

Exploring dynamics in larval fish diversity, assemblages, and abundance across four mangrove areas in Peninsular Malaysia

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Abstract. Azmir IA, Esa Y, Aqmal-Naser M, Yasin ISM, Amin SMN, Yusof FZM, Ahmad A. 2025. Exploring dynamics in larval fish diversity, assemblages, and abundance across four mangrove areas in Peninsular Malaysia. *Biodiversitas* 26: 1229-1237. Understanding larval fish populations is crucial for assessing the impact of habitat disturbances and ensuring consistent stock recruitment. However, challenges include extensive sampling requirements, time-consuming identification, and limited identification keys. This study aims to explore larval fish diversity, assemblages, and abundance in four mangrove areas across Peninsular Malaysia: Matang (Perak), Pekan (Pahang), Setiu (Terengganu), and Pendas (Johor). Sampling was conducted during the highest tide and full moon phases using a Bongo net (500 µm mesh size, 60 cm diameter) towed at 0.5 m depth, with a flow-meter to calculate the water volume filtered. Larval fish were identified to the nearest genus or species. Pendas exhibited the highest species diversity, richness, and evenness, whereas Setiu recorded the lowest. Species compositions varied across sites, with Gobiidae dominating in Pekan, Matang, and Pendas; Clupeidae in Pendas; and Engraulidae across all sites except Setiu. Community similarity was assessed, showing 20% similarity between Matang, Pekan, and Pendas, and 30% similarity between Matang and Pekan. All sites were dissimilar at a 40% similarity threshold. Pendas also hosted the highest number of unique species (n: 13), followed by Pekan (n: 6), Matang (n: 5), and Setiu (n: 3). Species overlap was noted, with Pendas sharing nine species with Pekan, five with Matang, and one with Setiu. These findings offer valuable insights for conservation efforts, emphasizing the importance of safeguarding larval fish populations and their habitats to support ecosystem health and fish recruitment. This study provides crucial data for decision-makers to implement targeted conservation strategies to preserve larval fish diversity and mitigate the effects of habitat disturbance.

Keywords: Fish recruitment, larval fish diversity, mangrove ecosystem, Peninsular Malaysia marine biodiversity, species assemblages

INTRODUCTION

Most marine fishes have larval and adult forms so distinct that at times in the past they were formally described as different species (Nurjirana et al. 2023). Adults are either sessile or roaming a localized home range associated with the seafloor, while larvae are capable of riding ocean currents and can settle either close to the spawning site or be dispersed great distances (Hixon et al. 2021; Hasan et al. 2023a). The larval fish is the early life period of a fish starting from the hatching of an egg until the transient larval characteristics develop such as pigment patterns, in some species, specialized head spines and fin structures form. In the very early stages, larvae migrate vertically following the general plankton migrations in the journey between finding food and hiding from predators (Hedberg et al. 2018; Hasan et al. 2023b). Larval fish migration always ends at the mangrove ecosystem as an optimal destination for larval fish to reside and settle as nursery grounds due to the nutrient-rich environment created by the decomposition of leaf litter, which serves as a valuable food source for their development (Ram et al. 2020; Nurjirana et al. 2022).

The migration of larval fish is not merely a biological phenomenon; it plays a crucial role in shaping the diversity, assemblages, and abundance of larval fish in the mangrove areas (Nurjirana et al. 2024). The migration event plays a pivotal role in influencing the recruitment and management of fish stocks (Huwet et al. 2016; Hedberg et al. 2018). Hence, surveillance of larval fish species composition and diversity provides useful information for management and conservation of marine ecosystems (Ndobe et al. 2022). It helps to determine adult fish population dynamics as well as their dispersal and settlement events, which are imperative in ensuring consistent stock recruitment (Azmir et al. 2019; Huang et al. 2022).

Fish population dynamics are typically studied at the adult stage, yet successful stock replenishment depends significantly on the early development of larval fish (Purnomo et al. 2020). Considering the microscopic size and low mobility of the larval fish, success in their movement and distribution is important as it guarantees their success in growing into the adult phase. However, this phase is highly influenced by environmental factors such as artificial light pollution (O'Connor et al. 2019), increased temperature

(Allan et al. 2015), ocean acidification (Sundin 2023), waterborne chemical pollutants (Taslim et al. 2022) and habitat disturbances (Wibowo et al. 2015). These factors eventually contribute to the disability of the larval fish to detect predators and avoid predation (Besson et al. 2020), whereby the larvae are susceptible to high mortality rates caused by predation (Jatmiko et al. 2018). These factors can also accelerate or delay reproductive processes and generate favorable or unfavorable conditions for egg and larval development, growth, and survival (Chhuoy et al. 2023).

