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Application of the QBRs Index for riparian habitat quality assessment along Sugut River, Sabah, Malaysia

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Abstract. *Chik NFV, Godoong E. 2025. Application of the QBRs index for riparian habitat quality assessment along Sugut River, Sabah, Malaysia. Biodiversitas 26: 4137-4145.* Riparian zones, which are crucial for biodiversity and ecosystem services, are increasingly threatened by land use changes, encroachment, and erosion. This study applied the QBRs (Qualitat del Bosc de Ribera-Sabah adaptation) Index to assess the ecological condition of riparian zones along a 245 km stretch of Malaysia's Sugut River. A total of 120 plots (50×50 m each) were evaluated using satellite imagery and field assessments, focusing on canopy cover, vegetation structure, riparian habitat quality, and channel alterations. QBRs scores ranged from 25 to 100. Overall, only 2% of plots were classified in natural condition (≥95), while 17% were good (75-90), 20% fair (55-70), 38% poor (30-50), and 23% very poor (≤25). Despite the non-significant land-use effect, degradation was concentrated in the lower catchment, where semi-open canopies, shrub dominance, and oil palm cultivation were prevalent. The Kruskal-Wallis test revealed no statistically significant differences in QBRs scores across land-use types (χ^2: 4.3144, df: 3, p: 0.2295), indicating that riparian health may be influenced by factors beyond land use alone. These findings highlight the limited extent of intact riparian habitats in the Sugut River basin and underscore the urgent need for targeted ecological restoration, improved riparian buffer enforcement, and sustainable land-use planning. The study also demonstrates the practical utility of the QBRs Index as a rapid assessment tool for prioritizing conservation actions in tropical river systems. We recommend prioritizing restoration of areas scoring between fair, poor and very poor, strengthening enforcement of riparian zones, targeted replanting of native riparian trees and regular QBRs re-assessment to track recovery.

Keywords: Habitat degradation, land use, QBRs Index, restoration planning, riparian quality, Sugut River

INTRODUCTION

Riparian zones, located along the banks of rivers and streams, are among the most ecologically important and productive areas within a water catchment. These areas contribute to ecosystem functioning by stabilizing riverbanks, filtering pollutants, controlling soil erosion, regulating microclimates, and supporting rich biodiversity. In tropical regions such as Sabah, Malaysia, riparian zones function as critical ecological corridors that facilitate wildlife movement and enhance habitat connectivity, especially in landscapes that have been fragmented mainly by agricultural development (Williamson et al. 2021; Zanuari et al. 2024). However, these ecosystems face mounting threats from extensive land-use change. The conversion of natural forests into oil palm plantations, along with other anthropogenic disturbances, has led to substantial degradation, which is manifested through habitat loss and the disruption of key ecological functions.

The Sugut River, located in the northeastern part of Sabah, Malaysia, demonstrates the environmental challenges faced by tropical riparian systems. We chose the Sugut River because it shows a clear mix of land uses from mostly protected forest in the highlands to areas covered with oil palm in the lowlands. It also has known damage along its riverbanks and is a priority for government action, making it a good example for research and planning. As land use activities intensified over time, the riparian zones along the Sugut River have become highly fragmented, with increasing signs of erosion, diminished vegetation cover, and the loss of native plant communities. This degradation threatens not only local biodiversity but also the ecosystem services on which communities depend.

We expected closed-canopy forest reaches to score higher on QBRs, reflecting greater total riparian cover, more complex vegetation structure, higher native-species dominance, and fewer channel alterations, while oil-palm-adjacent and shrub-dominated stretch would score lower due to reduced canopy continuity, bank modification, and the presence of disturbance-tolerant or invasive plants. Because land use changes along the longitudinal gradient, we also anticipated lower median scores in the middle and lower catchments than in headwaters. (H1) QBRs is highest in closed-canopy forest reaches and lowest in oil-palm-adjacent/shrub stretch; (H2) forest reaches have greater total cover and structural complexity and fewer channel alterations than non-forest stretch; (H3) median QBRs declines from upper to lower catchment.

Despite their importance, riparian zones in Sabah are under-studied. Field studies in Sabah's oil palm plantations have shown that the removal of riparian vegetation contributes to increased stream temperatures, reduced water quality, and declining aquatic biodiversity (Chellaiah and Yule 2018a; Rojas-Castillo et al. 2023). Yet Sabah lacks a standardized, field-validated riparian index calibrated to local flora and channel forms, and no basin-scale assessment has benchmarked riparian condition across the Sugut catchment or tested differences among dominant land-use types using a tropical adaptation of QBR. Our objectives were to: (i) adapt the QBR index for Sabah (QBRs); (ii) map riparian habitat condition along approximately 245 km stretch of the Sugut River; (iii) evaluate variation among land-use types; (iv) identify priority or segments of the river for restoration.

To address this gap, this study applies the QBRs Index (Qualitat del Bosc de Ribera-Sabah adaptation), a rapid assessment tool designed to evaluate riparian habitat quality particularly on with scoring based on four components: total riparian cover, vegetation structure, cover quality, and channel alterations. The original QBR Index was developed in Spain for Mediterranean rivers (Munné et al. 2003) and later adapted for mountainous ecosystems in Argentina (QBRy). Globally, QBR and its variants have been widely applied in Mediterranean and other temperate rivers, with multiple regional adaptations in Europe and the Americas, whereas applications in humid tropical systems remain comparatively scarce, particularly in Southeast Asia, underscoring the novelty and regional value of a Sabah-specific adaptation.

Other tools such as the River Quality Index (RQI) have also been used globally, especially in temperate contexts. While the Riparian Quality Index (RQI) includes a broader set of physical and functional attributes such as longitudinal continuity, natural regeneration, and lateral connectivity (del Tánago and de Jalón 2011), it is more complex and less adapted to rapid assessments in remote or resource-limited settings. Recent studies have demonstrated that integrating indices like QBR with land use and morphological variables can provide robust evaluations of riparian condition (Duo et al. 2024).

