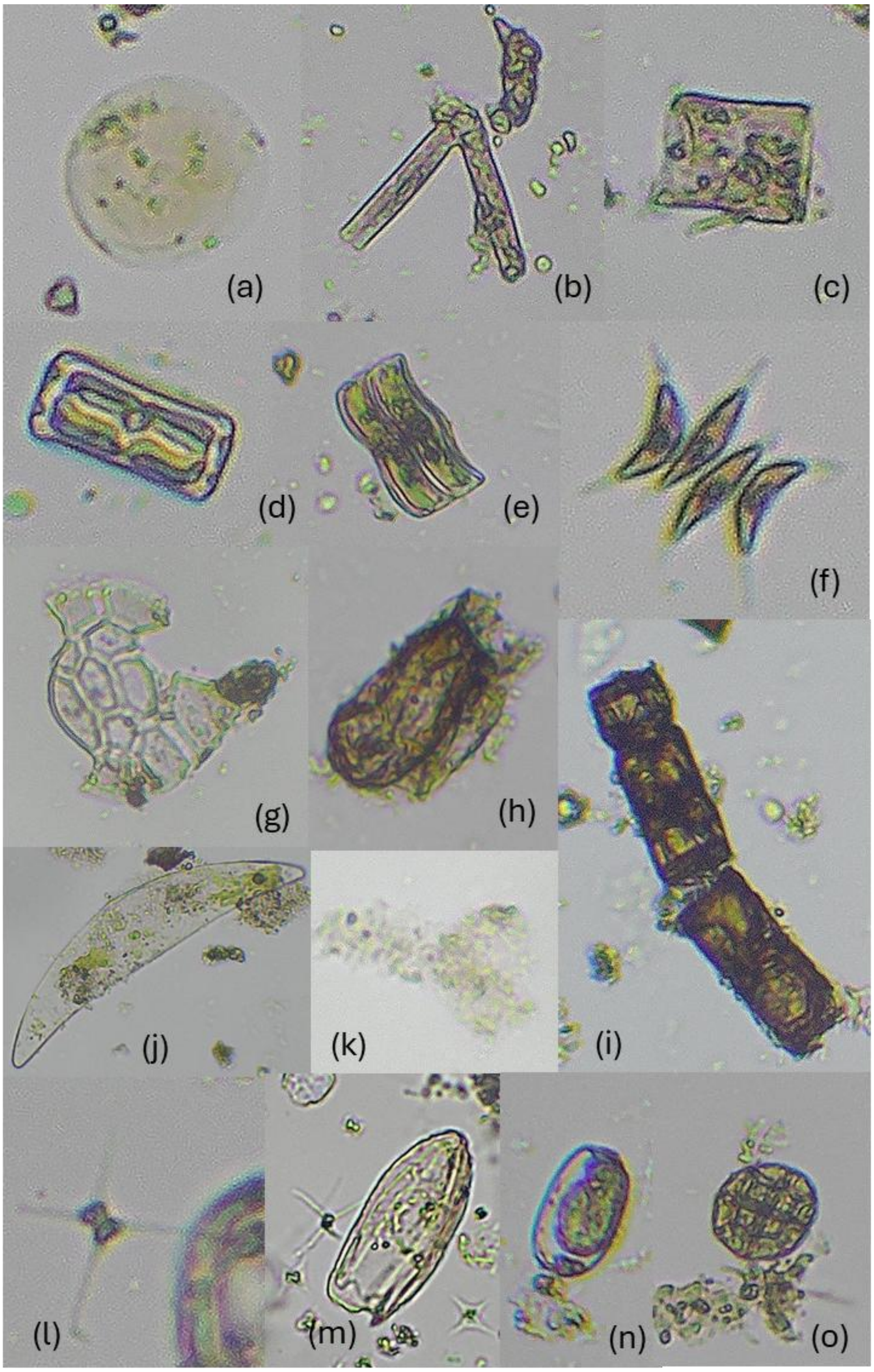


Figure 5. (a) *Stephanodiscus sp.*, (b) *Diatoma sp.*, (c) *Thalassiosira*, (d) G*rammatophora sp.*, (e) *Entomoneis*, (f) *Scenedesmus,* (g) *Pedastrium,* (h) *Dinophysis,* (i) *Pleurosira* sp. (j) *Cymbella*, (k) Amebozoan, (l) *Staurastrum* sp3, (m) *Lophocharis,* (n) *Euglypha*, (o) *Coelastrum*