High densities of larval fish are commonly found in low-velocity habitats such as backwaters, tributaries, and near-shore areas (Tucker et al. 2019), including seagrass beds and mangroves (Tarimo et al. 2022). Peninsular Malaysia is rich in these types of habitats where 99,180 ha of mangrove areas are distributed (Koh et al. 2018; Azmir et al. 2020) and about 78 seagrass beds are scattered in both East and West Malaysia (Ismail and Ling 2018). Larval fish studies in Peninsular Malaysia have been documented since the 90s (MCRST 1992), documenting 53 families of larval fish. The number of families caught varies among different surveys; 50 families (Termvidchakorn 1996), 46 families (Zulkifli et al. 2002), 19 families (Ooi and Chong 2011), 14 families (Arshad et al. 2012), 21 families (Azmir et al. 2019), to 7 families (Yeakub et al. 2021). There is growing concern about the declining trend of larval fish in Peninsular Malaysia; thus, we aimed to explore the dynamic in larval fish diversity, assemblages, and abundance across four study sites in Peninsular Malaysia. Two study sites, namely Pendas (Kamarulzaman and Jumain 2023) and Setiu

(Alkhadher et al. 2023) are exposed to anthropogenic activities including land reclamation, water pollution from automobile factories, and agricultural and recreational activities (Kamarulzaman and Jumain 2023), while the remaining study sites are in protected areas. Throughout time, the characteristics of an estuary are likely to vary, driven by natural variability, anthropogenic actions, and climate change, altering the natural functioning of the system. Therefore, larval fish monitoring is a valuable tool for assessing ecosystem changes (Rodrigues et al. 2022). By gathering datasets that encompass the composition, abundance, and diversity of larval fish assemblages, this study seeks to: (i) determine the composition of larval fish in four mangrove ecosystems in Peninsular Malaysia, and (ii) delineate larval fish communities and assemblages in the mangroves of Peninsular Malaysia.

MATERIALS AND METHODS

Study sites

Sampling was conducted in four mangrove localities along west coast of Peninsular Malaysia (Figure 1) in 2015. Pendas is located in the southern part of Peninsular Malaysia, while Pekan and Setiu are on the east coast, and Matang is on the west coast. The position of sampling sites and physical features are given in Table 1. The sampling sessions were done during the highest tide and full moon phase as the moon phase influences the distribution of larval fish species (Lima et al. 2016).

