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Species composition and diversity of waterbird communities in Important Bird and Biodiversity Area (IBA) of South West Johor Coast, Malaysia

NUR ATHIRAH FAUZI[1], KAVIARASU MUNIAN[1,2,3], AHMAD KHUSAINI MOHD KHARIP SHAH[4], NOR ATIQAH NORAZLIMI[1,3,♥]

[1]Department of Technology and Natural Resources, Faculty of Applied Sciences and Technology, Universiti Tun Hussein Onn Malaysia (Pagoh Campus). Hab Pendidikan Tinggi Pagoh, Jalan Panchor Km. 1, 84600 Panchor, Johor, Malaysia. Tel.: 06-9742001, ♥email: atiqah@uthm.edu.my
[2]Zoology Branch, Forest Biodiversity Division, Forest Research Institute Malaysia. 52109 Kepong, Selangor Darul Ehsan, Malaysia
[3]Environmental Management and Conservation Research Unit, Faculty of Applied Science and Technology, Universiti Tun Hussein Onn Malaysia (Campus Pagoh). Hab Pendidikan Tinggi Pagoh, Jalan Panchor Km. 1, 84600 Panchor, Johor, Malaysia
[4]Department of Wildlife and National Parks of Peninsular Malaysia. Jalan Cheras Km 10, 56100 Kuala Lumpur, Malaysia

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Abstract. *Fauzi NA, Munian K, Shah AKMK, Norazlimi NA. 2023. Species composition and diversity of waterbird communities in Important Bird and Biodiversity Area (IBA) of South West Johor Coast, Malaysia. Biodiversitas 24: 3471-3480.* Mangroves play a crucial role in supporting intertidal flats and providing habitats that enrich benthic communities, which in turn serve as feeding grounds for coastal waterbirds. However, the degradation of mangrove habitats caused by coastal reclamation activities indirectly impacts prey availability and, consequently, the populations of waterbirds. The coastline habitat along the Important Bird and Biodiversity Area (IBA) of the South West Johor Coast is currently under threat due to new and ongoing development projects involving large-scale reclamation activities. Therefore, this research was conducted to study the diversity and abundance of waterbirds and their relationship with prey availability. The study was conducted in three coastal mudflat sites along the South West Johor Coast, namely Tanjung Piai, Pontian Kechil, and Muar, from November 2020 to May 2021. The direct observation technique was used to determine the abundance of waterbirds, while the benthic core sampling method was employed to assess prey availability in all study sites. In total, 3,717 individual waterbirds, comprising 17 species, were counted across the three study sites. The study confirmed a significant positive relationship between the abundance of waterbirds and prey availability (R^2=0.501). The results of this study serve as important baseline data and references for the conservation of waterbirds along the South West Johor Coast. Through the study, we believe that the relevant authorities are able to formulate sound conservation strategies to preserve the habitat for a vast diversity of waterbirds.

Keywords: Coastal reclamation, mangrove, migratory, mudflat, prey availability, shorebird

INTRODUCTION

Waterbirds play a vital role in the enrichment of biodiversity in wetlands. Almost 10% of the world's avian species depend completely on wetland systems, and some species use the wetlands at some life cycle stages (Williamson et al. 2013). Intertidal mudflat is a part of the wetland ecosystem that serves as an important feeding area for coastal waterbirds for various reasons. This area often hosts rich benthic communities (Meijer et al. 2021), as most of the infauna and epifauna prey in the mudflat sediment is the primary food resource for coastal waterbirds (Bowgen et al. 2015). Furthermore, migratory waterbirds, especially shorebirds, rely on these habitats as stopover sites within their flyways during migration (Mathot et al. 2018).

The large coastal area in Malaysia offers ideal foraging and roosting habitat for many species of migratory waterbirds during the winter and migratory seasons. In particular, Malaysia holds the third-largest Important Bird and Biodiversity Areas (IBAs) of coastal wetlands in Southeast Asia (15 sites with a total cover of 4,316 km^2) after Indonesia and Myanmar (Yong et al. 2022). The west coast of Peninsular Malaysia (Malacca Strait) and Sumatra collectively hold the most extensive areas of intertidal flats, mangroves, and associated wetlands in Southeast Asia, and these areas have significant congregations of migratory waterbirds (Polgar and Jaafar 2018; Yong et al. 2022). The Asian Waterbird Census (AWC) carried out in 2015 successfully counted a total of 327 migratory waterbird species, and these species accounted for about 38.6% of the overall total bird species recorded in Malaysia (Atiqah and Ng 2015).