This research thus fills a critical gap in riparian zone assessment in Sabah and extends QBR-based methodology to tropical ecosystems The study evaluated the condition of riparian zones in the upper, middle, and lower parts of the river using four indicators such as canopy cover, vegetation structure, cover quality, and channel alteration to classify habitat quality and find priority areas for restoration. The results provide a basin-scale baseline that enables evidence-based riparian management and conservation planning, helping authorities target restoration and safeguard the ecological health of this freshwater system.

MATERIALS AND METHODS

Study area

Figure 1 illustrates the Sugut River Basin in northeast Sabah, Malaysia, spanning about 334,635 hectares. The basin's land use is varied: 8% is within State Parks, and 37% is forest reserves of which 13% are Protection Forests, 22% are logging concessions, and small areas are mangroves and virgin jungle reserves. The remaining 55% is agricultural land, including 17% is oil palm plantations primarily managed by large corporations and 38% privately or communally owned, mostly cultivated by smallholders with oil palm, rubber, and paddy. The Sugut River is a crucial water source for these communities and the surrounding oil palm industries, serving both operational and domestic needs. The Sugut River Basin spans the Ranau district in its upper catchment and the Beluran district in the middle and lower catchment. The upper catchment predominantly features sandstone and mudstone soils, while the lower catchment include alluvium, supporting extensive oil palm plantations.

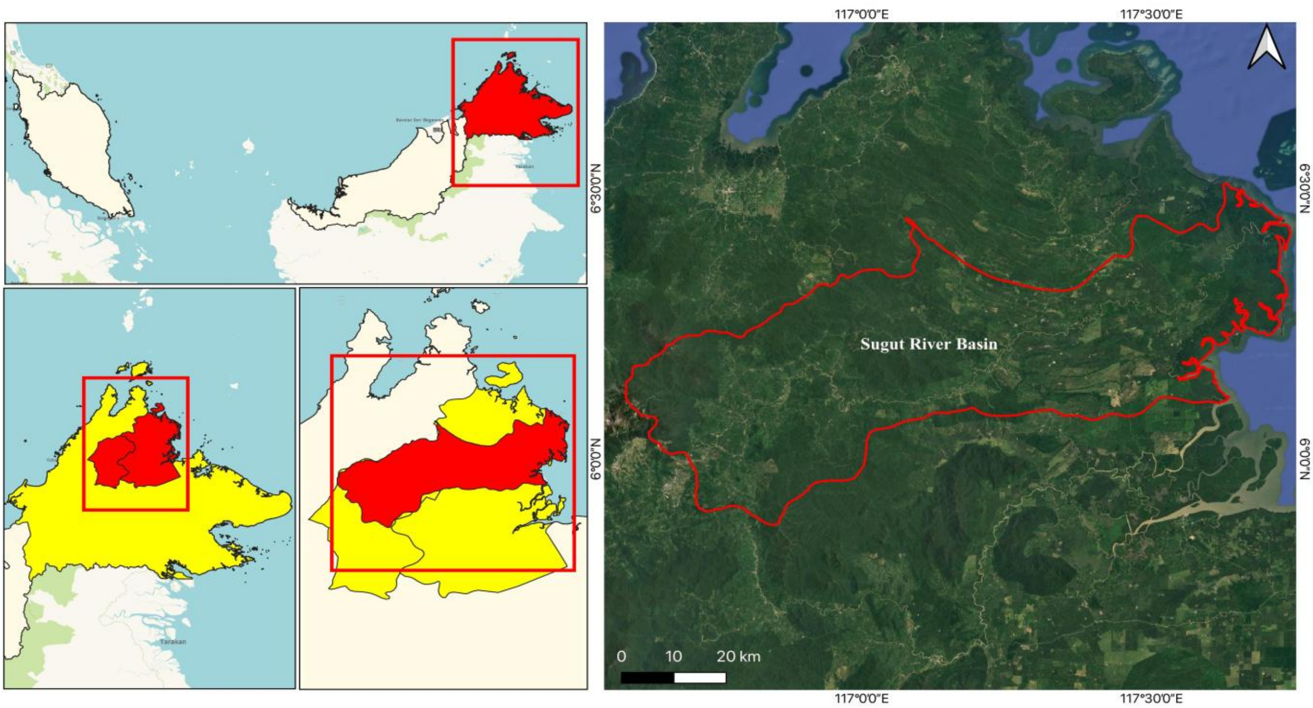

Figure 1. Map of study area in Sugut River Basin, Sabah, Malaysia

Key activities within the basin encompass shifting cultivation, oil palm and hill paddy farming, fruit and vegetable growing, fishing, gravity-flow water supply system, transportation, and palm oil milling. Water quality data from the Malaysia Environmental Quality Report (2019-2023) consistently rated the river's quality within class 1 to 2 (WQI: 91 to 93), indicating generally good conditions. However, studies by WWF-Malaysia have shown that the Lower Sugut River ranges from slightly to fully polluted, highlighting the need for further investigation into riparian zone effectiveness. These zones are critical natural filters that prevent surface runoff from contaminating watercourses.

Spatial planning exercises have been conducted to pinpoint areas of high biodiversity value, such as lowland forests and freshwater ecosystems, which are threatened by unsustainable development. The Sugut basin has been identified as a priority for conservation due to the significant human impact on its riparian habitats, which have deteriorated due to riverbank erosion, river channelization, mining, and diversions. These activities degrade the riparian zones' functionality, necessitating a thorough assessment of their health to guide restoration and management efforts.

Procedures

Field sampling design

The Sugut River was divided into three segments or sub-basins: upper, middle, and lower. As many 120 plots, each measuring 50 meters by 50 meters, were randomly selected within these sub-basins based on satellite imagery and accessibility considerations. The riparian assessment was conducted between January and February 2018. The plot size was chosen to align with Sabah's riparian legislation which is ranging from a minimum of 20 meters for private land and 30 meters in forest reserve while a study by Grebner et al. (2022) provide an overview that a typical riparian buffer ranging from 3 to 50 meters from ensuring that there will be adequate representation of vegetation types in all the plots. The Upper Sugut is accessible from Ranau Town via an unpaved road, the Middle Sugut is reached from Lingkabau via Jalan Sapi Nangoh, and the Lower Sugut is accessible from Beluran via Jalan Sungai-sungai. Four distinct plot types were identified at each assessment site: close canopy, semi-open canopy, shrub, and oil palm, each characterized by unique species composition and environmental conditions.