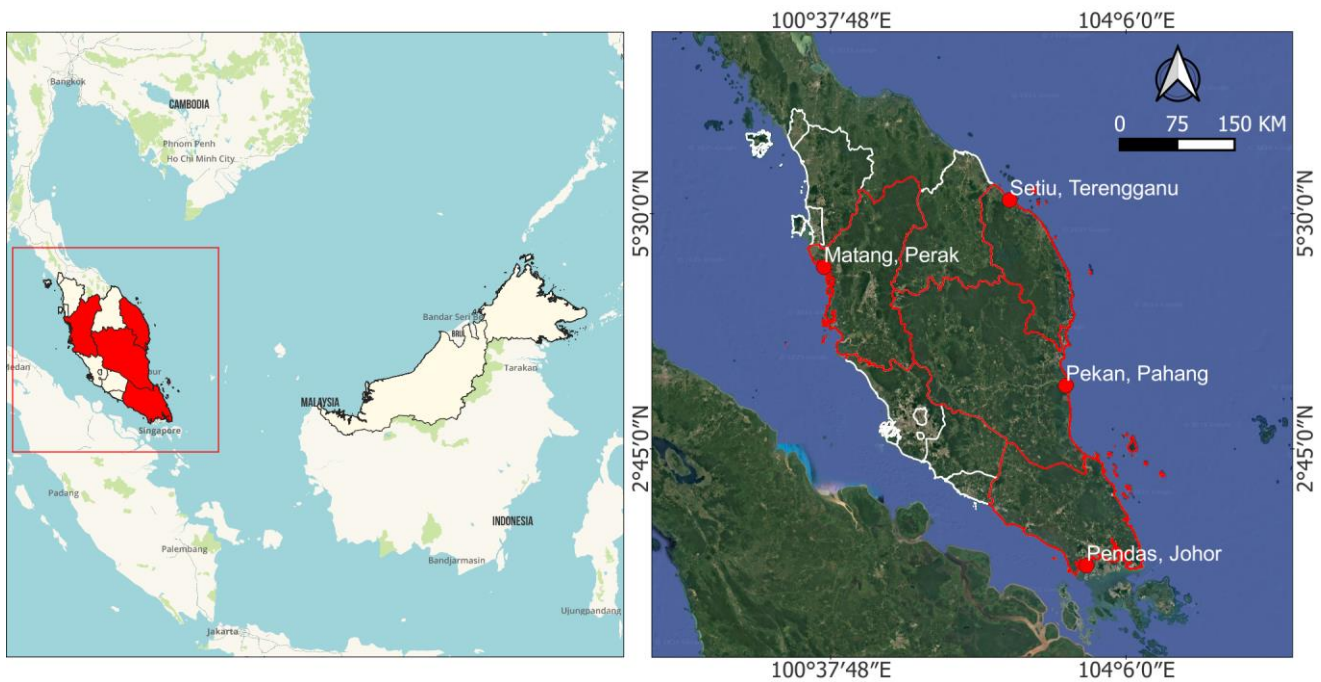


Figure 1. Sampling stations of larval fish from four selected mangrove areas at different states in Peninsular Malaysia denoted by the solid red circle

Table 1. Sampling sites at mangrove area in Peninsular Malaysia with its locality and habitat description

Station	Coordinates	Site description
Matang, Perak	4°N to 5°N, 100°2'E to 45°E	Mangrove forest intact. Depth \geq 8 m. Water: clear and greenish in colour. Flow velocity: Steady. (2540-3420 sm^3/s)
Pendas, Johor	1°23'0"N, 103°38'0"E	Minimal disturbance of mangrove forest due to road works. Depth \leq 8 m. Water: clear and bluish black in color. Flow velocity: Steady. (3250-4370 sm^3/s).
Pekan, Pahang	3°29'31.54"N, 103°23'22.36"E	Minimal amount of mangrove vegetation. Depth \leq 6 m. Water: Muddy and brown in color. Flow velocity: Medium tide with minimal wave. (1390-6250 sm^3/s).
Setiu, Terengganu	5°39'36"N, 102°43'48"E	Mangrove forest intact. Depth \leq 2 m. Water: Very clear and greenish in color. Abundant of fish farming activities. Flow velocity: Steady. (1490-2760 sm^3/s).

The Pendas mangrove is a fisherman village near Tanjung Kupang in Johor, Malaysia. There are ten mangrove forest reserves in South Johor (including Pendas Forest reserve), covering about 18,002.7 ha in 1986 (MCRST 1992). A few studies concentrating on fish larvae have been conducted in the seagrass, mangrove areas around this vicinity. Currently, rapid land reclamation is seen at the sampling sites. The Pekan mangrove is a coastal plain representing one of the largest coastal deposits in Malaysia (Hamzah et al. 2020). Pahang River is the longest river in Peninsular Malaysia which flows into the South China Sea through the Pekan Pahang estuary. This estuary area is prone to pollution by the waste from automobile factories and agricultural and recreational activities (Kamarulzaman and Jumain 2023). The Matang mangrove is located on the northwest coast of Peninsular Malaysia. Matang covers an extensive area of 40,288 hectares and is managed by the Forestry Department of Perak. It is the largest sustainably managed mangrove forest in Malaysia, having been under sustainable management for over 100 years, primarily for the purpose of charcoal production (Muhamad et al. 2019).

The Setiu mangrove is located in the Setiu Wetland that the Government of Terengganu has gazette as the first State Park in Terengganu in 2015. This sampling site is part of the Setiu River Basin and the larger Setiu-Chalok-Bari-Merang basin wetland complex that lies in Terengganu on Peninsular Malaysia's east coast. Extending to 23,000 ha, it comprises riparian forests lining the riverbanks, freshwater Melaleuca swamps, peat swamps, mangroves, brackish water lagoon with vegetated sand islands, seagrass beds and sandy beaches (WWF 2017). The total coverage of forest and swamp in Setiu have reduced greatly, either from being cleared for intensive aquaculture activities such as tilapia (Noor-Shahirah et al. 2018), oysters, and cockles (Mahmud et al. 2015) or reclaimed for settlements (Mohd-Salim et al. 2015).

Sample collection

Larval fish were collected using a Bongo net (500 μm mesh size; 60 cm diameter, 300 cm length) towed at 0.5 m depth from the surface with a flow meter attached at the net opening to assess the rate of water flow. One cycle of towing took 5 min at the speed of 2 knots, and this was performed in triplicate. The sampling was conducted in designated mangrove areas, covering a total of three plots, each encompassing 50 m^2 (Azmir et al. 2019). All samples were labeled and preserved in 95% ethanol.

