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Research Article

A sustainable approach for aquatic ecosystem enrichment: Assessing bamboo-based artificial habitats for prawn community enhancement in the Petagas River

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Keywords

Prawn abundance,
Species diversity,
Bamboo structure,
Habitat restoration,
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Abstract

Artificial habitats, human-made structures designed to mimic natural habitats, have emerged as an integral approach in fisheries management to mitigate habitat degradation in aquatic ecosystems. This study evaluates the effectiveness of bamboo-based artificial habitat in enhancing prawn community abundance as part of the efforts to replenish and restore the prawn community in Petagas River. We assessed species richness, diversity, and distribution of prawn communities in areas with and without bamboo structures. A total of 111 individuals from five species—*Macrobrachium mammillodactylus*, *M. equidens*, *M. rosenbergii*, *Caridina gracilipes*, and *M. idae*—from two families were recorded. Phylogenetic analysis of the Cytochrome Oxidase I (COI) gene revealed two distinct clusters representing the genera *Macrobrachium* and *Caridina*, with bootstrap support ranging from 39% to 100%. *M. mammillodactylus* was the most dominant species (35%), followed by *M. equidens* (22%), *M. rosenbergii* (20%), *C. gracilipes* (19%), and *M. idae* (4%). Sites with bamboo structures exhibited higher prawn abundance and greater species diversity than control sites. The habitat complexity introduced by these structures provided various microhabitats, promoting species resilience and ecological stability. These findings underscore the potential of low-cost, nature-based solutions like bamboo structures to support aquatic biodiversity and prawn stock recovery. This study provides the first genetic and ecological assessment of bamboo artificial habitats in Sabah, offering valuable baseline data for future habitat-based restoration initiatives.

Article info

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Introduction

Habitat serves as a vital component of ecosystems, providing organisms with the necessary resources for survival—such as shelter, food, and breeding sites—that allow populations to thrive and interact within their environment (Lennox *et al.,* 2025). However, habitats across the globe face alterations in physical structure due to land use and human activities, loss of biodiversity and population extinction, fragmentation, pollution, and to a certain extent, natural habitat collapse which adversely impacts the ability of organisms to inhabit and thrive in the natural environment (Tilker *et al*., 2019; Banks-Leite *et al*., 2020; Mokany *et al*., 2020; Liu *et al*., 2024). These disruptions extend across all major ecosystems—marine, freshwater, and terrestrial—posing risks to both environmental health and the communities that depend on their services (Piczak *et al*., 2023; Zhuang *et al*., 2024; Zhao *et al*., 2025).

In recent years, implementing artificial habitats has become one of the commonly used management tools to address challenges associated with habitat for various groups of organisms (John, 2011; Lambrechts and Schatz, 2014; Cantonati *et al*., 2020). This strategy involves deploying human-made structures in degraded, disturbed, and modified environments to mimic natural habitats for animal populations (Watchorn *et al.,* 2022). Such structures are designed to restore ecological functions by offering shelter, feeding grounds, and breeding sites for animal populations (Cowan *et al*., 2021; Bishop *et al*., 2022; Gameiro *et al*., 2022).

In aquatic environments, artificial structures were initially used to enhance fisheries through simple local materials. Over time, they have evolved into widely adopted conservation tools in both freshwater and marine ecosystems (Watchorn *et al*., 2022). These structures help in the enhancement of habitat complexity, which increases the number and variety of ecological niches available in the ecosystem and subsequently influences species interactions, population dynamics, and ecosystem functioning (Cannizzo *et al*., 2020; Toledo *et al.,* 2020, Gameiro *et al*., 2022). For benthic organisms that depend on submerged surfaces for attachment and shelter, artificial habitats provide crucial refuge from predators and serve as spawning substrates (Hudatwi *et al*., 2021; Marchetti *et al*., 2024). These structures can lead to increased survival rates and potentially enhance recruitment success within the community (Kawamura *et al*., 2017; Song *et al*., 2022). By offering additional space and resources, artificial habitats also help reduce both interspecific and intraspecific competition, ultimately supporting greater species richness and abundance (Knoester *et al*., 2023). Moreover, the introduced artificial structures promote the colonization of algae and detritus, which are key food sources for many aquatic invertebrates, thus supporting the foraging needs of higher trophic levels, including prawns and fish.

In this study, an artificial habitat constructed from bamboo structures was deployed in the riverbed of the Petagas River, designed to mimic a natural habitat that would attract prawn communities. This approach aims to replenish the Petagas

River, offering comprehensive benefits that include increased harvest opportunities, ecosystem restoration, and providing food and a main income for the riverine community.

Materials and methods

Study sites and design

In this study, samples were obtained from three stations along the Petagas River (Fig. 1), spanning from the downstream to the upstream region (Table 1). The river is in the district of Penampang Sabah, flows through adjacent villages and empties into the South China Sea (Valentine Eboy and Lian, 2021).