The multiple functions supported by the intertidal wetland have unfortunately led to its extensive exploitation. These coastal ecosystems, especially mangrove forests, have the highest loss rate in developing countries, including Malaysia. The destruction rate was estimated to increase by about 1% or 1,282 hectares annually starting from 1990 to 2010 mainly due to agriculture, aquaculture land conversion and coastal erosion (Zakaria and Sharma 2020). Similar to the fast pace urbanization at the global level, the loss of mangroves in Johor is the third largest in Malaysia, after Selangor and Pahang (Kuenzer et al. 2011). The intertidal landscapes along the South West Johor coast are continuously being cleared by massive coastal reclamation (Kanniah et al. 2015), mainly focuses on residential, commercial and industrial activities (Sukirman et al. 2021). The projects have changed the physical appearance of the coastal areas and affected the ecosystems. A few examples of mega reclamation projects in Johor are Forest City mixed development (Rahman 2017), the Pengerang Integrated Petroleum Complex (PIPC) (Rahman 2018), Tanjung Piai Maritime Industrial Park and the newly proposed Maharani Energy Gateway in Muar.

Numerous studies have highlighted the detrimental impacts of coastal reclamation, including its adverse effects on ecosystems and the organisms inhabiting these areas (Wang et al. 2012; Hossain et al. 2019; Numbere 2020). However, previous research on waterbirds in Malaysia has primarily focused on non-coastal wetlands, leaving several aspects of the ecological functions of waterbirds in coastal wetlands unresolved. Moreover, the correlation and relationship between waterbird abundance and the factors influencing their distribution have received little attention.

Therefore, this study aims to investigate the diversity and abundance of waterbirds across three mudflat areas along the South West Johor coast. Additionally, this study seeks to establish the relationship between waterbirds and prey availability in these areas. The information obtained from this study will be crucial for developing effective management plans and conservation strategies. Furthermore, the ornithological data collected will provide insights into the impact of land reclamation activities on the waterbird populations in the study sites. By addressing these objectives, this research contributes to filling the knowledge gaps regarding waterbird ecology in coastal wetlands and provides valuable insights for sustainable coastal development and conservation efforts.

MATERIALS AND METHODS

Study areas

Three study sites, namely Tanjung Piai National Park (TP), Pontian Kechil Coast (PK), and Muar Coast (MU), located along the South West Johor Coast, were selected to assess the waterbird assemblage and prey availability (Figure 1). The study sites were chosen according to the highest reported waterbird presence based on previous studies (Wei et al. 2006) and the annual report of the Asian Waterbird Census (Atiqah and Ng 2015). In addition, these selected sites were shown to have received different intensities of coastal reclamation activities. The coordinates and protection status of each study site are summarized in Table 1.

Table 1. Location and protection status of study sites

Study sites	Study plots		Coordinates		Protection status
			Latitude	Longitude	
MU	Pantai Leka	PL 1	1°56'58.35"N	102°37'54.94"E	Not protected
	Pantai Mesra Seri Menanti	PSM 1	1°53'8.44"N	102°40'26.40"E	
		PSM 2	1°52'49.43"N	102°40'39.41"E	
PK	Pontian Kechil	PK 1	1°28'35.89"N	103°23'22.43"E	Not protected
		PK 2	1°28'53.42"N	103°23'1.94"E	
		PK 3	1°29'14.13"N	103°23'8.25"E	
TP	Tanjung Piai	TP 1	1°16'46.40"N	103°30'38.99"E	Legally protected
		TP 2	1°15'52.76"N	103°30'20.31"E	
		TP 3	1°16'8.79"N	103°30'40.66"E	