Modification of the QBRs Index for use in riparian vegetation in Sabah

The QBR Index (Qualitat del Bosc de Ribera), initially developed to assess the ecological quality of riparian forests in Mediterranean river systems in Spain (Munné et al. 2003), has demonstrated adaptability to various biogeographical contexts, including mountainous riparian ecosystems in Argentina (Fernández et al. 2016). In this study, the QBR Index was further adapted for application in the tropical environment of Sabah, Malaysian Borneo. The adaptation process incorporated regional ecological and floristic characteristics, resulting in the QBR-Sabah (QBRs) Index, a standardized and rapid field-based framework for assessing riparian site conditions, enabling cross-site comparisons and informing ecological restoration strategies.

As a diagnostic tool, the QBRs Index emphasizes both structural and ecological integrity of riparian zones. Preliminary field testing in the Kiulu-Tamparuli region of western Sabah informed the contextual modifications, assessing the method's applicability to tropical settings. Key indicators evaluated during pilot trials included canopy cover, vegetation stratification, and anthropogenic disturbance. The original QBR framework comprises four principal components: (i) total riparian vegetation cover; (ii) vegetation structure; (iii) vegetation quality; (iv) channel alteration (Munné et al. 2003). For use in Sabah's tropical forests, several key modifications were implemented. These included the incorporation of tropical indicator species such as *Ficus racemosa*, *Pterospermum* spp., and *Kleinhovia hospita*, commonly linked to healthy riparian habitats in Southeast Asia (Chellaiah and Yule 2018a; Prasetyo and Ramadhan 2021). Invasive species, particularly *Chromolaena odorata*, were introduced as negative indicators due to their prevalence and ecological impact in disturbed sites (Deere et al. 2022).

Scoring thresholds were recalibrated to capture the structural complexity and floristic composition of Bornean riparian forests. Each of the four components contributes a maximum of 25 points, yielding a total score ranging from 0 to 100. The refined QBRs Index offers an ecologically grounded and practical approach for assessing riparian habitat quality in Southeast Asian tropical landscapes. Specifically: (i) total riparian vegetation cover assessed the continuity and completeness of canopy, shrub, and herbaceous layers within the 50×50 m^2 plot; (ii) vegetation structure evaluated vertical complexity, regeneration presence, and canopy layering; (iii) vegetation quality focused on species richness, dominance of native vs. exotic species, and indicators of disturbance or degradation; (iv) channel alteration documented physical modifications to the stream channel, including bank erosion, straightening, or artificial barriers.

Field assessments were conducted using standardized datasheets refined during the 'Kiulu-Tamparuli' pilot adaptation phase. All data collection was carried out by trained field personnel to maintain methodological consistency. For each 50×50 m plot, three independent scorings were performed and subsequently averaged to derive the final QBRs value.

Data analysis

The Shapiro-Wilk test assessed the normality of average QBRs Index scores across 40 plots, suitable for sample sizes under 50. This test uses a p-value to determine data distribution; a p-value greater than 0.05 indicates normal distribution, while a lower value suggests significant deviation. In this study, the data were not normally distributed for the upper Sugut (P: 0.003473), middle Sugut (P: 0.001012), and lower Sugut (P: 0.02284). Consequently, the non-parametric Kruskal-Wallis test was utilized to analyze QBRs Index scores across four land uses: close canopy, semi-open canopy, shrubs, and oil palm plantations. The test checks for significant differences in land use impacts, accepting the null hypothesis (no significant difference) if p>0.05. Additionally, ANOVA was conducted to further verify these findings, using R Studio 2022.12.0 Build 353 for all statistical analyses.

RESULTS AND DISCUSSION

Riparian habitat quality classification

A total of 120 riparian plots were evaluated using the QBRs Index across the upper, middle, and lower catchment of the Sugut River. During sampling, trained personnel assessed specific parameters within each category using standardized methods. This ensures data consistency and accuracy. After fieldwork, data was compiled and analyzed to determine the overall riparian quality at each site. The results of this analysis will guide management decisions and conservation strategies to improve or maintain riparian health.

QBR scores ranged from a minimum of 25 (severely degraded) to a maximum of 100 (natural condition). Only 3 plots (2%) were classified as in natural condition (≥95), 24 plots (17%) as good (75-90), 26 plots (20%) as fair (55-70), 57 plots (38%) as poor (30-50), and 10 plots (23%) as very poor (≤25).

Figure 2 below presents an integrated spatial map showing the location of the 120 sampling plots along the Sugut River, with embedded QBR scores and classifications color-coded by habitat quality. Their condition classified according to the QBR classification and differentiated by color codes. The full numerical dataset is provided in the Table 1.

Distribution by land use and segment

Figure 3 shows that higher QBR scores were concentrated in the upper Sugut segment, where closed-canopy riparian forest was relatively intact. In contrast, plots in the middle and lower catchment, especially those adjacent to oil palm plantations and disturbed shrubland, were dominated by lower scores (≤50). The upper Sugut had mean QBR of 73.5±12.4, followed by middle Sugut with 54.7±11.6, and the lower Sugut had the lowest with 45.3±10.8. Closed canopy sites had the highest mean QBR score (77.83), followed by semi-open canopy (62.4), shrubs (51.2), and oil palm plot (25.0).