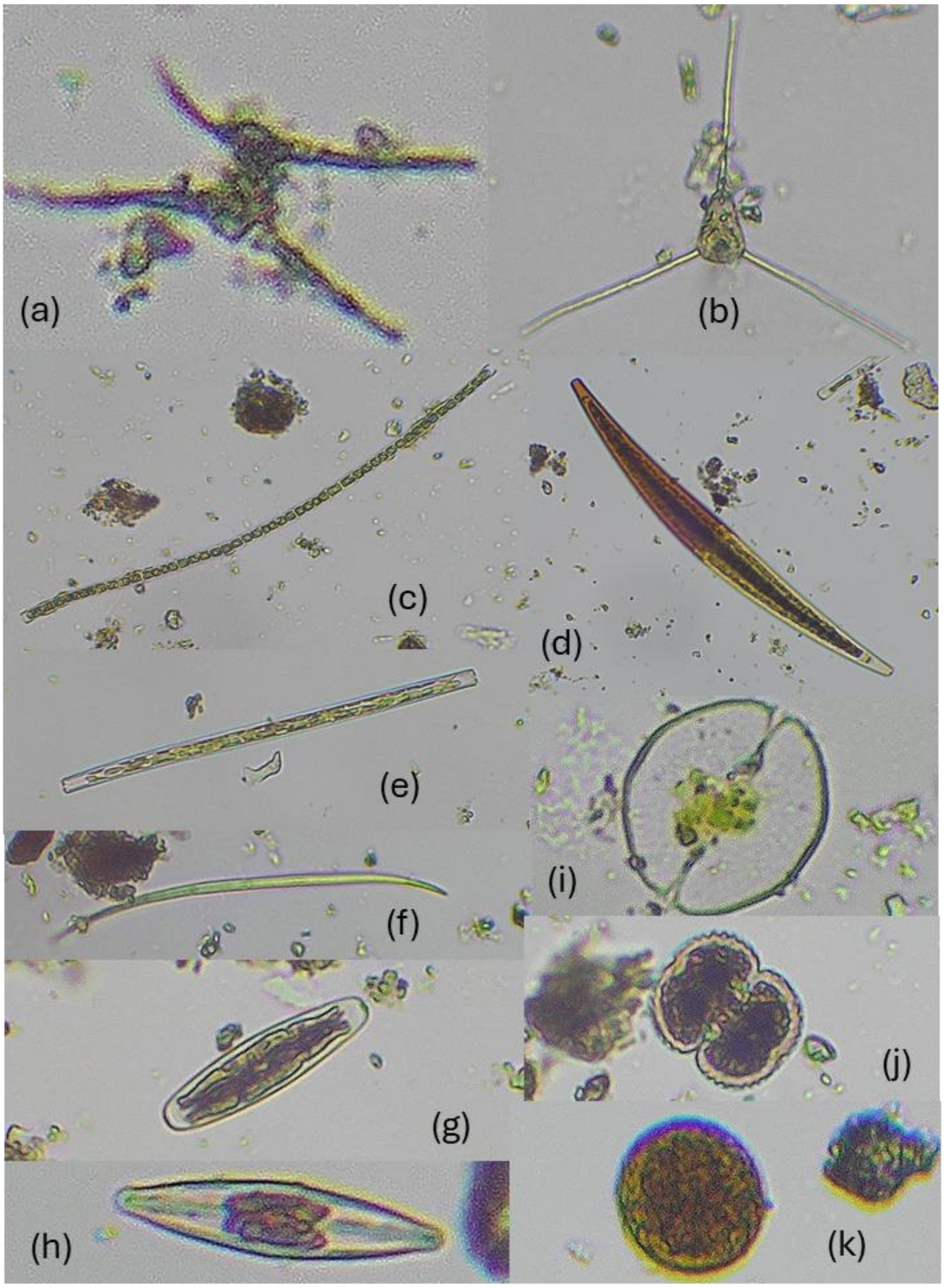


Figure 6. (a) *Staurastrum sp.1*, (b) *Staurastrum sp2*, (c) *Ulotrichales,* (e) *Closterium sp.*, (f) *Gonatozygon sp.*, (g) *Closterium sp.1,* (h) *Closterium sp.2,* Netrium sp.1*,* (i) *Cosmarium* sp.1, (j) *Cosmarium* sp.2, (k) *Haematococcus* sp.,

FISH DIVERSITY

INTRODUCTION

Freshwater ecosystems are among the most imperilled globally, facing mounting pressures from human activities such as deforestation, land conversion, and agricultural expansion (Carpenter et al., 2011). In Southeast Asia, these challenges are particularly acute, with the rapid growth of oil palm plantations posing significant threats to aquatic biodiversity (Giam et al., 2015). In Sarawak, Malaysian Borneo, land-use changes driven by oil palm cultivation have transformed freshwater habitats, yet their effects on ichthyofaunal communities remain poorly documented, especially in remote areas like Lana, Kapit. Freshwater fish play crucial ecological roles and are essential to rural livelihoods, providing food, income, and key ecosystem services (McIntyre et al., 2016). However, pressures such as habitat alteration, sedimentation, and intensified fishing associated with plantation development can disrupt species composition and lead to population declines (Ferreira et al., 2018).

In response to these pressures, a study conducted in Central Kalimantan, Indonesia examined the role of forested riparian reserves in conserving freshwater fish communities within oil palm plantations. The findings revealed that these reserves successfully maintained local fish species richness and functional diversity at levels comparable to those before land conversion (Giam et al., 2015). The presence of riparian forests likely helped sustain both the quantity and quality of leaf litter input, matching pre-conversion conditions (Lidman et al., 2017). This leaf litter plays a vital role in supporting fish populations by enhancing and concentrating food resources such as invertebrates, biofilm, and algae (Dala-Corte et al., 2016). Additionally, it offers essential microhabitats that are cool, shaded, and provide protection from predators (Sazima et al., 2006). Furthermore, the fine-scale partitioning of space and food resources among species living