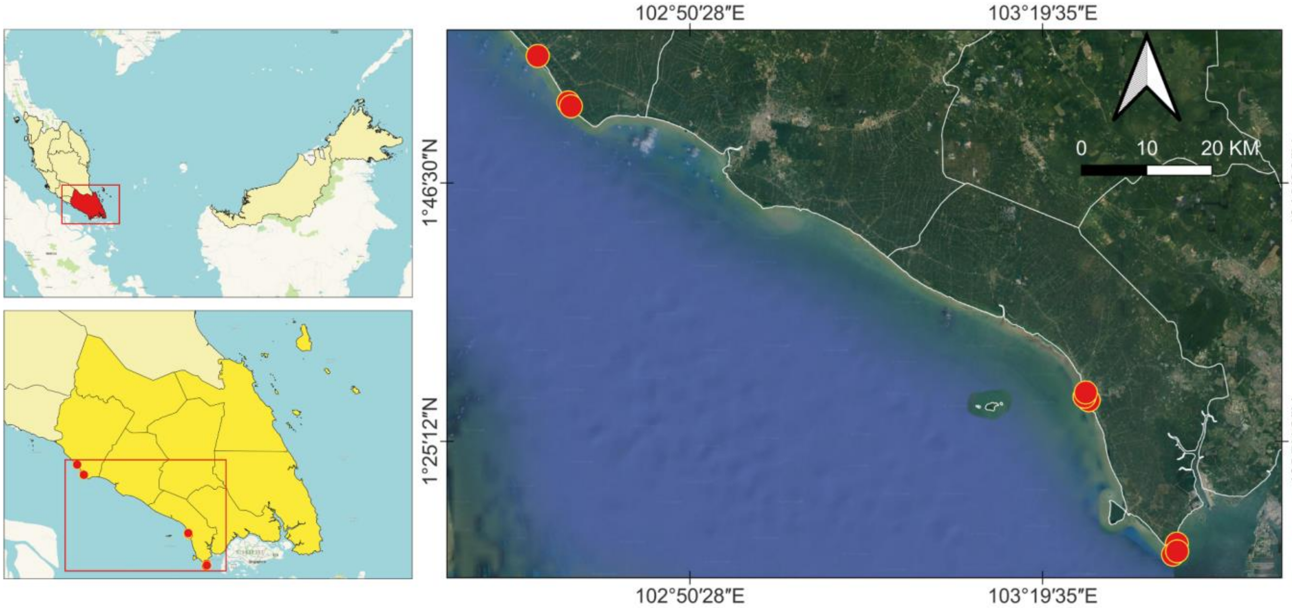

Figure 1. Maps of study areas: A. Map of Malaysia, B. Map of Johor state, C. Map of South-west Johor coast. The Purple line shows the IBA boundary meanwhile the yellow star represents the location of the study sites chosen (Yeap et al. 2007)

Tanjung Piai National Park (TP) is situated at the southernmost tip of Peninsular Malaysia and is predominantly covered by coastal mangroves, spanning an area of approximately 526 hectares. It was declared a Ramsar site in 2003. On the other hand, PK, previously a small fishing village with a fishing port facing the Strait of Malacca, has undergone rapid economic growth, resulting in the reclamation and development of the shore areas into a town center for the Pontian Kechil District, catering to commercial and recreational purposes. Three study plots were established randomly on the mudflat areas of TP and PK. Within TP, two plots, TP2 and TP3, were located within the national park, while TP1, situated near Tanjung Piai Resort just outside the park, featured only a small patch of surviving mangrove trees. Meanwhile, in PK, all three plots (PK1, PK2, PK3) were established in an area that experiences high levels of human disturbance but has medium-density mangrove patches.

In MU, the mudflats of Pantai Leka (PL) and Pantai Mesra Seri Menanti (PSM) recorded a high presence of residential Lesser Adjutant (*Leptoptilos javanicus* Horsfield 1821) in Johor based on Asian Waterbird Census. Both areas are surrounded by dense mangrove forests, providing suitable high-tide roosting and nesting sites for the storks and other waterbirds. A single plot, PL1, was established in PL, covering an area of approximately 20 hectares and located near an active fishing port. The other two plots (PSM1 and PSM2) were situated in PSM, approximately 8.7 kilometers away from PL, which is the closest suitable area for waterbird observation. Despite the location, all three plots were gathered as one study site (MU).