Fish species identification

Individual larval fish were identified at the family level and if possible, at the genus level based on appropriate literature (Russell 1976; Okiyama 1988; Jeyaseelan 1998; Leis and Carson-Ewat 2000; Ghaffar et al. 2010). Morphological identifications were usually successful up to the family level and, for some individuals, up to the genus and species levels. All individuals were measured to the nearest 0.1 mm total length using digital calipers (no: 500-712-10) (Hussin et al. 2023), except for certain individuals lacking tailfins and having tightly coiled or folded body shapes. Voucher specimens were kept at the Aquatic Laboratory, Aquaculture Department, Faculty of Agriculture, Universiti Putra Malaysia, Serdang.

Data analysis

Chord diagram analysis was used to show the occurrence and connection of larval fish families among four sampling sites (<http://www.datasmith.org/>). Venn diagrams were established to display the shared species of larval fish between all four study sites (<https://bioinformatics.psb.ugent.be/webtools/Venn/>). Species accumulation curves for all four study sites were plotted into the abundance-based curve using Paleontological Statistics Software (PAST version 4.3) to determine completeness of sampling (Chao et al. 2020). The species accumulation curves then were further analyzed through the extrapolation of sampling curves via iNEXT online software (<https://chao.shinyapps.io/iNEXTOnline/>) following Chao et al. (2016).

Rank abundance curves were plotted to assess the pattern of species richness and species evenness (Qureshi et al. 2022). Then, the model for each curve was determined using visual inspection (Fisher et al. 1943) and Pearson's chi-squared test value (Matthews and Whittaker 2014). Six diversity indices were used to measure the diversity of larval fish in all four study sites using PAST software: Shannon (H) and Simpson (1-D) indices for species diversity, Margalef (R1) and Menhinick (R2) for species richness, and Equitability (EH) and Evenness (E) for species evenness. Six diversity indices were used to give a robust result (Aqmal-Naser et al. 2023).

Larval fish assemblages between four study sites were grouped according to their similarity, based on the abundance via the Bray-Curtis similarity index. A 2D non-multidimensional scaling (nMDS) was carried out to determine the separation between the fish assemblages in all sites using PRIMER6 software (<http://www.primere.com>).

The robustness of the nMDS analysis was measured according to the stress value where a stress value of >0.2 is considered poor, <0.1 is considered fair, and <0.05 is considered a good fit (Buttigieg and Ramette 2014).

RESULTS AND DISCUSSION

The chord diagram shows that Gobiidae have the largest species richness and common in Pekan, Matang, and Pendas's mangroves, Clupeidae are common in Pendas mangrove, and Engraulidae are common in all study sites except Setiu. Other families contribute almost similar species richness in the four study sites (Figures 2 and 3). The Venn diagram indicates that Pendas recorded the highest number of unique larval fish species (n: 13), followed by Pekan (n: 6), Matang (n: 5), and Setiu (n: 3). Interestingly, Matang and Setiu do not share similar larval fish species. Pendas and Pekan only share one larval fish species with Setiu. Meanwhile, all sites do not share any common larval fish species (Figure 4).

The species accumulation curves for all study sites show an increasing trend with no sign of reaching asymptote. Species richness increases with the increase of larval fish abundance (Figure 5). The extrapolation of species accumulation curves indicates three sites (Pendas, Pekan, and Matang) showing an early sign of reaching asymptote at 150 individuals (Pekan), 180 individuals (Pendas), and 300 individuals (Matang), but not for Setiu. The curve for Setiu

still increases rapidly after 50 individuals (Figure 6).

Based on the rank abundance curves, three study sites (Pendas, Pekan, and Matang) exhibit a log-normal distribution, where some species have high or low abundance, while others show intermediate abundance. In contrast, Setiu follows geometric distribution: one species is high in abundance while others have lower abundance (Figure 7). The diversity measurement indicates that Pendas have the highest species diversity, species richness, and species evenness compared to other study sites, while Setiu has the lowest species diversity, species richness, and species evenness (Table 2). Larval fish communities were grouped at 20% similarity between Matang, Pekan, and Pendas, 30% similarity between Pekan and Matang, and dissimilar at all locations at 40% similarity (Figure 8)

Table 2. Diversity measurement of larval fish in the study sites

Item	Sites			
	Pendas	Pekan	Matang	Setiu
Taxa	29	19	20	6
Individuals	94	78	153	29
Simpson	0.9249	0.88	0.823	0.3615
Shannon	2.955	2.443	2.21	0.8327
Menhinick	2.991	2.151	1.617	1.114
Margalef	6.163	4.132	3.777	1.485
Equitability	0.8775	0.8299	0.7378	0.4648
Evenness	0.6619	0.606	0.4558	0.3833