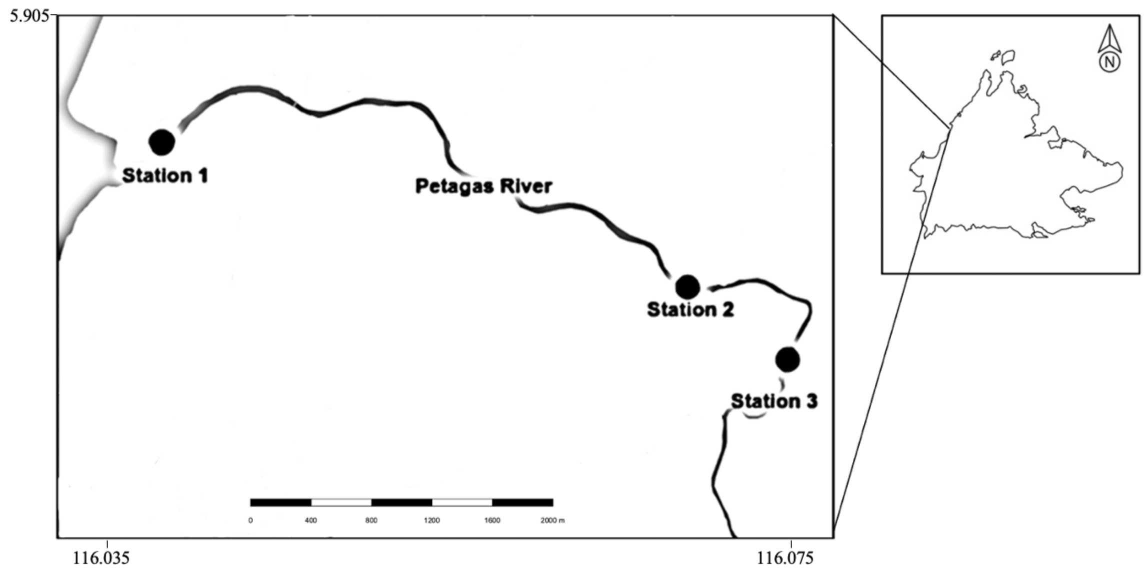

Figure 1: Map of Borneo showing the sampling sites at Petagas River, Sabah.

Table 1: Coordinate sampling stations in the Petagas River.

Station	GPS coordinate
1	N5° 54' 45" E116° 2' 38.148"
2	N5° 54' 36.648" E116° 4' 5.52"
3	N5° 54' 1.98" E116° 4' 50.448"

Bamboo collected from the near-stream riparian zone was stacked and tied together (approximately 0.5m × 0.5m) before being deployed in the river at three sampling stations. The structure was submerged for approximately 3 weeks before prawn sampling for the formation of biofilm and algal production, creating a suitable habitat and potential food source for prawn colonization. Nearby locations, 5 meters apart, without bamboo structures, were designated as the control. Prawn samples were collected quarterly for one year in April 2022, June 2022, September 2022, January 2023, and April 2023. Prawns were captured using prawn traps, which were deployed in the morning and left overnight before being retrieved. In each sampling station, two prawn traps (bubu traps) were used, with one placed in the control area and the other in the treatment area, each measuring 90 cm in diameter and 40 cm in height, with a 5 cm entrance funnel diameter, 0.2 cm nylon mesh size, and baited with 50 g of shrimp paste to attract prawns. Environmental parameters, including water depth, temperature, salinity, dissolved oxygen, turbidity, and pH were measured at each sampling station using the YSI Professional Plus (Pro Plus) Multi-parameter instrument (Brannum Lane, USA). Each station was sampled only once per sampling period.

Species identification and biodiversity assessment

The collected prawn samples were sorted, counted, and identified based on their morphological characteristics and stations. Taxonomic keys for species identification were referenced from Wowor and Choy (2001), Cai *et al*. (2007), and Munasinghe and Thushari (2010) upon confirmation.

Further confirmation of the collected prawn species was conducted using genetic analyses. The genomic DNA of the captured prawns was extracted using Wizard ® Genomic DNA Purification Kit (Promega, Corporation, Madison, WI). Cytochrome Oxidase I (COI) gene with a length of 600-700 bp was amplified using primers LCO1490 (5'-GGTCAACAAATCATAAAGATATTGG-3') and HC02198 (5'-TAAACTTCAGGGTGACCAAAAAATCA-3'). The 25µL reaction volume consisted of 12.5µL Vivantis master mix, 8µL distilled water, 1.5µL of each primer, and 1.5µL DNA template. The thermal cycle was performed using Applied Biosystem Veriti Thermal Cycler as follows: initial denaturation for 5 minutes at 94°C, followed by 35 cycles of 30 seconds at 94°C, 30 seconds at 50°C and 60 seconds at 72°C for extension, with a final extension of 10 minutes at 72°C. The PCR products were verified using agarose gel electrophoresis (1.7% agarose). Successful PCR products were purified and sequenced using ABI PRISM 3730xl Genetic Analyzer (Applied Biosystem, USA).

Statistical analyses

The obtained DNA sequences were aligned and edited using the ClustalW program in MEGA 11.0 (Tamura *et al.,* 2021). The COI sequence was deposited in the Barcode of Life Data System (BOLD) database and submitted to GenBank. Genetic distances and phylogenetic tree were constructed based on the Kimura Two Parameter (K2P) distance and Maximum Likelihood model with 1000 bootstrap replicates.