within leaf litter habitats may further explain the high fish species richness observed in streams bordered by riparian forests (Hough-Snee et al., 2015). Despite these valuable insights from Indonesia, baseline data on freshwater fish diversity within plantation-dominated landscapes in Sarawak remain scarce, highlighting a critical gap in regional biodiversity research.

This study seeks to fill that knowledge gap by documenting the freshwater fish assemblages in streams situated within oil palm plantation areas in Lana, Kapit, Sarawak. By establishing baseline data on species occurrence and diversity, the research contributes to a better understanding of how land-use change influences freshwater ecosystems and provides valuable insights for future conservation planning and sustainable management in tropical plantation landscapes.

Materials and Methods

Sampling Site

Study was conducted at the palm oil Estate of Glenealy Sdn. Bhd. in Lana, Kapit Division (Figure 1). Four rivers such as Sg. Sematai (SS), Sg. Tingga (ST), Sg. Lalit (SL) and Sg. Bah (SB) that flows in the estate was selected for the fish inventory study.

Figure 1: Four sampling stations for freshwater fish inventory in Lana Estate.

Sampling Procedure and Analysis

A total of 4 sampling stations which river that located in the Lana Estate were used as fish sampling site. Sampling was carried once in April 2025. Fish sample was collected using fishing gear (gill net) with length 50 m and 2 m wide which consisting of mesh size of 2 inch (Figure 2). The nets were placed using stack across the river for three hours. After the located time, trapped fish in the net were collected for observation, measurement and photographed. Fish samples were identified to the species and family levels through morphological examination, referencing standard taxonomic keys and field guides based on (Froese & Pauly, 2025; Parenti & Lim, 2005; Sholihah et al., 2020; Sulaiman & Mayden, 2012) works. The number of species and their respective families were recorded manually. Species identification was based on distinguishing features such as fin structure, body shape, scale pattern, and coloration. Each of the identified fish were compare with the International Union for Conservation of Nature (IUCN) list.