Note: Bold values represent the highest value, while italicized values represent the lowest value

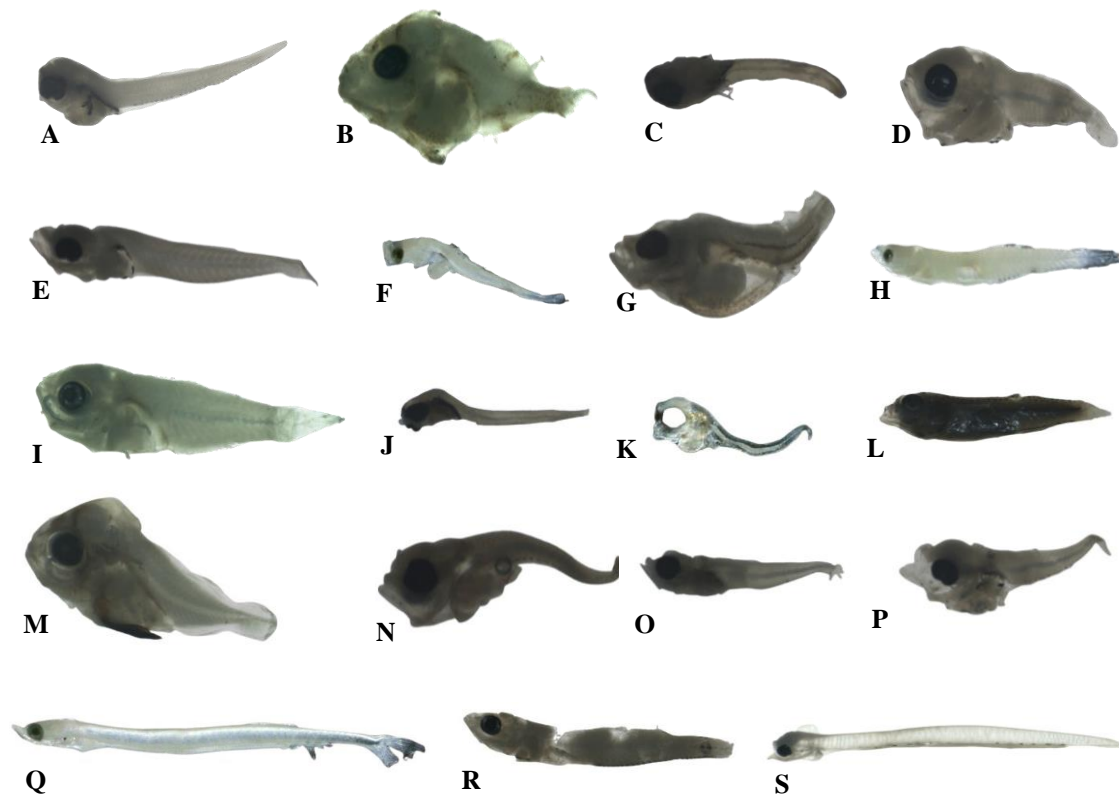


Figure 2. Larval fish families at four study sites in Peninsular Malaysia. A. Sparidae (0.8x12 mm); B. Monacanthidae (3x4.1 mm); C. Lutjanidae (1.5x2.5 mm); D. Leiognathidae (3x5 mm); E. Gerreidae (2x5 mm); F. Eleotridae (0.5x3 mm); G. Apogonidae (3x5 mm); H. Gobiidae (0.7x5 mm); I. Tetradontidae (1.5x5 mm); J. Blennidae (1.5x4 mm); K. Scianidae (2x4.5 mm); L. Mugilidae (1.7x11 mm); M. Scatophagidae (2x3.3 mm); N. Pomacentridae (3x7.5 mm); O. Mullidae (2.5x4 mm); P. Ambassidae (3x5 mm); Q. Engraulidae (0.5x10 mm); R. Sillaginidae (0.8x12 mm); S. Clupeidae (1.5x8 mm)