Waterbird surveys

A standardized observation protocol for each site was carried out with the same equipment and tools. Observation sessions were also held for the same number of days and hours for each of the study sites. A total of nine study plots were established on the tidal flats of the three study sites, with three plots dedicated to waterbird observations at each site. Each observation plot had a length of approximately 100 meters, and the width varied based on the distance between the shore and the edge of the water, ranging from 0 to 700 meters, considering the influence of tide cycles on tidal flats. The observations of waterbirds were conducted for two months in each study area, starting from TP in November and December, PK in February and March, and MU in April and May. Each observation was conducted during four-time intervals: from 0800 to 1000 hours, 1000 to 1200 hours, 1400 to 1600 hours, and 1600 to 1800 hours. The time interval between 1200 to 1400 hours was excluded from the study, as preliminary sampling indicated a lack of waterbird activity during that period.

Waterbird surveys were conducted using a direct observation method with the assistance of spotting scopes (Nikon 13-30x50mm ED Angled) and a DSLR camera (Nikon D5500) with a Nikkor lens (Nikon 200-500mm F/5.6E ED VR AF-S). Waterbird species observed in the field were identified up to the species level. Individual waterbirds on the mudflats within each study plot were counted using the direct count method, which has been previously used by Pandiyan and Asokan (2016). Waterbirds flying forward were excluded from the count, and only those feeding, resting, and flying within the observation area were recorded (Ramli and Norazlimi 2016). The bird counts were conducted by two experienced bird observers under clear and sunny weather conditions. To minimize the chances of double counting, observation points for each observer had a radius of 1 km and did not overlap with others (Li et al. 2022). However, it is still possible that the same individuals were counted twice by two observers from different points. Most of the mudflat sites where the counts took place had clear and obvious physical boundaries, such as jetties, breakwater structures, and mangrove patches. Therefore, these natural and man-made boundaries were used to delineate the counting areas for each observation point (Delany 2010). Waterbird counts were not conducted under extreme weather conditions, such as strong winds or rainy days, to avoid potential adverse effects on waterbird activity.

Benthic macroinvertebrate sampling

Benthic core sampling was employed to assess the availability of benthic macroinvertebrate prey. In each sampling session, two days were allocated for benthic macroinvertebrate collection. To determine the prey availability for waterbirds, five subplots with an area of 5m × 5m were randomly marked within each observation plot. The location of the subplots could vary in each sampling session, as they were chosen based on areas with a high number of foraging waterbirds, as waterbirds tend to forage in areas with readily accessible prey. Five replicates of sediment samples were randomly taken from each subplot using a corer with a diameter of 5 cm and a depth of approximately 20 cm.

After 30 minutes, each sediment core was extracted and immediately sieved through a 1.0 mm sieve. The sediment samples were gently washed with distilled water to separate the sediment grains from the benthos organisms. The remaining organisms were then extracted from the sieve, sorted on a white tray, and preserved in a glass jar containing 70% ethanol. In the laboratory, the size of the benthic macroinvertebrates was measured using a clear grid ruler for identification purposes. The benthic macroinvertebrates were counted and identified to the lowest possible taxonomic level. Taxonomic identification was based on previous studies, such as Idris and Arshad (2013) for polychaetes and Baharuddin et al. (2018) for bivalvia and gastropods. Online resources, such as WoRMS (WoRMS Editorial Board 2023) and MyBIS, (MyBIS 2023) were also utilized as these repositories are frequently updated by users.

Data analysis

All collected data were organized using the Microsoft Excel database software. For the analysis, statistical software such as Paleontological Statistic (PAST) (Hammer and Harper 2006) and Rstudio (Rstudio Team 2020) were utilized. The non-parametric Kruskal-Wallis test was employed to assess differences in waterbird abundance between the three study sites and plots. Subsequently, pairwise comparisons based on Dunn's Test were conducted to further analyze the differences. The similarity in waterbird community composition across the study plots was evaluated using Non-Metric Multidimensional Scaling (NMDS) ordination. To maintain consistency and reduce visual clutter in the graph, numerical values were used to represent the plots in the NMDS ordination graph.

The diversity of waterbirds in each study plot was calculated using diversity indices in Paleontological Statistics (PAST) software. Shannon-Weiner's Index and Simpson's Index were used to calculate alpha diversity in each study area. These diversity indices were selected as they are widely used and considered reliable methods for measuring species diversity. Rarefaction curves were computed using iNEXT Online (Hsieh et al. 2016) to estimate the completeness of the waterbird assemblage inventory in the three study sites. Kruskal-Wallis tests and pairwise comparisons were then conducted to determine significant differences in waterbird diversity among the different study plots.