Figure 2: Installation of gill net across the stream.

RESULTS AND DISCUSSION

A total of 19 freshwater fish species were recorded during the survey conducted across all sampling stations (Table 1). Among the recorded species, *Barbonymus collingwoodii* was identified as the most widely distributed species, being present at all sampling stations surveyed. This indicates the species' broad ecological tolerance and potential adaptability to varying environmental conditions within the study area.

Table 1: Species of freshwater fishes recorded from Glenealy Lana Estate

No	Family	Scientific name	Common name	IUCN list	Station			
					SS	ST	SL	SB
1	Bagridae	*Hemibagrus fortis*	Baung	LC			+	+
2	Cobitidae	*Acantopsis octoactinotos*	Horseface loaches	VU				+
3	Cyprinidae	*Barbonymus collingwoodii*	Kepiat	LC	+	+	+	+
4	Cyprinidae	*Crossocheilus obscurus*	Kulong	DD	+			
5	Cyprinidae	*Cyclocheilichthys apogon*	Boeng	LC		+		
6	Cyprinidae	*Hampala macrolepidota*	Adong/Seberau	LC		+	+	+
7	Cyprinidae	*Labiobarbus leptocheilus*	Umbu	LC		+		
8	Cyprinidae	*Lobocheilos kajanensis*	Kulong	LC	+	+		

9	Cyprinidae	*Osteochilus kahajanensis*	Palau	LC		+		
10	Cyprinidae	*Osteochilus vittatus*	Bantak	LC		+	+	
11	Cyprinidae	*Puntius* sp.	Bangah	LC	+			
12	Cyprinidae	*Tor douronensis*	Semah	NE	+	+	+	
13	Danionidae	*Luciosoma setigerum*	Panjut/ lansi	LC		+		
14	Danionidae	*Luciosoma trinema*	nyenyuar	LC		+	+	
15	Danionidae	*Rasbora argyrotaenia*	seluang	LC	+			
16	Danionidae	*Rasbora dusonensis*	seluang ekor kuning	LC		+	+	+
17	Danionidae	*Rasbora tornieri*	seluang ekor merah	LC	+		+	
18	Danionidae	*Rasbora laticlavia*	Seluang	LC	+			
19	Gastromyzontidae	*Gastromyzon ctenocephalus*	Borneo sucker	NT	+			
			TOTAL		9	11	8	5

Conversely, several species exhibited restricted distributions, occurring only at single, specific stations. These unique species included *Rasbora argyrotaenia*, *Gastromyzon ctenocephalus*, *Rasbora laticlavia*, and *Puntius* sp., highlighting localized habitat preferences or potentially limited population sizes in the region. The presence of unique species, often associated with pristine habitats, highlights the need for future monitoring and conservation attention (Colvin et al., 2019).

In terms of conservation status based on the International Union for Conservation of Nature (IUCN) Red List, the species recorded showed varied classifications. *Acantopsis octoactinotos* was categorized as Vulnerable (VU), indicating a high risk of extinction in the wild. *Gastromyzon ctenocephalus* was listed as Near Threatened (NT), suggesting that it may be considered threatened with extinction in the near future if causal factors persist. *Tor douronensis* has yet to be evaluated under the IUCN Red List, while *Crossocheilus obscurus* was classified as Data Deficient (DD), reflecting the insufficient information available to assess its risk of extinction. The remaining species recorded during the survey were categorized as Least Concern (LC), indicating that they are currently not at significant risk. The primary threats to species categorized as Vulnerable and Near Threatened include habitat loss, water pollution, overfishing, and the impacts of climate change (Arthington et al., 2016). Land-use changes such as deforestation, agricultural expansion, and river modification have resulted in the fragmentation and degradation of aquatic habitats, while agricultural runoff and palm oil mill effluent further deteriorate water quality (Razali et al., 2018). Additionally, overfishing and rising temperatures driven by climate change continue to disrupt fish populations by altering spawning cycles, reducing food availability, and affecting habitat suitability (Pankhurst & Munday, 2011).