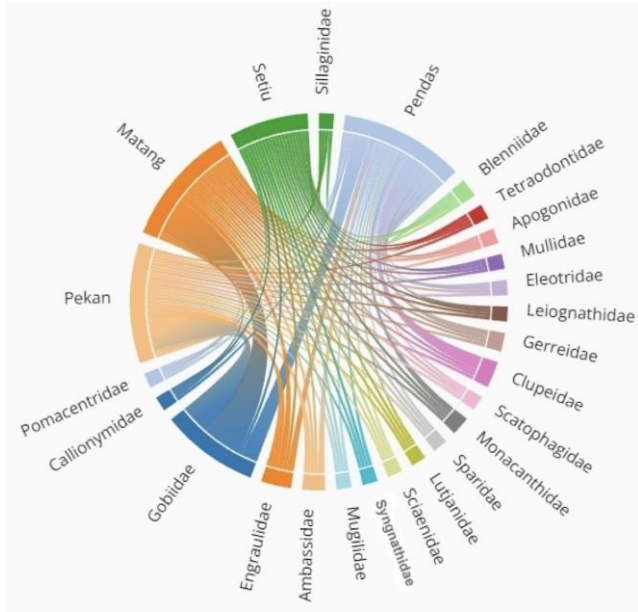


Figure 3. The occurrence of larval fish families at four study sites in Peninsular Malaysia

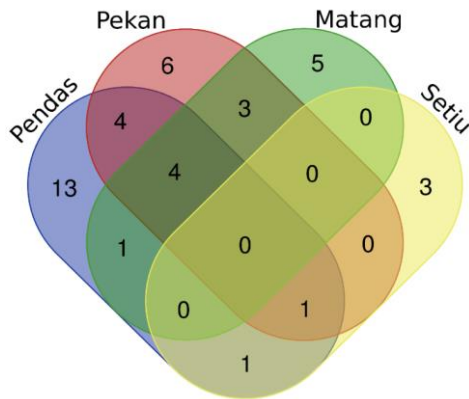


Figure 4. Venn diagram of shared species richness of larval fish at the study sites

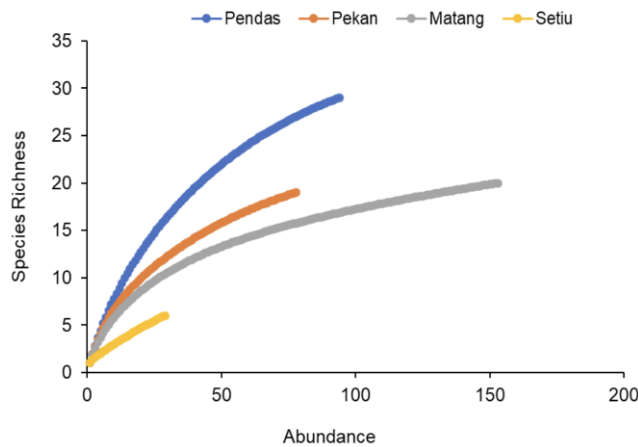


Figure 5. Species accumulation curves for all four study sites in Peninsular Malaysia