The relationship between waterbird abundance and the abundance of benthic macroinvertebrates was assessed using a simple linear regression analysis. The regression model with a higher R^2 value indicates a better fit for the relationship between the abundance of the waterbird and the abundance of benthic macroinvertebrates.

RESULTS AND DISCUSSION

In all three study sites along the South-west Johor Coast, a total of 3,717 waterbird individuals belonging to 17 species and four families were observed (Table 2). Among these families, Scolopacidae was the most diverse, with seven species (41.18%) recorded. The family Ardeidae followed with five species (29.41%), while Ciconiidae had three species (17.65%). Two species (11.76%) were recorded from the family Charadriidae.

Scolopacidae is one of the largest and most diverse avian families, consisting primarily of migrant species. These migratory birds play a significant role in the waterbird populations in coastal areas, as they often make stopovers along the coast during their migratory journeys to replenish their energy reserves (Putera et al. 2014). The open-water mudflat areas found in the study sites offer abundant food sources, attracting many waterbirds, especially those belonging to the Ardeidae family, which includes egrets and herons. These species are commonly observed in the study area throughout the sampling periods due to their partially migratory distribution in Malaysia. The Ardeidae family, in particular, relies on wetlands for various activities such as feeding, roosting, and nesting (Mohd-Taib et al. 2020).

Abundance of waterbirds

Out of the 3,717 waterbird individuals observed, Tanjung Piai (TP) had the highest count with 1,999 individuals, followed by Muar (MU) with 1,409 individuals, and Pontian Kechil (PK) with 309 individuals. The most abundant species recorded across all study sites was the Lesser Sand-plover (*Charadrius mongolus* Pallas, 1776), with 1,740 individuals (46.81%) observed. The second most abundant species was the Common Redshank (*Tringa totanus* Linnaeus, 1758), with 1,231 individuals (33.1%) recorded (Figure 2). Figure 3 presents the morphology of these two species, as well as several other species recorded in the study.

Table 2. List of waterbird species found in overall three study sites with their distribution and IUCN status

Family	Species	Common name	Distribution	IUCN status	Species code	No. of individuals per study site		
						TP	PK	MU
Ardeidae	*Ardea cineria* Linnaeus, 1758	Grey Heron	PM	LC	GH	58	14	58
	Ardea alba Linnaeus, 1758	Great Egret	PM	LC	GE	24	23	31
	Butorides striata Linnaeus, 1758	Striated Heron	PM	LC	SH	13	22	18
	Egretta garzetta Linnaeus, 1766	Little Egret	PM	LC	LE	23	20	38
	Egretta eulophotes Swinhoe, 1860	Chinese Egret	M	VU	CE	0	0	8
Charadriidae	*Charadrius mongolus* Pallas, 1776	Lesser Sand-Plover	M	LC	LSPV	1077	0	663
	Charadrius leschenaultii Lesson, 1826	Greater Sand-Plover	M	LC	GSPV	4	2	0
Scolopacidae	*Numenius phaeopus* Linnaeus, 1758	Whimbrel	M	LC	WBR	72	0	9
	Numenius arquata Linnaeus, 1758	Eurasian Curlew	M	NT	ERCW	8	1	0
	Calidris ruficollis Pallas, 1776	Red-necked Stint	M	NT	RNS	0	0	6
	Xenus cinereus Guldenstadt, 1775	Terek Sandpiper	M	LC	TSP	21	4	78
	Actitis hypoleucos Linnaeus, 1758	Common Sandpiper	M	LC	CSP	62	10	10
	Tringa nebularia Gunnerus, 1767	Common Greenshank	M	LC	CGS	14	0	0
	Tringa totanus Linnaeus, 1758	Common Redshank	M	LC	CRS	592	186	453
Ciconiidae	*Leptoptilos javanicus* Horsfield, 1821	Lesser Adjutant	R	VU	LA	12	10	37
	Mycteria leucocephala Pennant, 1769	Painted Stork	V	NT	PSTK	3	7	0
	Mycteria cineria Raffles, 1822	Milky Stork	R	EN	MSTK	16	10	0

Note: PM: Partially Migrant, R: Resident, M: Migrant, V: Vagrant, LC: Least Concern, NT: Near Threatened, VU: Vulnerable, EN: Endangered

Both the Common Redshank and Lesser Sand-plover were migrant species and were recorded in significant numbers across all study sites, with the exception of PK, where the Lesser Sand-plover was absent. The absence of the Lesser Sand-plover (*C. mongolus*) in Pontian Kechil (PK) during the study period is a notable finding. Previous surveys conducted in 2004 and 2005 had successfully detected a significant number of Lesser Sand-plovers in PK, with approximately 1,035 individuals recorded (Wei et al. 2006). However, the current study did not observe any individuals of this species in PK. This discrepancy suggests a change in the distribution and habitat usage of the species in the area.