The distribution of fish species varied among the stations (Table 1). Sungai Tingga recorded the highest number of fish species, indicating greater species richness in this location compared to the other sampling sites. In contrast, Sungai Bah exhibited the lowest number of fish species, suggesting lower habitat suitability or environmental quality for fish communities in this area. Sungai Sematai and Sungai Lalit showed moderate numbers of fish species, with values falling between those of Sungai Tingga and Sungai Bah.

A total of four fish families were recorded in the study area, with varying levels of representation (Figure 3). The highest number of species was found in the family Cyprinidae, which accounted for 55% of the total fish families observed. This indicates that Cyprinidae is the most dominant family within the surveyed ecosystem.

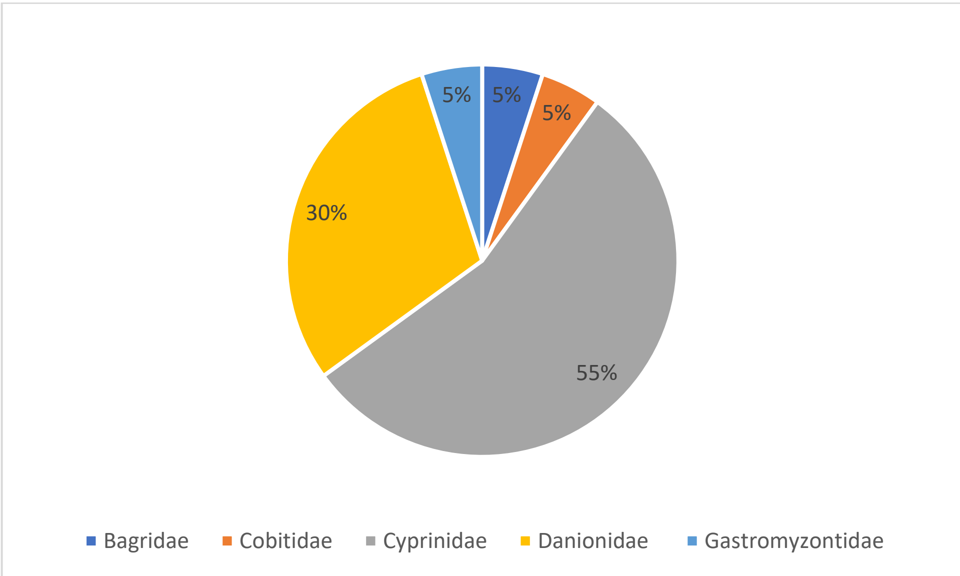


Figure 3: Percentage of fish family from the Glenealy Lana estate

The Danionidae family represented the second largest proportion, comprising 30% of the total families recorded. In contrast, the families Cobitidae, Gastromyzontidae, and Bagridae were the least represented, each contributing 5% to the total fish family composition. The dominance of Cyprinidae observed in this study aligns with established patterns in freshwater ecosystems throughout Southeast Asia, where this family is recognized for its ecological versatility and high species richness (van der Sleen & Albert, 2022). Particularly noteworthy is the genus *Barbonymus*, which frequently occurs in lowland rivers and anthropogenically influenced habitats, serving as an effective bioindicator of ecological resilience and habitat quality (Chow et al., 2016).

The documentation of these species at Glenealy Lana Estate represents a significant addition to the ichthyofaunal records for this area, providing essential baseline data for ongoing and future ecological assessments, as well as informing plantation landscape management. Although overall species richness is relatively low, the absence of invasive or exotic species is ecologically meaningful, indicating a freshwater habitat that, while subject to surrounding land-use pressures, remains comparatively undisturbed a condition increasingly uncommon in Sarawak's inland water systems (Wilkinson et al., 2018).