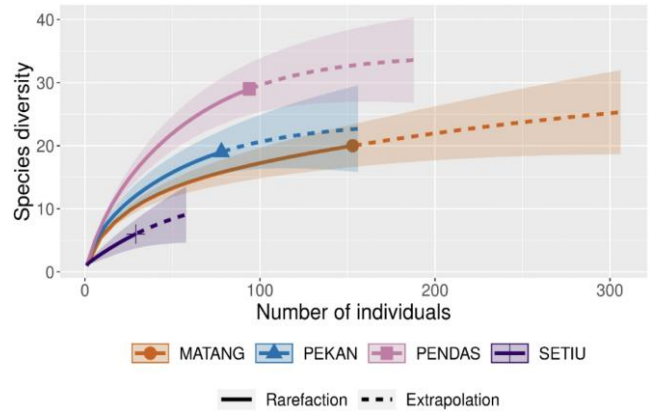


Figure 6. The extrapolation of species accumulation curves for all study sites

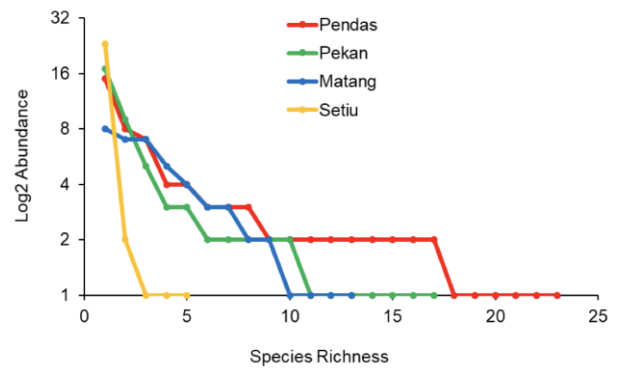


Figure 7. Rank abundance curves of larval fish at all four study sites

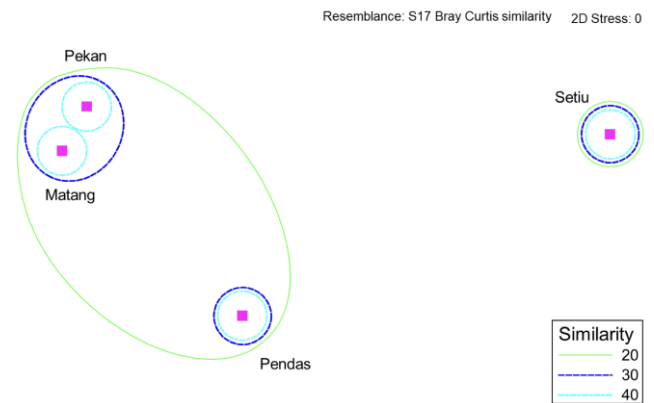


Figure 8. Two-dimensional nMDS with superimposed clusters at 20%, 30%, and 40% similarities in all four study sites

Discussion

Gobiidae larvae were observed at three sampling sites (Pendas, Matang and Pekan), and this is not surprising as Gobiidae are known to be a resident fish in mangrove area where their occurrence is relative to brackish water habitat and estuary (Huang et al. 2013; Bayot et al. 2014; Aqmal-Naser and Ahmad 2018a,b). They are sometimes known as

secondary freshwater species (Aqmal-Naser et al. 2019; Hasan et al. 2022; Valen et al. 2022). They can also be found in soft substratum habitats with little debris cover (Troyer et al. 2018; Kurniawan et al. 2020). The larval phase of Gobiidae takes approximately 40 days to develop into juvenile stage (Thresher 1984; Azmir et al. 2019), and this long larval phase is the likely reason for them to dominate the mangrove area. Ooi and Chong (2011) claimed to find all ontogenetic stages throughout the mangrove estuary in Matang, Perak, thus indicating their use of the mangrove estuary as feeding, spawning, and nursery grounds (Muzaki et al. 2017). Engraulidae were also found in all sampling sites except Setiu, Terengganu. They are known as seasonal estuarine spawners (Arevalo et al. 2023), where their larval fish assemblages vary both in terms of species composition and distribution patterns. This pattern classifies them as marine migrants that predominantly enter estuaries during the postflexion and postlarval stages (Ooi and Chong 2011; Kisten and Strydom 2023). On the other hand, Engraulidae also serve as prey for piscivorous fishes (Quah 2020). Given that Setiu actively practices aquaculture farming, their absence may be attributed to increased predation pressure or habitat alterations associated with aquaculture activities. Larvae from Clupeidae family found in Pendas, also known as a common resident to mangrove habitats, were similarly found in high abundance. Clupeid larvae complete their entire life cycle within the estuary and are of high ecological importance, linking lower and higher trophic levels through their role as a planktivorous forage fish consumed by piscivorous birds and fishes (Smit et al. 2023).

Mangrove forests can survive in the extreme conditions of estuaries. Estuaries play an important role in protecting fish from predation, besides being the best ground for feeding, reproduction, and growth (Arshad et al. 2012; Wibowo et al. 2016; Wibowo et al. 2018; Hasan et al. 2023c). Pendas is a part of Johor Strait, a channel separating Malaysia and Singapore (Ismail et al. 2016) dotted with small fishing villages that depend economically on the vast stretch of mangrove forests along the coastal area. This area is also home to the largest seagrass bed in Peninsular Malaysia, a common ground for larval fish development (Ara et al. 2011; Omar et al. 2020). Despite Pendas being a highly developing ground including land reclamation since 2014 (William 2016), this site recorded the highest diversity of larval fish species among four sampling locations, trumping the number of larval fish species found in the protected areas of Matang, Perak. The possible factor leading to this is the presence of Merambong and Tanjung Adang Shoals which are 2.0 km adjacent to the Port Tanjung Pelepas and about 100 m from the mouth of Sungai Pendas. These shoals have become a refuge for marine flora and fauna. Especially with the presence of seagrass bed, they are a suitable residing habitat for larval fish. The shoal functions as a feeding ground for various animal species as well as aid in the stabilization of near-shore sediments (Bujang et al. 2016).

Zero species overlapped among the four sampling sites, and this is influenced by a few factors such as the ocean current. Larval fish drift with currents as they cannot swim since their morphological development is still incomplete.