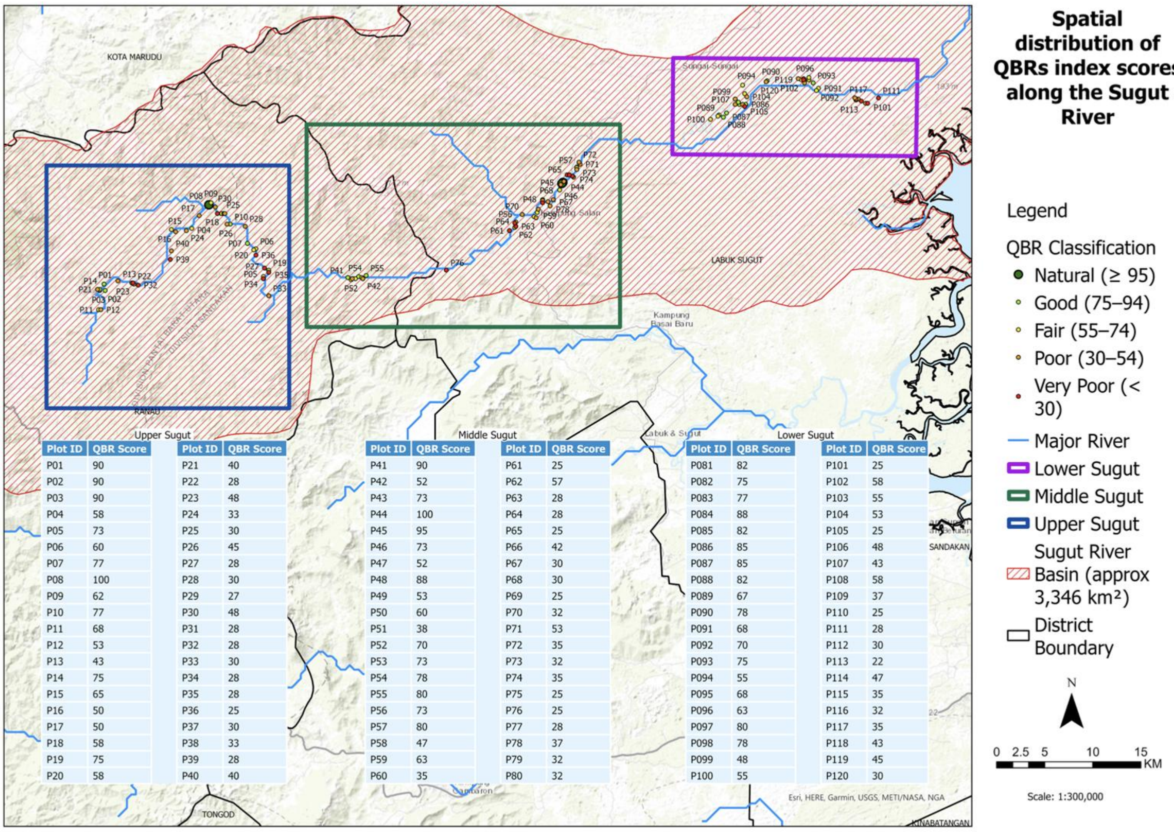

Figure 2. Classification of sampling points (n: 120) in Sugut River Basin, Malaysia, based on the QBR (Qualitat del Bosc de Ribera) Index

Table 1. QBR classification in Sugut River Basin, Sabah, Malaysia

Plot ID	Latitude (°N)	Longitude (°E)	River segment	Vegetation cover	QBR score	Classification
P01	6.100	116.814	Upper Sugut	Close canopy	90	Good (75-94)
P02	6.094	116.815	Upper Sugut	Close canopy	90	Good (75-94)
P03	6.094	116.81	Upper Sugut	Close canopy	90	Good (75-94)
P04	6.152	116.896	Upper Sugut	Close canopy	58	Fair (55-74)
P05	6.107	116.963	Upper Sugut	Close canopy	73	Fair (55-74)
P06	6.133	116.956	Upper Sugut	Close canopy	60	Fair (55-74)
P07	6.138	116.948	Upper Sugut	Close canopy	77	Good (75-94)
P08	6.174	116.912	Upper Sugut	Close canopy	100	Natural (≥95)
P09	6.176	116.914	Upper Sugut	Close canopy	62	Fair (55-74)
P10	6.156	116.932	Upper Sugut	Close canopy	77	Good (75-94)
P11	6.076	116.809	Upper Sugut	Semi-open canopy	68	Fair (55-74)
P12	6.076	116.811	Upper Sugut	Semi-open canopy	53	Poor (30-54)
P13	6.101	116.84	Upper Sugut	Semi-open canopy	43	Poor (30-54)
P14	6.095	116.81	Upper Sugut	Semi-open canopy	75	Good (75-94)
P15	6.151	116.877	Upper Sugut	Semi-open canopy	65	Fair (55-74)
P16	6.149	116.881	Upper Sugut	Semi-open canopy	50	Poor (30-54)
P17	6.164	116.903	Upper Sugut	Semi-open canopy	50	Poor (30-54)
P18	6.166	116.924	Upper Sugut	Semi-open canopy	58	Fair (55-74)
P19	6.113	116.968	Upper Sugut	Semi-open canopy	75	Good (75-94)
P20	6.132	116.954	Upper Sugut	Semi-open canopy	58	Fair (55-74)
P21	6.095	116.808	Upper Sugut	Shrubs	40	Poor (30-54)
P22	6.101	116.841	Upper Sugut	Shrubs	28	Very Poor (<30)
P23	6.100	116.842	Upper Sugut	Shrubs	48	Poor (30-54)
P24	6.150	116.891	Upper Sugut	Shrubs	33	Poor (30-54)
P25	6.166	116.926	Upper Sugut	Shrubs	30	Poor (30-54)
P26	6.156	116.929	Upper Sugut	Shrubs	45	Poor (30-54)
P27	6.115	116.964	Upper Sugut	Shrubs	28	Very Poor (<30)
P28	6.154	116.946	Upper Sugut	Shrubs	30	Poor (30-54)
P29	6.166	116.92	Upper Sugut	Shrubs	27	Very Poor (<30)
P30	6.172	116.918	Upper Sugut	Shrubs	48	Poor (30-54)
P31	6.101	116.841	Upper Sugut	Oil palm	28	Very Poor (<30)
P32	6.099	116.846	Upper Sugut	Oil palm	28	Very Poor (<30)
P33	6.089	116.968	Upper Sugut	Oil palm	30	Poor (30-54)
P34	6.105	116.963	Upper Sugut	Oil palm	28	Very Poor (<30)
P35	6.111	116.968	Upper Sugut	Oil palm	28	Very Poor (<30)
P36	6.127	116.956	Upper Sugut	Oil palm	25	Very Poor (<30)
P37	6.166	116.927	Upper Sugut	Oil palm	30	Poor (30-54)
P38	6.103	116.827	Upper Sugut	Oil palm	33	Poor (30-54)
P39	6.123	116.876	Upper Sugut	Oil palm	28	Very Poor (<30)
P40	6.131	116.877	Upper Sugut	Oil palm	40	Poor (30-54)
P41	6.106	117.042	Middle Sugut	Close canopy	90	Good (75-94)
P42	6.105	117.056	Middle Sugut	Close canopy	52	Poor (30-54)
P43	6.106	117.055	Middle Sugut	Close canopy	73	Fair (55-74)
P44	6.195	117.243	Middle Sugut	Close canopy	100	Natural (≥95)
P45	6.194	117.242	Middle Sugut	Close canopy	95	Natural (≥95)
P46	6.188	117.24	Middle Sugut	Close canopy	73	Fair (55-74)
P47	6.173	117.233	Middle Sugut	Close canopy	52	Poor (30-54)
P48	6.177	117.224	Middle Sugut	Close canopy	88	Good (75-94)
P49	6.170	117.22	Middle Sugut	Close canopy	53	Poor (30-54)
P50	6.163	117.216	Middle Sugut	Close canopy	60	Fair (55-74)
P51	6.105	117.046	Middle Sugut	Semi-open canopy	38	Poor (30-54)
P52	6.104	117.045	Middle Sugut	Semi-open canopy	70	Fair (55-74)
P53	6.105	117.049	Middle Sugut	Semi-open canopy	73	Fair (55-74)
P54	6.107	117.052	Middle Sugut	Semi-open canopy	78	Good (75-94)
P55	6.108	117.059	Middle Sugut	Semi-open canopy	80	Good (75-94)
P56	6.158	117.199	Middle Sugut	Semi-open canopy	73	Fair (55-74)
P57	6.209	117.256	Middle Sugut	Semi-open canopy	80	Good (75-94)
P58	6.193	117.241	Middle Sugut	Semi-open canopy	47	Poor (30-54)
P59	6.167	117.219	Middle Sugut	Semi-open canopy	63	Fair (55-74)
P60	6.162	117.218	Middle Sugut	Semi-open canopy	35	Poor (30-54)
P61	6.150	117.193	Middle Sugut	Shrubs	25	Very Poor (<30)
P62	6.153	117.198	Middle Sugut	Shrubs	57	Fair (55-74)
P63	6.154	117.199	Middle Sugut	Shrubs	28	Very Poor (< 30)