This study contributes valuable insights to the limited but growing body of research on freshwater fish diversity within Sarawak, particularly within estate and plantation-dominated landscapes (Wilkinson et al., 2018). Comprehensive inventories such as this are critical for identifying biodiversity hotspots, monitoring ecosystem health, and providing a scientific foundation for evidence-based conservation planning and sustainable land-use policy development.

Conclusion

This study documented 19 freshwater fish species from four families in oil palm plantation streams in Lana Kapit, Sarawak, with Cyprinidae being the most dominant family. *Barbonymus collingwoodii* was the most widely distributed species, while several others, such as *Rasbora argyrotaenia* and *Gastromyzon ctenocephalus*, showed highly localized distributions, indicating specific habitat preferences. Conservation assessments revealed most species were of Least Concern, though the presence of Vulnerable and Near Threatened species highlights the ecological value of these habitats. Species richness varied across sampling stations, with Sungai Tingga supporting the highest diversity and Sungai Bah the lowest, likely due to differences in habitat quality. These findings provide essential baseline data for Sarawak's plantation landscapes and emphasize the need for ongoing biodiversity monitoring and conservation-focused land-use planning.

REFERENCE

Arthington, A. H., Dulvy, N. K., Gladstone, W., & Winfield, I. J. (2016). Fish conservation in freshwater and marine realms: status, threats and management. Aquatic Conservation: Marine and Freshwater Ecosystems, 26(5), 838-857.

Carpenter, S. R., Stanley, E. H., & Vander Zanden, M. J. (2011). State of the world's freshwater ecosystems: Physical, chemical, and biological changes. *Annual Review of Environment and Resources*, *36*, 75–99. https://doi.org/10.1146/annurev-environ-021810-094524

Chow, V. K. K., Mohd Said, M. I., Mohamed, M., & Sabri, S. (2016). Species Composition and Abundance of Freshwater Fishes in Selected Rivers of Johor, Malaysia. *International Journal of Research in Chemical, Metallurgical and Civil Engineering*, *3*(2). https://doi.org/10.15242/ijrcmce.iae0716411

Colvin, S. A. R., Sullivan, S. M. P., Shirey, P. D., Colvin, R. W., Winemiller, K. O., Hughes, R. M., Fausch, K. D., Infante, D. M., Olden, J. D., Bestgen, K. R., Danehy, R. J., & Eby, L. (2019). Headwater Streams and Wetlands are Critical for Sustaining Fish, Fisheries, and Ecosystem Services. *Fisheries*, *44*(2), 73–91. https://doi.org/10.1002/fsh.10229

Dala-Corte, R. B., Giam, X., Olden, J. D., Becker, F. G., Guimarães, T. D. F., & Melo, A. S. (2016). Revealing the pathways by which agricultural land-use affects stream fish communities in South Brazilian grasslands. *Freshwater Biology*, *61*(11), 1921-1934.

Ferreira, M. C., Begot, T. O., da Silveira Prudente, B., Juen, L., & de Assis Montag, L. F. (2018). Effects of oil palm plantations on habitat structure and fish assemblages in

Amazon streams. *Environmental Biology of Fishes*, *101*(4), 547–562. https://doi.org/10.1007/s10641-018-0716-4

Froese, R., & Pauly, D. (2025). *FishBase*. Www.Fishbase.Org.

Giam, X., Hadiaty, R. K., Tan, H. H., Parenti, L. R., Wowor, D., Sauri, S., Chong, K. Y., Yeo, D. C. J., & Wilcove, D. S. (2015). Mitigating the impact of oil-palm monoculture on freshwater fishes in Southeast Asia. *Conservation Biology*, *29*(5), 1357–1367. https://doi.org/10.1111/cobi.12483

Hough-Snee, N., Laub, B. G., Merritt, D. M., Long, A. L., Nackley, L. L., Roper, B. B., & Wheaton, J. M. (2015). Multi-scale environmental filters and niche partitioning govern the distributions of riparian vegetation guilds. *Ecosphere*, *6*(10), 1-22.

IUCN. (2025). *The IUCN Red List of Threatened Species*. Https://Www.Iucnredlist.Org.