The diversity, richness, and evenness indices at each sampling site were analyzed by implementing Shannon-Wiener's Diversity Index (H') (1), Margalef's Species Richness Index (D') (2) and Pielou's Evenness Index (J') (3), respectively, as follows:

1. Shannon Weiner index (H') formula;

$H = -\sum (pi) ln(pi)$

Where, H $\overset{S}{\underset{i=1}{=}}$ Shannon Diversity Index; Pi=Proportion of individuals belonging to the ith species, ln = Natural logarithm

2. Margalef's Species Richness Index (D') formula;

$D = S - 1/\ log\, N$

Where, D=Margalef's Species Richness Index; S=Total number of species observed; N=Total number of counts or individuals in the sample

3. Pielou's evenness index (J') formula;

$J' = H'/ln(S)$

Where, J'= Pielou's evenness index; H= Shannon Diversity Index; S= Total number of species

All data were analyzed using Excel and SPSS. To assess differences in prawn abundance between areas with and without bamboo structures, Mann–Whitney U test was conducted. All statistical analyses were performed using IBM SPSS Statistic version 31.0.0.0.

Results

In total, 111 individuals from 5 species (*Macrobrachium mammillodactylus Macrobrachium equidens*, *Macrobrachium rosenbergii*, *Caridina gracilipes*, and *Macrobrachium idea*) belonging to 2 families were recorded in this study.

Water quality parameters

Table 2 summarizes the mean and standard deviation for the observed water quality parameters. Statistical analysis indicates that the observed variations in these parameters among the three stations were statistically significant ($p<0.05$), except for water depth. Comparative analysis reveals that Station 1 recorded the highest mean values for temperature (29.24±1.60°C), salinity (30.59±1.59 ppt), and pH (7.48±0.48), while Station 3 had the lowest mean values for these parameters at 26.28±1.06°C, 0.05±0.05 ppt, 6.79±0.14, respectively. In contrast, Station 3 recorded the highest mean values for DO (6.97±0.71 mg/L), turbidity (60.09±12.71), and water depth (1.82±0.66 m) whereas Station 1 had the lowest mean values for these parameters at 5.62±0.31 mg/L, 18.76±5.41 NTU, and 1.22±0.27 m, respectively.

Table 2: Mean and standard deviation of water quality parameters recorded across three stations.

Parameter	Station 1 (Mean ± SD)	Station 2 (Mean ± SD)	Station 3 (Mean ± SD)
Temperature (°C)	29.24 ± 1.60	27.72 ± 1.50	26.28 ± 1.06
Salinity (ppt)	30.59 ± 1.59	1.68 ± 0.6	0.05 ± 0.05
Dissolved oxygen (mg/L)	5.62 ± 0.31	5.94 ± 0.81	6.97 ± 0.71
pH	7.48 ± 0.48	6.94 ± 0.45	6.79 ± 0.14
Turbidity (NTU)	18.76 ± 5.41	33.64 ± 3.70	60.09 ± 12.71
Water depth (m)	1.22 ± 0.27	1.7 ± 0.51	1.82 ± 0.66

When examining the relationship between prawn abundance and water quality parameters (Table 3), a positive correlation was observed between prawn abundance with temperature and salinity at all stations. In contrast, turbidity showed a negative correlation with prawn abundance at all three stations. At Station 2, prawn abundance decreased as DO, pH, and water depth increased, while Station 3 exhibited the opposite trend, with prawn abundance increasing as these parameters rose. The R-squared values for these relationships ranged from low to moderate.

Phylogenetic analyses

Figure 2 shows the phylogenetic tree constructed based on the 692 bp COI sequences obtained from the five prawn species found in the Petagas River. For this analysis, four to five individuals from each species were sequenced in the phylogenetic construction.

Table 3: Correlation between number of prawn and water quality parameters.

Parameters	Station 1		Station 2		Station 3	
	Coefficient	R^2 Value	Coefficient	R^2 Value	Coefficient	R^2 Value
Temperature (°C)	1.440	0.0398	6.6163	0.6142	0.9011	0.2484
Salinity (ppt)	1.5365	0.0451	18.32	0.7425	9.615	0.065
Dissolved oxygen (mg/L)	-10.361	0.434	16.424	0.193	0.1991	0.005
pH	-17.041	0.51	-20.199	0.5242	12.598	0.8206
Turbidity (NTU)	-1.670	0.6147	-1.829	0.2885	-0.110	0.5306
Water depth (m)	-30.417	0.5016	-6.7925	0.0762	2.326	0.6319