It is speculated that the population of Lesser Sand-plovers has relocated to other intertidal mudflats that offer better quality habitats. This shift may be attributed to changes in the prey structure caused by habitat degradation. Studies conducted by Sato (2006) in a reclamation area in Japan demonstrated that such habitat alterations could lead to the decline of benthic macroinvertebrate species, particularly mollusks, due to changes in salinity or hypoxia. These changes in prey availability can disrupt the food supply for waterbirds.

Although the extent of reclamation in PK was not as extensive as in Japan (Sato 2006), it is possible that gradual changes in the prey composition have occurred over time, leading to the absence of the Lesser Sand-plover in PK. This highlights the vulnerability of migrant species to habitat degradation and changes in resource availability.

In contrast, resident species such as herons and egrets were observed thriving in the same area. Resident species generally have better abilities to respond to fluctuations in resource availability and habitat quality compared to migrant species (Martin and Fahrig 2018). They are often more tolerant of human disturbance and better adapted to exploiting anthropogenic resources (Martin and Fahrig 2018; Xu et al. 2019). This may explain why the resident species in PK were able to persist in the face of habitat changes, while the migrant species like the Lesser Sand-plover faced challenges in adapting to the altered conditions.

A significant number of waterbird individuals were detected across all three study plots in TP (H=8.009, p<0.001) and MU (H=11.44, p=0.001). TP1 exhibited the lowest abundance of waterbirds compared to TP2 and TP3, and it was primarily dominated by resident species. The only migrant species recorded in TP1 was the Common Redshank. TP1's location outside the national park, near the floating resort, attracted a high number of visitors, especially local people and resort guests. In contrast, TP2 and TP3 were situated within the national park area, where access was fully controlled by the park authority. This likely contributed to the lower abundance of migrant species in TP1. Migrant species are generally more sensitive to energetic stresses and tend to avoid areas with high disturbance levels, particularly during the migratory season when they need to regain body condition and weight for their long migration journey (Martín et al. 2015). Meanwhile, resident species may habituate to predictable and non-threatening events, becoming more tolerant of disturbances (Martins et al. 2015).

A different scenario was observed in PL1 of MU, where the abundance and number of waterbird species were high, despite the plot's proximity to a crowded active fishing port. Although PL1 experienced similar anthropogenic disturbances as TP1, it supported a better composition of waterbird species. This difference could be attributed to the contrasting areas of adjacent mangroves around the plots. TP1 had only a small patch of mangrove area, while PL1 had a vast stretch of mangrove forest surrounding the mudflat area. Lu (2005) suggested that mudflat areas with healthy nearby mangrove forests can support diverse macrobenthos due to the constant influx of nutrients from the mangrove trees. Healthy mangroves with denser canopies produce more leaf litter, cycling more nutrients and maintaining soil moisture (Tolhurst et al. 2020). The abundance of the macrobenthos population in mudflats can influence fluctuations in the waterbird population (Grond et al. 2015). Additionally, waterbirds primarily utilize the mangrove forest for resting during high tide and as nesting sites. Ramli and Norazlimi (2017) also suggested that adjacent mangrove forests serve as protected areas for coastal waterbirds, allowing them to escape disturbances by flying toward the mangrove forest.

The observation was further supported by the site cluster analysis conducted using Non-Metric Multidimensional Scaling (NMDS) ordination (Figure 4). The results revealed two clusters, Cluster A and Cluster B, comprising all nine plots. These clusters are believed to be influenced by the presence of adjacent mangrove forests near each sampling plot. Cluster A consisted of plots with low or no adjacent mangroves and was dominated by partially migrant and resident species, except for PSM1 and PSM2. Both PSM1 and PSM2 had dense adjacent mangrove areas, as observed and confirmed through satellite map analysis using Google Earth Pro. However, the observation periods occurred after the migratory season, resulting in low abundance and species numbers restricted to resident species. On the other hand, Cluster B comprised three plots (TP2, TP3, and PL1) associated with extensive and dense mangrove areas and recorded the highest abundance of waterbirds.