Lidman, J., Jonsson, M., Burrows, R. M., Bundschuh, M., & Sponseller, R. A. (2017). Composition of riparian litter input regulates organic matter decomposition: Implications for headwater stream functioning in a managed forest landscape. *Ecology and Evolution*, *7*(4), 1068-1077.

McIntyre, P. B., Liermann, C. A. R., & Revenga, C. (2016). Linking freshwater fishery management to global food security and biodiversity conservation. *Proceedings of the National Academy of Sciences of the United States of America*, *113*(45), 12880–12885. https://doi.org/10.1073/pnas.1521540113

Pankhurst, N. W., & Munday, P. L. (2011). Effects of climate change on fish reproduction and early life history stages. *Marine and Freshwater Research*, *62*(9), 1015-1026.

Parenti, L. R., & Lim, K. K. P. (2005). Fishes of the RAJANG basin, Sarawak, Malaysia. In *The Raffles Bulletin of Zoology* (Issue 13).

Razali, A., Syed Ismail, S. N., Awang, S., Praveena, S. M., & Zainal Abidin, E. (2018). Land use change in highland area and its impact on river water quality: a review of case studies in Malaysia. *Ecological processes*, *7*, 1-17.

Sazima I., Carvalho L.N., Mendonca F.P., & Zuanon J. 2006. Fallen leaves on the water-bed: diurnal camouflage of three night active fish species in an Amazonian streamlet. Neotropical Ichthyology **4:**119–122.

Sholihah, A., Delrieu-Trottin, E., Sukmono, T., Dahruddin, H., Risdawati, R., Elvyra, R., Wibowo, A., Kustiati, K., Busson, F., Sauri, S., Nurhaman, U., Dounias, E., Zein, M. S. A., Fitriana, Y., Utama, I. V., Muchlisin, Z. A., Agnèse, J. F., Hanner, R., Wowor, D., … Hubert, N. (2020). Disentangling the taxonomy of the subfamily Rasborinae (Cypriniformes, Danionidae) in Sundaland using DNA barcodes. *Scientific Reports*, *10*(1). https://doi.org/10.1038/s41598-020-59544-9

Sulaiman, Z. H., & Mayden, R. L. (2012). Cypriniformes of borneo (actinopterygii, otophysi): An extraordinary fauna for integrated studies on diversity, systematics, evolution, ecology, and conservation. *Zootaxa*, *3586*, 359–376. https://doi.org/10.11646/zootaxa.3586.1.34

van der Sleen, P., & Albert, J. S. (2022). Patterns in Freshwater Fish Diversity. In *Encyclopedia of Inland Waters, Second Edition* (Vol. 3, pp. 243–255). Elsevier. https://doi.org/10.1016/B978-0-12-819166-8.00056-6

Wilkinson, C. L., Yeo, D. C. J., Tan, H. H., Fikri, A. H., & Ewers, R. M. (2018). Land-use change is associated with a significant loss of freshwater fish species and functional richness in Sabah, Malaysia. *Biological Conservation*, *222*, 164–171. https://doi.org/10.1016/j.biocon.2018.04.004

APPENDIX

Rasbora argyrotaenia

Puntius sp.