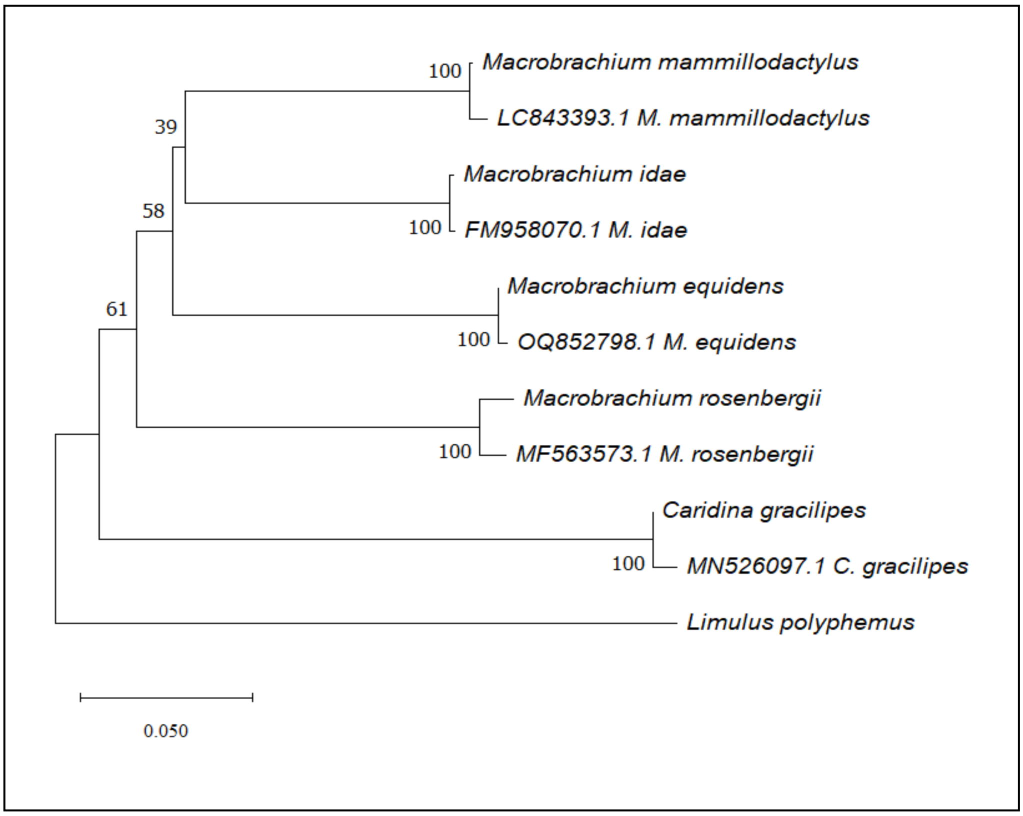

Figure 2: Molecular phylogenetic tree of prawn samples in the Petagas River based on cytochrome oxidase I (COI) sequences using the Neighbor-joining method with a bootstrap value of 1000.

To confirm species identification, COI sequences of each prawn species were retrieved from GenBank and compared with the sequences obtained in this study. Additionally, the COI sequence of *Limulus polyphemus* was retrieved from GenBank and used as the outgroup for phylogenetic analysis. This phylogenetic analysis confirmed the presence of prawn species and supported their accurate classification in the study. All sequences showed 99% to 100% identification similarity in the National Center for Biotechnology Information (NCBI) database. Of the 692 bp segment, 379 (54.77%) were conserved, 260 (37.57%) were variable, 214 (30.92%) were parsimony-informative, and 46 (6.65%) were singletons. For the mean nucleotide composition, the highest was Thymine (T)=29.27%, followed by Adenine (A)=27.27%, Cytosine (C)=25.17% and the least was Guanine (G)=18.28%. The pairwise distance analysis between the prawn species ranged from 0.1583 to 0.2806, with the lowest genetic distance observed between *M.*

mammillodactylus and *M. idae* while the highest genetic distance was found between *M.rosenbergii* and *C.gracilipes* (Table 4).

Table 4: Genetic distance analyses of the COI gene between the prawn samples in Petagas River.

	1	2	3	4	5
1. C. gracilipes					
2. M. mammillodactylus	0.2591				
3. M. equidens	0.2715	0.1843			
4. M. idae	0.2647	0.1583	0.1749		
5. M. rosenbergii	0.2806	0.2153	0.2122	0.1987	

Species composition and prawn abundance

Among the five species recorded in this study, *M.mammillodactylus* dominated with 39 individuals (35%), followed by *M.equidens* (22%) with 24 individuals, *M.rosenbergii* with 22 individuals (20%), *C.gracilipes* (19%) with 21 individuals, and *M. idae* with 5 individuals (4%) (Fig. 3).

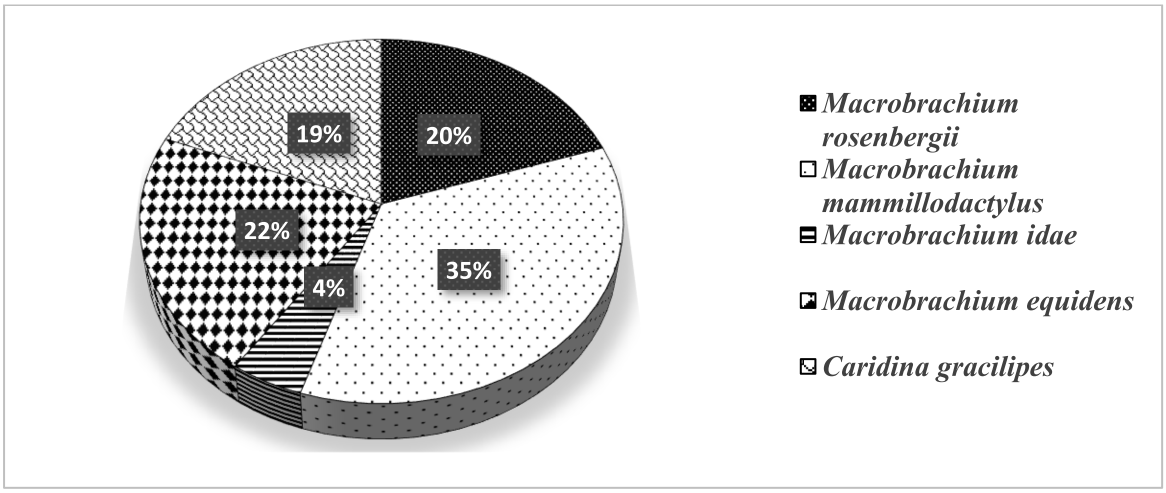

Figure 3: Percentage of prawn species caught in Petagas River.