P64	6.157	117.198	Middle Sugut	Shrubs	28	Very Poor (< 30)
P65	6.202	117.247	Middle Sugut	Shrubs	25	Very Poor (< 30)
P66	6.196	117.244	Middle Sugut	Shrubs	42	Poor (30-54)
P67	6.179	117.234	Middle Sugut	Shrubs	30	Poor (30-54)
P68	6.179	117.224	Middle Sugut	Shrubs	30	Poor (30-54)
P69	6.176	117.224	Middle Sugut	Shrubs	25	Very Poor (< 30)
P70	6.165	117.205	Middle Sugut	Shrubs	32	Poor (30-54)
P71	6.212	117.259	Middle Sugut	Oil palm	53	Poor (30-54)
P72	6.214	117.258	Middle Sugut	Oil palm	35	Poor (30-54)
P73	6.207	117.256	Middle Sugut	Oil palm	32	Poor (30-54)
P74	6.200	117.253	Middle Sugut	Oil palm	35	Poor (30-54)
P75	6.201	117.252	Middle Sugut	Oil palm	25	Very Poor (< 30)
P76	6.113	117.134	Middle Sugut	Oil palm	25	Very Poor (< 30)
P77	6.202	117.249	Middle Sugut	Oil palm	28	Very Poor (< 30)
P78	6.173	117.231	Middle Sugut	Oil palm	37	Poor (30-54)
P79	6.177	117.229	Middle Sugut	Oil palm	32	Poor (30-54)
P80	6.178	117.224	Middle Sugut	Oil palm	32	Poor (30-54)
P081	6.272	117.523	Lower Sugut	Close canopy	82	Good (75-94)
P082	6.281	117.481	Lower Sugut	Close canopy	75	Good (75-94)
P083	6.291	117.479	Lower Sugut	Close canopy	77	Good (75-94)
P084	6.296	117.471	Lower Sugut	Close canopy	88	Good (75-94)
P085	6.290	117.469	Lower Sugut	Close canopy	82	Good (75-94)
P086	6.268	117.414	Lower Sugut	Close canopy	85	Good (75-94)
P087	6.260	117.396	Lower Sugut	Close canopy	85	Good (75-94)
P088	6.256	117.393	Lower Sugut	Close canopy	82	Good (75-94)
P089	6.258	117.389	Lower Sugut	Close canopy	67	Fair (55-74)
P090	6.290	117.434	Lower Sugut	Close canopy	78	Good (75-94)
P091	6.283	117.482	Lower Sugut	Semi-open canopy	68	Fair (55-74)
P092	6.281	117.48	Lower Sugut	Semi-open canopy	70	Fair (55-74)
P093	6.288	117.477	Lower Sugut	Semi-open canopy	75	Good (75-94)
P094	6.286	117.411	Lower Sugut	Semi-open canopy	55	Fair (55-74)
P095	6.291	117.473	Lower Sugut	Semi-open canopy	68	Fair (55-74)
P096	6.293	117.473	Lower Sugut	Semi-open canopy	63	Fair (55-74)
P097	6.268	117.408	Lower Sugut	Semi-open canopy	80	Good (75-94)
P098	6.270	117.407	Lower Sugut	Semi-open canopy	78	Good (75-94)
P099	6.273	117.404	Lower Sugut	Semi-open canopy	48	Poor (30-54)
P100	6.254	117.381	Lower Sugut	Semi-open canopy	55	Fair (55-74)
P101	6.269	117.528	Lower Sugut	Shrubs	25	Very Poor (< 30)
P102	6.291	117.466	Lower Sugut	Shrubs	58	Fair (55-74)
P103	6.278	117.413	Lower Sugut	Shrubs	55	Fair (55-74)
P104	6.275	117.415	Lower Sugut	Shrubs	53	Poor (30-54)
P105	6.266	117.413	Lower Sugut	Shrubs	25	Very Poor (< 30)
P106	6.268	117.411	Lower Sugut	Shrubs	48	Poor (30-54)
P107	6.268	117.404	Lower Sugut	Shrubs	43	Poor (30-54)
P108	6.257	117.388	Lower Sugut	Shrubs	58	Fair (55-74)
P109	6.288	117.469	Lower Sugut	Shrubs	37	Poor (30-54)
P110	6.291	117.468	Lower Sugut	Shrubs	25	Very Poor (< 30)
P111	6.274	117.538	Lower Sugut	Oil palm	28	Very Poor (< 30)
P112	6.269	117.526	Lower Sugut	Oil palm	30	Poor (30-54)
P113	6.271	117.522	Lower Sugut	Oil palm	22	Very Poor (< 30)
P114	6.273	117.519	Lower Sugut	Oil palm	47	Poor (30-54)
P115	6.272	117.517	Lower Sugut	Oil palm	35	Poor (30-54)
P116	6.273	117.517	Lower Sugut	Oil palm	32	Poor (30-54)
P117	6.274	117.516	Lower Sugut	Oil palm	35	Poor (30-54)
P118	6.292	117.468	Lower Sugut	Oil palm	43	Poor (30-54)
P119	6.292	117.463	Lower Sugut	Oil palm	45	Poor (30-54)
P120	6.289	117.433	Lower Sugut	Oil palm	30	Poor (30-54)