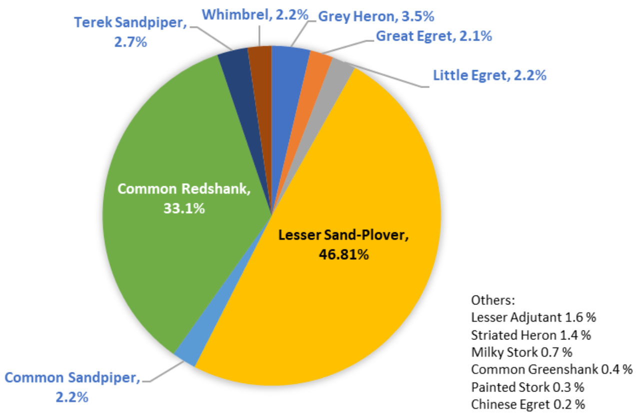

Figure 2. The relative abundance of each waterbird species recorded in three mudflat areas along the South West Johor Coast, Malaysia

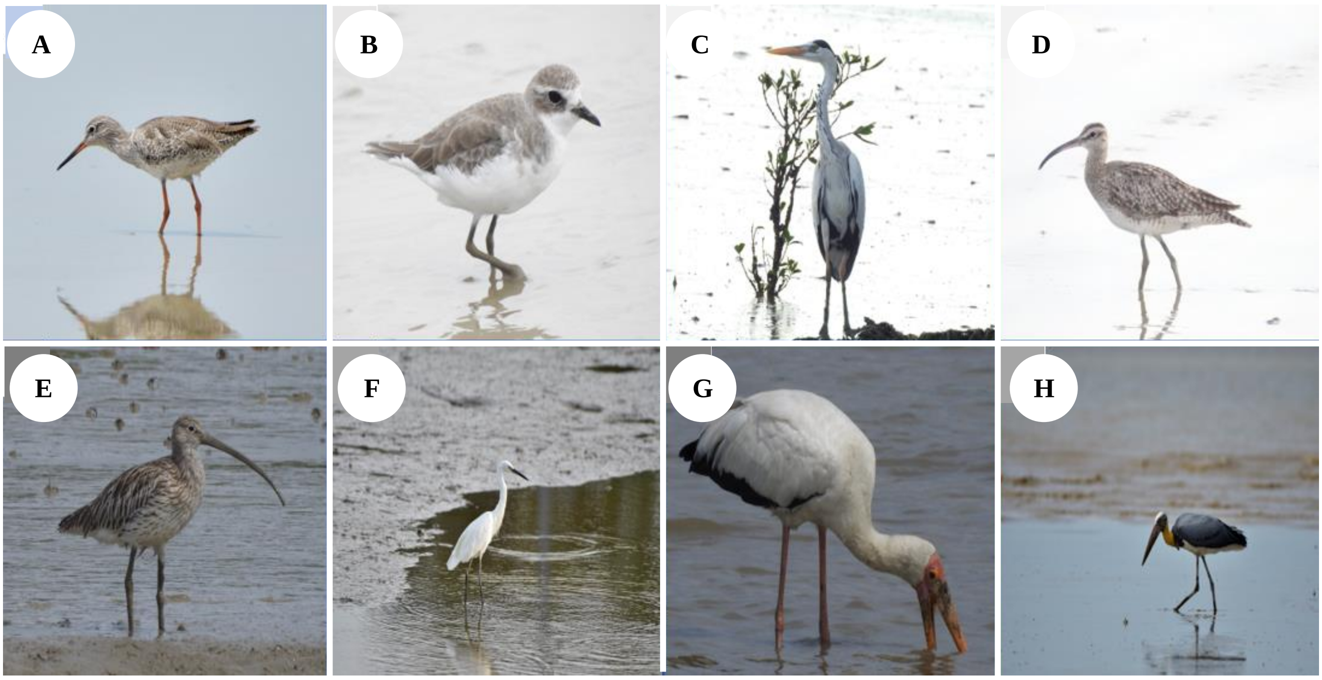

Figure 3. The two most predominant waterbird species along the South West Johor Coast, Malaysia: A. *Tringa totanus*, B. *Charadrius mongolus*, and the other species are C. *Ardea cineria*, D. *Numenius phaeopus*, E. *Numenius arquata*, F. *Egretta garzetta*, G. *Mycteria cineria*, H. *Leptoptilos javanicus*