The distribution of the five prawn species found is presented in Figure 4. With the addition of bamboo structure, the population of *M. equidens* was highest at Station 1. At Station 2, *C. gracilipes* was the most abundant species found, while at Station 3, *M. mammillodactylus* was the dominant species. Without the bamboo structure, *M. mammillodactylus* was the dominant species at Stations 2 and 3, whereas at Station 1, *M. rosenbergii* was the most abundant species.

A preliminary study conducted before the addition of the bamboo structure revealed that prawns were present only at Station 3, with a total count of five individuals. With bamboo addition, the data revealed that the highest abundance of prawns was observed at Station 2, with a total of 40 individuals, while Station 3 recorded the lowest number of prawns, with a total of 24 individuals (Fig. 5).

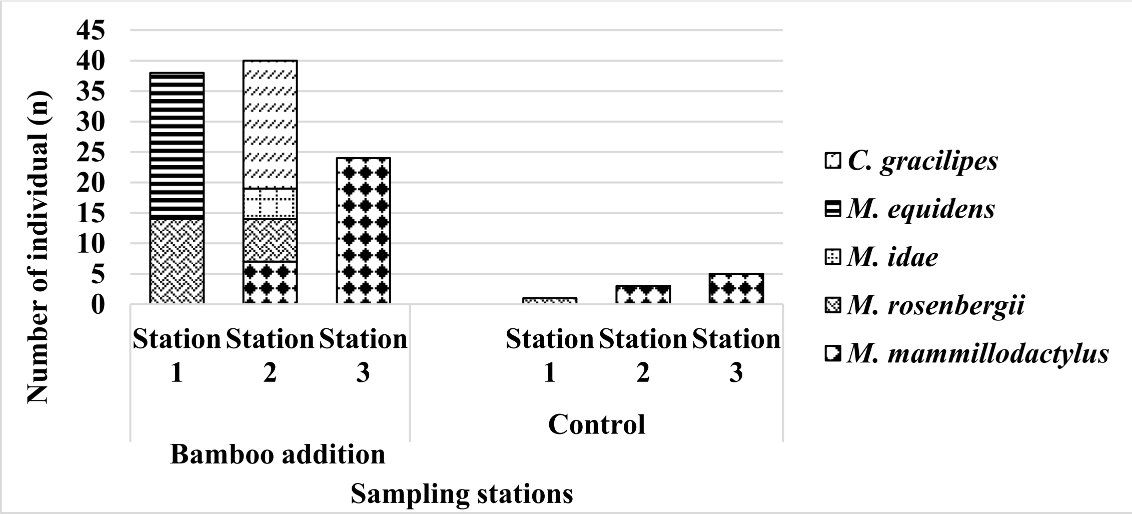

Figure 4: The composition of prawn species with and without (control) the addition of bamboo structure.

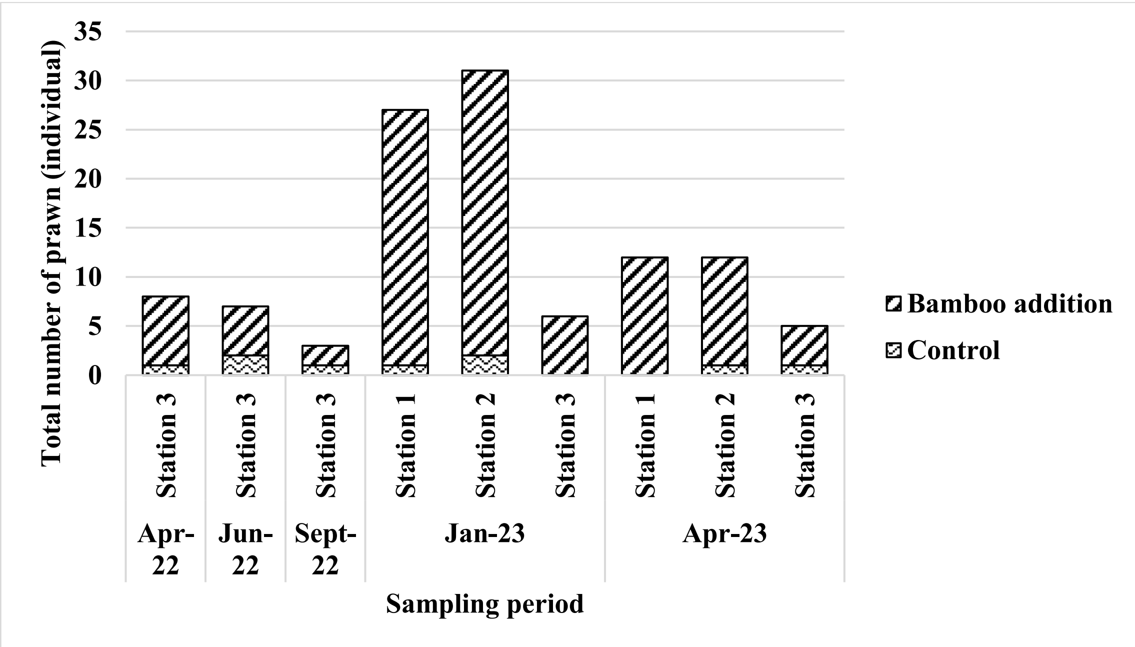

Figure 5. Total number of prawns caught at three stations from April 2022 to April 2023 in Petagas River.