The predominance of lower-quality classes indicates considerable human impacts, primarily due to agricultural and industrial activities, notably around oil palm plantations. These findings align closely with those of Prasetyo and Ramadhan (2021), who reported that human disturbances substantially affected the quality of riparian vegetation along the Amprong River in Indonesia. On the other hand, the findings from the Sugut River and Amprong River are similar, as areas with better vegetation or canopy cover exhibit limited connectivity beyond the riparian zone, particularly in highly disturbed areas such as agricultural lands. The scale of impact and type of human disturbance differ significantly between the two river basins and hence the final classification varies. This trend underscores the urgent need for conservation and restoration efforts. Riparian zones play vital roles in biodiversity, pollution filtration, and aquatic ecosystem protection. Without significant intervention, ecological degradation within the Sugut River basin is likely to worsen. The poor riparian quality observed across the Sugut River demands urgent and targeted environmental management. Restoration efforts should prioritize areas classified as "poor" and "very poor" by implementing buffer zones and promoting sustainable land-use practices to enhance riparian health. Ongoing monitoring and assessment are crucial to evaluate the effectiveness of these interventions and adjust management strategies accordingly.

QBRs Index total score

The QBR index scores for each plot were determined by averaging the assessments of three observers, minimizing bias and ensuring a more realistic representation. The average variance across observers was ±5. Figure 4 shows that most riparian zones along the Sugut River are in degraded condition: 20% Fair, 38% Poor, and 23% Very Poor. Only 17% are in Good condition, and 2% remain Natural. This indicates that over 80% of the riparian areas require restoration or management intervention.

Statistical analysis

An ANOVA was initially conducted to compare the QBR index scores among the four land-use types. The results showed no statistically significant differences among the groups ($F(3, 116)$: 1.593, p: 0.195). Post-hoc Tukey HSD tests further supported this finding. None of the pairwise comparisons between land-use groups showed significant differences at the 0.05 significance level, indicating that the observed variations in mean scores among the groups were likely due to chance.

Although the Shapiro-Wilk test indicated non-normality (W: 0.92458, p: 4.485e-06). We also conducted ANOVA to verify the robustness of results, as the method is generally tolerant to moderate deviations from normality under balanced designs and large sample sizes. The agreement between ANOVA and Kruskal-Wallis outcomes (both non-significant) (χ^2: 4.3144, df: 3, p: 0.2295). Strengthens confidence that the lack of statistical differences is robust to test choice. While oil palm sites had consistently low scores, high variability in the semi-open and shrub categories may have contributed to the non-significance.

Discussion

The application of the QBRs Index revealed considerable variation in riparian habitat quality along the Sugut River, with patterns closely linked to land use, vegetation structure, and disturbance levels. Riparian plots in the upper catchment, where closed-canopy forests are still relatively intact, consistently obtained high QBR scores and exhibited characteristics such as minimal erosion, dominance of native species, and complex vertical vegetation layering. These features are known to positively influence riparian ecosystem integrity and are consistent with findings from other ecological assessments (Munné et al. 2003; Gurnell et al. 2012). Comparable relationships between canopy structure and QBR have been reported, for example, tropical agricultural corridors in Indonesia where QBR classes tracked Normalized Difference Vegetation Index (NDVI)-derived canopy cover (Prasetyo and Ramadhan 2021), and in eastern India where QBR contributed to diagnosing riparian condition alongside other indices (Saha et al. 2020).