This eventually shapes the population's genetic structure and the evolution of species through the impact of drifting life stages on rates of gene flow (Hays 2017). Another factor is the decline in species richness with depth in the ocean. The mangrove forest in Matang, Perak is influenced by the Malacca Strait and merges with the Andaman Sea, reaching about 200 m in depth (Wisha et al. 2023), Setiu in Terengganu and Pekan in Pahang are exposed to the South China Sea with the depth ranging from 60 to 2000 m depth at the continental slope (Mohd-Akhir 2012; Liu et al. 2023), while Pendas in Johor is surrounded by the Johor Strait with 12 m depth (Mohd-Rusli and Zairi 2022). The Johor Strait was once 42 m in depth back in 1370 (Baco et al. 2022). The presence of seagrass beds in Pendas also increases the number of larval fish species. This trend has been observed in Tanzania as well, where fragmented seagrasses caused by anthropogenic activities have affected larval fish assemblages (Malesa et al. 2022). The non-overlapping or exclusive species of larval fish are normally found in reefs whereas in mangrove habitats, the exclusive species tend to be found in lower occurrence (Kulbicki et al. 2022).

Higher species richness in Pendas was seen as the sampling session was done towards the middle of the ocean instead of nearing the mangrove habitat as practiced in Matang, Pekan, and Setiu. Serious sedimentation impacts on Johor Strait have been reported (Williams 2016) and changes in sediments from anthropogenic release in this area (Omar et al. 2020) have reduced the depth of Johor Strait, which eventually hinders sampling activities near the shore region where the mangrove habitat is populated. Due to this, there is a possibility of mixed larval species being sampled, representing mangrove, seagrass, and coral reef species. The coral reef larval fish found were the Callionymidae (Quah 2020), Pomacentridae (Gopakumar et al. 2002; Johansen et al. 2017), and Syngnathidae (Shepherd et al. 2017). These species were not caught in other sampling sites as they reside in reef habitats.

Both species accumulation curves and the extrapolation of species accumulations indicate that more fish species can be recorded with an increase of sampling efforts. The completeness of the sampling is influenced by various factors including fish abundance (Yu et al. 2024), sampling method (Zajicek and Wolter 2018), habitat complexity (Consoli et al. 2018), and the patchy distribution of the fish species (Yu et al. 2024) the duration of sample collection (Aqmal-Naser et al. 2023) and the type of ecosystem (Aqmal-Naser et al. 2022). The mangrove ecosystem is a nursery ground for larval fish; hence, future studies should consider multiple habitats, especially within the vegetation or leaf debris and mostly attracted to habitat with high food availability (Tirani et al. 2022). Fish are mobile organisms; they sometimes drift away following the water current, especially the larvae. Habitats such as mangrove creeks and tidal pools are also other alternative habitats to record additional larval fish (Tarimo et al. 2022), where they use this microhabitat to avoid predation and for shelter.

All analyses show that Setiu has the lowest diversity and is separated from the other mangrove ecosystems based on the nMDS analysis. The larval fish from Setiu was sampled within Setiu Wetlands, a healthy ecosystem with a well-

preserved habitat and exhibits no symptoms of disturbances (Ikhwanuddin et al. 2017). However, this site is an enclosure where aquaculture activities such as brackish water cage culture, pond culture, pen culture, and oyster farming are the major and fastest-growing economic activities in Setiu Wetlands (Suratman et al. 2014). This intensive aquaculture activity might lead to the loss of mangrove forests, dwindling fish stock due to disease outbreaks, and discharge of particulate organic materials (Sabdaningsih et al. 2023). A similar observation of organic material accumulation, commonly referred to as biofouling, was noted at the oyster culture site (Mahmud et al. 2015). The biofouling resulted from the shallow water and reduced water flow, which allowed fish feed trapped in the nets to accumulate. This environment benefited the farmed fish, but it also led to an increase in sedimentation rates due to the accumulation of organic debris. Thus, the underlying reason for the dominant larval fish species and the lowest diversity in Setiu, as shown by the rank abundance curve, is possibly due to the active aquaculture activities since 1970 (Alipiah et al. 2018). According to Toone et al. (2022), cultured shellfish populations have the potential to directly reduce recruitment into fishery populations through the consumption of eggs and larvae.

In conclusion, our study distinguished the assemblages of larval fish across four mangrove habitats in Peninsular Malaysia, revealing distinct differences in species composition among the study sites. The findings suggest that larval fish communities vary across different mangrove environments, with Setiu exhibiting the lowest species diversity and abundance. This reduction is likely influenced by intensive aquaculture activities, which may contribute to habitat degradation, increased sedimentation, and changes in water quality. Given the observed impact of aquaculture in Setiu, it is crucial to implement sustainable aquaculture practices that minimize environmental disturbances. This includes enforcing proper waste management, promoting eco-friendly aquaculture techniques, and establishing buffer zones to reduce the direct impact on natural fish nursery areas. Future conservation efforts should prioritize the mitigation of aquaculture-related impacts to ensure the long-term sustainability of larval fish populations and the overall health of mangrove ecosystems.

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