The highest prawn count was recorded in January 2023, especially at stations 1 and 2. Meanwhile, Station 3 had the highest prawn count in the control group, with five individuals, whereas Station 1 recorded the lowest, with only one individual. When comparing the abundance of prawns between the bamboo addition and control groups at each station, Mann–Whitney U test shows no significant difference in prawn abundance at Station 1 (U=9.00, p=0.368) and Station 2 (U=10.50, p=0.638), while a significant difference was observed at Station 3 (U= 0.50, exact p=0.008), with higher prawn abundance recorded in the area with bamboo structures.

Species diversity, richness, and evenness indices

The values of species diversity, richness, and evenness indices for each of the three stations for the bamboo addition and control groups are shown in Table 5. At Station 2 of the treatment group, the species diversity was the highest, with an index value of 1.06 (H'). On the other hand, Station 3 has the lowest species diversity index value of 0 (H'). Station 2 also has the highest species richness index value, which was 2.05 (D') while the lowest index value was at Station 1 with a value of 0.275 (D'). For the evenness index, the highest value of 0.95 (J') was observed at Station 1, while the lowest value of 0.76 (J') was found at Station 2. As for the control group, only one species was found in all three stations, hence, the species diversity index value for all stations was 0 (H'). The richness and evenness indices were not calculated.

Table 5: Species diversity (H'), richness(D') and evenness indices (J') values for each station in the treatment and control group.

Station	Group	H'	D'	J'
1	Bamboo addition	0.658	0.275	0.95
	Control	0	-	-
2	Bamboo addition	1.06	2.05	0.76
	Control	0	-	-
3	Bamboo addition	0	-	-
	Control	0	-	-

Diversity indices were calculated for the entire survey period rather than for each individual sampling event to avoid limitations associated with small sample sizes.

Discussion

Petagas River, according to Saikim *et al.* (2023) is experiencing severe pollution due to the discharge of industrial effluents, domestic waste, sewage as well as erosion and sedimentation. These harmful pollutants can contribute to a decline in the water quality of the river (Giri, 2021; Anh *et al.*, 2023). In the present study, the higher salinity and pH level observed at Station 1, which was in the downstream area of the river, were likely due to saltwater intrusion or tidal influence (He *et al.*, 2018). Similarly, the highest temperature recorded at Station 1 could be attributed to factors such as stream flow, tidal dynamics, or channel morphology (Du *et al.*, 2020; Miller, 2021). Meanwhile, the highest turbidity level recorded was at Station 3. This might be due to the natural or human-induced erosion of the surrounding area, contributing to sedimentation and subsequent increase in water turbidity (Pollock *et al.,* 2014; Zhang *et al*., 2022).

In the present study, an increase in prawn abundance has been associated with the increasing temperature and salinity levels at all stations. Commonly, the preference for optimum temperature to move, grow and reproduce is species-specific (Bonacina *et al*., 2023). According to Sejian *et al.* (2018), organisms have developed adaptation mechanisms to cope with the fluctuation and variations in temperature for them to thrive and survive. The observed positive relationship between temperature and prawn abundance in this study was similar to those reported by Diop *et al.* (2007) in their study on white shrimp (*Litopenaeus setiferus*) harvest and temperature. Salinity, along with other water quality parameters, plays an important role that influences the abundance and distribution of many aquatic organisms (El-Damhogy *et al*., 2017). The effect of salinity, according to Velasco *et al*. (2019) can be direct, such as resulting in physiological changes, and indirect, leading to modification in community structure. Thus, many researchers use variation in salinity as a key environmental factor to investigate the distribution and abundance pattern of the targeted species populations. The findings of this study were consistent with those of study conducted by Maidin *et al*. (2017) at the same river, where they found that prawn abundance increased as salinity increased.

This study also observed that the increasing abundance of prawns was associated with the increasing levels of dissolved oxygen at Stations 2 and 3. Dissolved oxygen, a crucial factor affecting the survival and growth of prawns, influences various physiological processes which can potentially lead to mortality and hinder prawn development when the concentration is below the optimal range (Li and Zhang, 2019; Duan *et al.,* 2022). The dissolved oxygen levels at all stations were mostly found to deviate from the acceptable range of 5 mg/L as stated by Mokhtar *et al*. (1994). Lunt and Smee (2020) have stated that turbidity, along with other abiotic factors, significantly affects the habitat occurrence and community structure of fish and shrimp. High turbidity levels have been observed to have adverse effects on aquatic organisms including altered physiological function, reduced chances of survival, slowed growth rate, and decreased reproduction and recruitment (Kathyayani *et al*., 2019; Tigan *et al*., 2020). The present study aligns with the finding by Slathia *et al*. (2023) which demonstrates that high turbidity is associated with a decline in water quality, resulting in a reduction in prawn abundance.

A negative correlation was also found as prawn abundance decreased with the increasing pH values at Stations 1 and 2. The optimal range of pH for prawn populations varies depending on the species. A study conducted by Berezina (2001) on the influence of pH on freshwater invertebrates shows that species diversity decreases at pH below 4 and above 9, while the highest invertebrate diversity was at pH of 4.09 to 8.65. In general, deviations from the optimal range can have detrimental effects on the prawn population and according to Blewett *et al*. (2022), aquatic animals in extreme environmental conditions tend to migrate towards more favorable environments or habitats. In this study, the pH range deviate from the typical pH levels observed for most invertebrates (6.5-8.5).