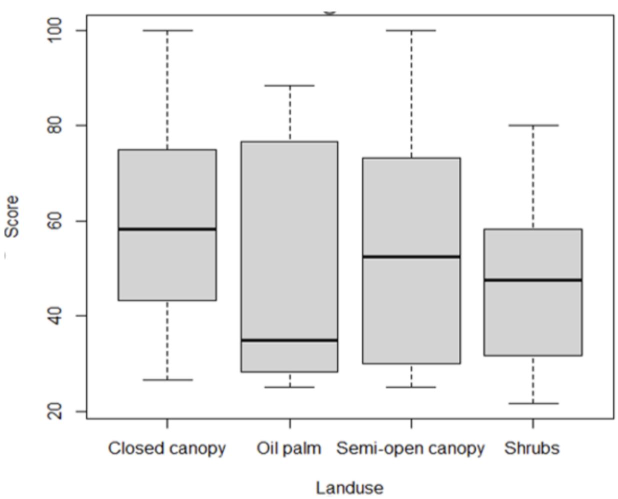

Figure 3. Distribution of QBR scores across four land-use types in the Sugut River Basin, Sabah, Malaysia. Closed canopy plots show the highest median scores, while oil palm sites consistently exhibit poor quality (≤30)

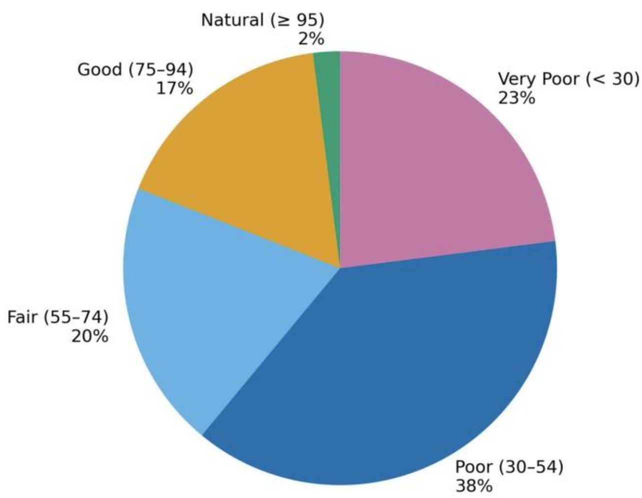

Figure 4. Proportion of riparian zones within each QBR classification along the Sugut River Basin, Sabah, Malaysia

In contrast, sites located in the middle and lower catchment of the river, particularly those adjacent to oil palm plantations or dominated by shrubs, were associated with poor or very poor QBR scores. Observations at these sites indicated substantial ecological degradation, including disrupted canopy continuity, reduced native tree cover, and physical bank modification. The presence of invasive species such as *C. odorata* was also prominent, further contributing to the decline in habitat quality. Similar degradation patterns have been documented in other tropical regions subjected to agricultural expansion and land conversion (Chellaiah and Yule 2018b; Prasetyo and Ramadhan 2021). From a management perspective, prioritization should center on areas with QBRs ≤50 in the lower and middle catchment, combining wider riparian buffers (≥30-50 m where feasible) with enrichment planting of native trees and invasive-species control. Evidence from oil-palm landscapes shows that biodiversity responses generally improve with buffer width and vegetation quality, with 40-100 m per bank supporting markedly higher richness than narrow statutory minima, irrespective of surrounding land-use category (Williamson et al. 2021; Deere et al. 2022).

Although a clear spatial trend was observed, the Kruskal-Wallis test did not detect statistically significant differences in QBR scores across different land use types. These results may reflect substantial heterogeneity within land-use classes, particularly in transitional areas such as semi-open vegetation zones and degraded shrublands. We interpret the non-significant global test as a likely Type II error driven by high within-class variance, spatial clustering (autocorrelation), and a strong longitudinal signal that cuts across land-use labels. To better resolve these patterns, future studies may require a larger sample size, finer land-use categorization, or stratification based on specific disturbance gradients. Because taxa respond non-linearly to riparian width and condition, pairing QBRs with biotic indicators (e.g., macroinvertebrates) and microclimate measurements can better detect management-relevant differences (Williamson et al. 2021; Deere et al. 2022).

The adaptation of the QBR framework, originally developed for Mediterranean ecosystems, to the tropical conditions of Borneo was largely successful. Key modifications were implemented to enhance ecological relevance, including the inclusion of tropical indicator species such as *F. racemosa* and *Pterospermum* spp., and *K. hospita*. Adjustments were also made to account for invasive plant species and to redefine scoring thresholds in accordance with the structural characteristics of tropical riparian forests. Despite these improvements, further refinements of the index are recommended. Additional variables, such as direct indicators of human disturbance or invasive vine cover, could improve the sensitivity of the index. Moreover, integrating complementary metrics such as water quality parameters or remote sensing indicators, including NDVI, could increase the diagnostic power of the tool for broader landscape-scale assessments (Gurnell et al. 2012; Lattuada et al. 2016). There were some limitations found in using the QBR/QBRs method. It mainly focuses on vegetation and river structure, which means it may overlook changes in water quality and animal life. The scoring system uses broad categories that can hide small differences. Scores can vary depending on who carries out the assessment and the season. Additionally, choosing where to measure and how to define the riverbank can be subjective. To reduce these problems, we suggest checking water quality and living organisms, and trying out GIS-based versions like QBR-GIS. These can help make mapping more consistent and allow for repeatable studies across the whole river basin (Segura-Méndez et al. 2023).

Only a small fraction of plots (2%) met the criteria for "natural" classification (QBR≥95), whereas more than half (61%) were classified within the poor or very poor categories. These results emphasize the ongoing and widespread degradation of riparian corridors along the Sugut River and therefore restoration efforts should prioritize the most affected areas in the middle and lower river catchment influenced by oil palm development. Management actions should focus on the re-establishment of native riparian tree species, the enforcement of buffer widths and the regulation of agrochemical application near waterways (Luke et al. 2019; Deere et al. 2022). In Sabah, the law requires riparian reserves of at least 20 meters on each side of rivers wider than 3 meters (State Government of Sabah 1998). To make the QBRs index more useful for planning and enforcement, we suggest linking its scores to specific actions: scores of 50 or below should trigger mandatory restoration and wider buffers beyond the legal minimum; scores between 55 and 70 should lead to enrichment planting and removal of invasive species; scores of 75 or higher should be protected and monitored by local communities.