Barbonymus collingwoodii

Crossocheilus obscurus

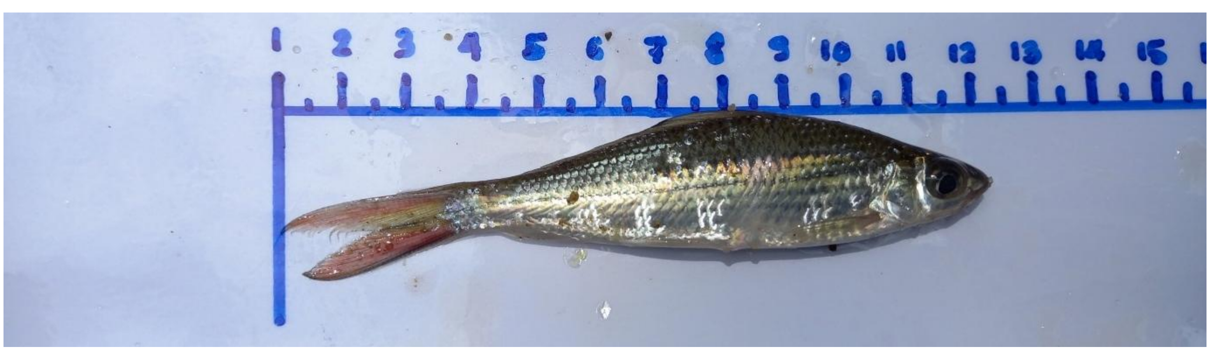
Rasbora laticlavia

Rasbora tornieri


Lobocheilos kajanensis

Gastromyzon ctenocephalus


Luciosoma trinema

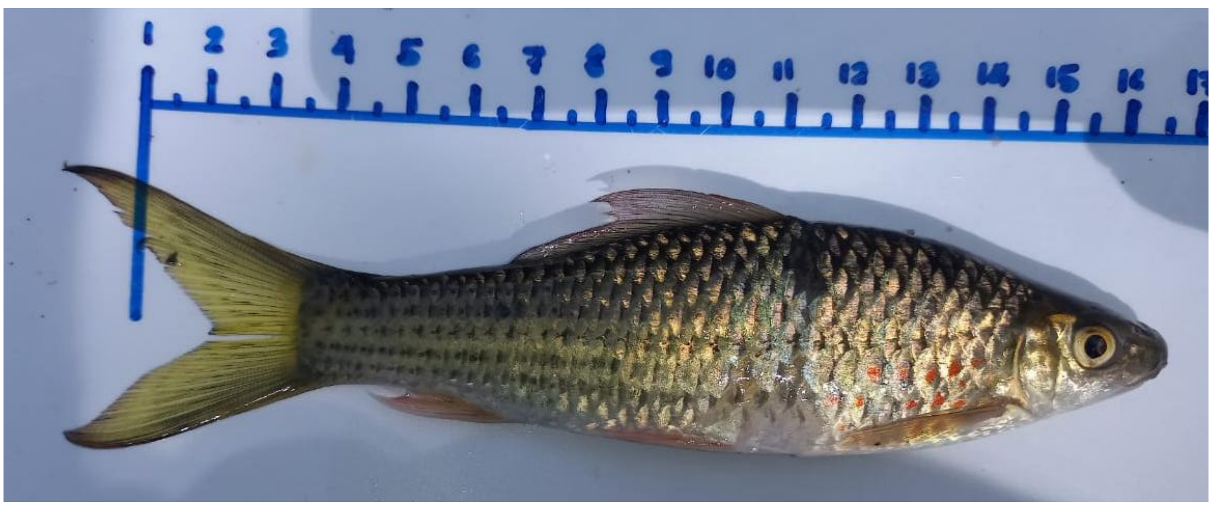

Labiobarbus leptocheilus

Hampala macrolepidota

Osteochilus kahajanensis

Tor douronensis

Cyclocheilichthys apogon



Osteochilus vittatus

Rasbora dusonensis

Luciosoma setigerum

Hemibagrus fortis

Acantopsis octoactinotos

ACKNOWLEDGEMENT

The authors would like to express sincere appreciation to Mr. Chieng Kai Soon, Mr. Belden Giman, and Mr. Rendall Richard for their invaluable contributions related to this Riverine Status Assessment of the Lana oil palm estates. Their commitment and active participation in ensuring the smoothness and efficiency before, during and after the assessment period is so valuable.

The authors are also deeply grateful to the Lana oil palm estates managers and staff for their solid support and encouragement throughout this conservation initiatives. Their dedication towards sustainable practices and willingness to facilitate the necessary resources and cooperation have been crucial to the successful completion of this assessment.

The collective efforts and collaboration demonstrated by all parties have significantly advanced the same goal of promoting responsible stewardship of riverine ecosystems within the Lana oil palm estates. The authors look forward to continued partnership in future conservation initiatives with Glenealy Plantations Sdn Bhd.

-UPMKB team-