Stations 1 and 2 also demonstrate a negative correlation between prawn abundance and water depth. Whereas, at Station 3, there was a positive correlation between prawn abundance and the increase in water depth. These findings suggest a difference in habitat preferences among different prawn species within the river system. In the present study, the prawn species at Stations 1 and 2 are likely to prefer a shallow-water habitat compared to the prawn communities at Station 3, which may favor a deep-water habitat.

The calculated R-squared values in this study were generally low, indicating a weak relationship between the variables. This highlights the need for further research to explore the detailed impact of water quality on prawn abundance and other factors that may influence the outcomes.

Using the mitochondrial COI gene as the genetic marker, the genetic identification of all prawn samples at the species level in this study was possible. In this study, the observed monophyletic clades formed by *M. mammillodactylus, M. idae, M. equidens* and *M. rosenbergii* indicated a close evolutionary relatedness among these species. Similarly, Samadan and Findra (2024) identified two genetically distinct clades within *Macrobrachium* from Gane Timur, Halmahera Island, Indonesia, while Pileggi and Mantelatto, (2010) reported that *Macrobrachium* species distributed across the Americas formed a distinct cluster. These findings support the hypothesis of the genus's monophyly. The bootstrap values obtained ranged from 39% to 61% showing a low to moderate support of the relationship among the prawn species. The relatively high proportion of conserved sites observed (54.77%) suggests that the sequences of different prawn species exhibit many regions that remained highly similar across evolutionary time, indicating a lower mutation rate in COI gene (Ismail *et al*., 2019; Chen *et al*., 2022). This is crucial to understand the evolutionary history and relationships across the animal tree of life (Kunal and Kumar, 2013; Pentinsaari *et al*., 2016). The nucleotide composition in COI sequence in this study was T (29.27%) >A (27.27%) >C (25.17%) >G (18.28%). This is contradicted by the finding by Yang *et al.* (2007) where the average contents of A, T, C and G were 30.7%, 28.9%, 21.2%, and 19.2%, (A>T>C>G), respectively, in their study on the genetic structure of the oriental river prawn (*Macrobrachium nipponense*) from the Yangtze and Lancang rivers.

The low genetic distance between *M. mammillodactylus* and *M. idae*, compared to other species pairs, indicates a close genetic relationship between the two within the *Macrobrachium* genus. This observation aligns with the findings by Makombu *et al*. (2019), who reported a similarly low genetic differentiation (Fst = −0.0105) between *Macrobrachium dux* and *Macrobrachium sollaudii*, both of which also belong to the *Macrobrachium* genus.

The prawn community composition recorded in this study aligns with previous findings in the Petagas River by Maidin *et al*. (2017). Their study identified four prawn genera, including *Macrobrachium* (*M.mammillodactylus, M.rosenbergii,* and *Macrobrachium* sp.) *Caridina* (*C.gracilipes* and *Caridina* sp.), Litopenaeus (*L. stylirostris*) and *Metapenaeus* (*M. ensis*).

M.mammillodactylus, which was the dominant prawn species found, has a higher abundance observed in the upstream region of the river. A preliminary study conducted in March 2022, prior to the introduction of the bamboo structure, revealed that *M.mammillodactylus* was the only species present. According to Short (2004), *M.mammillodactylus,* commonly known as knob-tooth prawn, was typically found on a lowland coast in shallow water, at depths ranging from 0.5m to 3.0m in freshwater area. This species migrates between freshwater and saltwater environments as part of its life cycle (Fuke and Maruyama, 2023). Due to the geographical condition of the Petagas River, which connects the sea to the freshwater areas, this river provides ideal conditions for *M. mammillodactylus* to thrive and support this population.

With the addition of bamboo structure, *M. equidens*, *C. gracilipes* and *M. mammillodactylus* were the most abundant species at Stations 1 (downstream), 2 (middle-stream) and 3 (upstream), respectively. The abundance of *M. equidens* at Station 1 was likely due to its preference for the middle and lower reaches of estuaries, mangroves, and areas rarely extending into freshwater (Ghory *et al*., 2022). Meanwhile, *C. gracilipes* and *M. mammillodactylus* are amphidromous freshwater prawn species that primarily inhabit freshwater environments (Han *et al*., 2011; Fuke and Maryama, 2023). The presence of these species in the bamboo-structured area implies their adaptability or attraction to the introduced structure. The bamboo structure might allow these species to thrive, enhancing their population and thereby potentially increase their abundance. According to Wehkamp and Fischer (2012), the addition of artificial habitat raises varying effects on the receiving population, with different species reacting differently to the alteration of their surroundings. Studies have shown that the addition of artificial structures can enhance species abundance. For instance, artificial reefs designed for lobsters supported 20 different species (Acarli and Kale, 2020), while marine species richness increased from 44 to 193 after one year and to 237 after two years following the deployment of artificial substrates (Nguyen *et al*., 2022).

Without the presence of the bamboo structures, *M. rosenbergii* became the dominant species at Station 1, whereas *M. mammillodactylus* dominated at Station 2 and 3. The distribution and dominance of these prawn species were influenced by the natural environmental condition of the river and reflected their ecological reference. Studies conducted by Slathia *et al*. (2023) and Dineshbabu *et al*. (2024) further supported this notion. Their studies indicate that the differences in environmental conditions observed in different regions influence the species composition and dominance patterns of the area.