In conclusion, QBRs captured a clear longitudinal gradient in the Sugut basin, with high scores in intact, closed-canopy headwaters and poor to very poor scores in shrub- and oil-palm-adjacent reaches, while the non-significant land-use test likely reflects within-class heterogeneity and a strong upstream to downstream signal. With only 2% of plots classified as “natural” and 61% as poor/very poor, management in Sabah should prioritize middle and lower reaches with QBRs ≤50 by widening riparian reserves beyond the legal 20 m minimum toward 30-50 m per bank where feasible, re-establishing native canopy and vertical structure, controlling invasive *C. odorata*, and tightening agrochemical setbacks. To embed QBRs in routine practice, link score classes to triggers (≤50: mandatory restoration and buffer widening; 55-70: enrichment planting and invasive control; ≥75: protection and community monitoring). For monitoring, pair QBRs with water-quality and biotic indicators, and use remote sensing (e.g., NDVI) and GIS to standardize basin-scale tracking and verify recovery through time.

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REFERENCES

Chellaiah D, Yule CM. 2018a. Effect of riparian management on stream morphometry and water quality in oil palm plantations in Borneo. Limnologica 69: 72-80. DOI: 10.1016/j.limno.2017.11.007.

Chellaiah D, Yule CM. 2018b. Riparian buffers mitigate impacts of oil palm plantations on aquatic macroinvertebrate community structure in tropical streams of Borneo. Ecol Indic 95: 53-62. DOI: 10.1016/j.ecolind.2018.07.025.

Deere NJ, Bicknell JE, Mitchell SL, Afendy A, Baking EL, Bernard H, Chung AYC, Ewers RM, Heroin H, Joseph N, Lewis OT, Luke SH, Milne S, Fikri AH, Parrett JM, Payne M, Rossiter SJ, Vairappan CS, Vian CV, Struebig MJ. 2022. Riparian buffers can help mitigate biodiversity declines in oil palm agriculture. Front Ecol Environ 20 (8): 459-466. DOI: 10.1002/fee.2473.

del Tánago MG, de Jalón DG. 2011. Riparian Quality Index (RQI): A methodology for characterising and assessing the environmental conditions of riparian zones. Limnetica 30 (2): 235-254. DOI: 10.23818/limn.30.18.

Duo L, Sánchez-Juny M, Bladé i Castellet E. 2024. Ecological environment assessment system in river-riparian areas based on a protocol for hydromorphological quality evaluation. Water 16 (21): 3025. DOI: 10.3390/w16213025.

Fernández RD, Ceballos SJ, González Achem AL, Fernández HR. 2016. Quality and conservation of riparian forest in a mountain subtropical basin of Argentina. Intl J Ecol 2016 (2): 4842165. DOI: 10.1155/2016/4842165

Grebner DL, Bettinger P, Siry JP, Boston K. 2022. Wildlife habitat relationships. In: Grebner DL, Bettinger P, Siry JP, Boston K (eds). Introduction to Forestry and Natural Resources. 2nd ed. Academic Press. pp. 131-152. DOI: 10.1016/B978-0-12-819002-9.00005-5.

Gurnell AM, Bertoldi W, Corenblit D. 2012. Riparian vegetation and hydrogeomorphology: Supporting sustainable river restoration. Ecohydrology 5 (3): 251-263. DOI: 10.1002/eco.214.

Lattuada M, Premoli AC, Longo MS. 2016. Riparian quality and vegetation structure assessed with QBR index in Argentinean Andean streams. Ecol Indic 61: 234-242. DOI: 10.1016/j.ecolind.2015.09.042.

Luke SH, Barclay H, Bidder HM, Turner EC. 2019. The effectiveness of riparian buffer zones in reducing the impacts of oil palm agriculture on biodiversity. Biol Conserv 233: 228-235. DOI: 10.1016/j.biocon.2019.02.019.

Malaysia Environmental Quality Report. 2023. Environmental Quality Report 2019-2023. Malaysia.

Munné A, Prat N, Solà C, Bonada N, Rieradevall M. 2003. A simple field method for assessing the ecological quality of riparian habitat in rivers and streams: QBR Index. Aquat Conserv 13 (2): 147-163. DOI: 10.1002/aqc.529.

Prasetyo HD, Ramadhan M. 2021. Quality profile of riparian zone and vegetation quality in Amprong River, Tumpang District based on QBR index and NDVI. Biotropika 9 (3): 229-236. DOI: 10.21776/ub.biotropika.2021.009.03.07.

Rojas-Castillo OA, Kepfer-Rojas S, Vargas N, Jacobsen D. 2023. Forest buffer-strips mitigate the negative impact of oil palm plantations on stream communities. Sci Total Environ 873: 162259. DOI: 10.1016/j.scitotenv.2023.162259.

Saha D, Banerjee A, Roy PK, Aditya G, Saha GK. 2020. Application of ecological and aesthetic parameters for riparian quality assessment of a small tropical river in eastern India. Ecol Indic 111: 105982. DOI: 10.1016/j.ecolind.2019.105982.

Segura-Méndez FJ, Pérez-Sánchez J, Senent-Aparicio J. 2023. Evaluating the riparian forest quality index (QBR) in the Luchena River by integrating remote sensing, machine learning and GIS techniques. Ecohydrol Hydrobiol 23 (3): 469-483. DOI: 10.1016/j.ecohyd.2023.04.002.

State Government of Sabah. 1998. Sabah Water Resources Enactment 1998 (No. 6 of 1998). State Legislative Assembly of Sabah, Kota Kinabalu, Malaysia.

Williamson J, Slade EM, Luke SH, Swinfield T, Chung AYC, Coomes DA, Heroin H, Jucker T, Lewis OT, Vairappan CS, Rossiter SJ, Struebig MJ. 2021. Riparian buffers act as microclimatic refugia in oil palm landscapes. J Appl Ecol 58 (2): 431-442. DOI: 10.1111/1365-2664.13784.

Zanuari AH, Abidin KZ, Mansor MS, Wan HY, Syed Abdullah SNA, Abdul-Patah P, Nor SM. 2024. Identifying priority corridors and bottlenecks for three threatened large mammal species in the oil palm-dominated landscape of Peninsular Malaysia. Glob Ecol Conserv 54: e03092. DOI: 10.1016/j.gecco.2024.e03092.