During the early phase of bamboo structure implementation, prawns were consistent observed at Station 3 while no prawns were detected at Stations 1 and 2. Station 3, located upstream of the Petagas River, faces higher levels of sedimentation and erosion compared to Stations 1 and 2, due to active development in the surrounding area. This disturbance likely reduced the availability of natural habitats for prawns, such as submerged roots or vegetation, thereby limiting suitable shelter and breeding grounds. The sudden presence of prawns in the bamboo-enhanced area suggests that the artificial structures served as a functional substitute for these lost microhabitats. Folpp *et al*. (2020) found that artificial reefs significantly increased fish abundance in estuaries with limited natural habitats due to anthropogenic pressures. Similarly, our study indicates that the bamboo structures may have enhanced the local carrying capacity by providing refuge, shelter, and potentially, spawning sites for prawns in an otherwise disturbed area.

No prawns were observed at Stations 1 and 2 during the early implementation of the bamboo structure. However, in January 2023, a sudden increase was recorded. This delayed colonization, compared to the immediate response observed at Station 3, can be attributed to the existing presence of dense mangrove vegetation and natural structural complexity in Stations 1 and 2. Such natural features already provide suitable shelter, breeding grounds, and refuge for prawns, potentially reducing their immediate reliance on the introduced bamboo structures (Zalmon *et al*., 2002).

In both the treatment and control groups, the variation observed in prawn abundance throughout the sampling period does not show a constant increasing or decreasing trend. The data presented in this study revealed that the impact of the bamboo structure was the same across the three established stations. Areas with bamboo structure generally had a higher number of prawns compared to areas without bamboo structure. The bamboo structures in this study mimic the natural habitat elements such as submerged root systems or fallen branches, which are known to provide shelter, feeding surfaces, and breeding grounds for aquatic organisms (Nagelkerken *et al*., 2010; Arceo-Carranza *et al*., 2021). The increased surface area and habitat complexity introduced by the bamboo structures may have reduced interspecific competition by providing more niches and promoting a broader range of species interactions (Haque *et al*., 2024). Moreover, the introduced bamboo structures likely facilitated the development of biofilm and algal layers, creating a supplementary food source for prawns, which in turn encourages colonization. This study demonstrates that bamboo-based structures offer a cost-effective and biodegradable option for enhancing habitats in inland and transitional freshwater systems.

However, toward the end of the sampling period, a decline in prawn abundance was observed. This is primarily due to natural environmental factors, such as variations in water temperature, salinity, or dissolved oxygen levels, which can significantly influence prawn survival, growth, and distribution (De Lucena *et al*., 2020; Zeng *et al*, 2020). In addition to these environmental changes, the physical degradation of the bamboo structures caused by strong river currents, sediment load, and weathering may have reduced the availability and quality of shelter and breeding grounds. This shows a major weakness in using natural materials for long-term use in this study. This finding also highlights the importance of selecting materials and designs that can endure environmental pressures over time, particularly in dynamic riverine systems. To improve long-term habitat function, future studies might consider reinforcing bamboo or combining it with more durable materials to enhance structural stability and sustain ecological benefits.

The calculated species diversity, richness, and evenness indices were higher in the treatment group compared to those at control sites. A similar finding can be seen in a study conducted by Tuly *et al.* (2014) where they conclude that the presence of substrates as additional habitat features significantly enhances the population development of the *M. rosenbergii*. Their study demonstrated a notable increase in both growth and survival rates of the species.

Moreover, a preliminary study conducted before the introduction of the bamboo structure showed a diversity index value of 0. After the introduction of a bamboo structure as an artificial habitat, the diversity index value increased. However, this increase does not indicate a true rise in species diversity in the Petagas River, as the species composition remained the same. A similar finding was observed in a study by Yuan *et al*. (2022), where fish in the artificial reef increased from 27.27% to 50.00%, 51.22%, and 52.38%, before dropping to 37.84% over four tracking periods. Similarly, a comparative study by Wang *et al*. (2015) on fish assemblages near aquaculture, artificial, and natural habitats in the Ma'an Archipelago off the east coast of China revealed that artificial reefs showed significantly highest species richness, abundance, and diversity index compared to areas without artificial habitats. This study supports the hypothesis that the deployment of artificial structures can enhance local aquatic assemblages and alter community structure compared with natural habitats, primarily due to the formation of new aggregation sites (Zhou *et al*., 2018). The use of bamboo demonstrates a potential as an ecologically meaningful habitat enhancement tool.

Conclusion

Five species from the genus *Macrobrachium* and *Cardina* were discovered, with different species reacting differently to the deployment of the bamboo structure as their new habitat. As part of the ongoing efforts to replenish and restore the Petagas River, the effectiveness of the deployed artificial structure in enhancing prawn population was discovered by conducting a comparative analysis of prawn abundance between the treatment groups, with artificial habitat (bamboo structure), and the control groups. The findings indicate a clear difference in species richness, diversity, and distribution between the areas with and without the bamboo structure. Based on the outcome and limitations in this study, additional research is necessary to optimize the use of artificial habitats for enhancing prawn communities in river ecosystems. First, future studies should consider increasing the coverage of artificial habitats across a wider area to capture more robust data on prawn populations. Second, the construction of stronger and more resilient structures is important to ensure long-term durability, especially in dynamic riverine environments where damage from currents or sedimentation occurs. This may involve testing alternative materials or improving the current bamboo design to prevent structural degradation. These improvements would help enhance the ecological benefits of artificial habitats and ensure more consistent outcomes.

Conflicts of interest

The authors declare no conflict of interest.

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