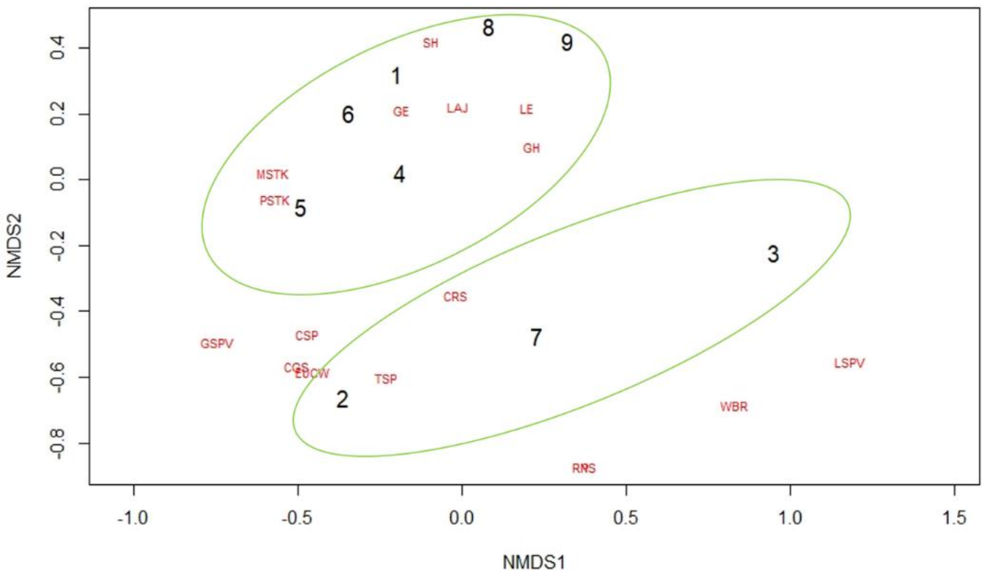

Figure 4. Ordination plot of waterbird species along Non-Metric Multidimensional Scaling (NMDS). Refer species code in Table 2. Plots: 1: TP1, 2: TP2, 3: TP3, 4: PK1, 5: PK2, 6: PK3, 7: PL1, 8: PSM1, 9: PSM2

Diversity of waterbirds

The analysis of the rarefaction curve showed that the curve for TP and MU had reached the asymptote, indicating that the species diversity for both sites may have been successfully identified (Figure 5). However, the total sampling effort was still inadequate for PK, as the cumulative curve was still exponential.

The diversity values varied among the study plots, as shown in Table 3. The high diversity in PK was primarily due to the highest diversity value recorded in PK2 (H'=2.150). Despite having the lowest abundance value among the plots, the waterbird composition in PK2 was more evenly distributed. As a result, it achieved the highest values for both the Shannon-Weiner Index and Simpson's

Index, combining species richness and evenness of individuals among species to measure diversity. A community is considered to have high species diversity when there are equally or nearly abundant species present. Conversely, if a community consists of only a few abundant species or a small number of less abundant species, the species diversity is low (Roswell et al. 2021). This observation is evident in TP3, where the plot exhibited the lowest species richness, with high abundance being dominated by a single species, namely the Lesser Sand-plover.

Composition of benthic macroinvertebrates

Among the study areas, TP had the highest abundance of macroinvertebrates (830 individuals), followed by MU (600 individuals) and PK (373 individuals). The mudflat area in TP is located within a protected national park, and the associated mangrove areas are considered healthy and well-maintained. This constant nutrient influx from the mangrove trees supports a diverse composition of benthic macroinvertebrates (Lu 2005). In terms of abundance, the collected macroinvertebrates consisted of 1,529 gastropods (85%), 207 bivalves (11%), and 67 polychaetes (4%) across all study sites. The Kruskal-Wallis test revealed a significant difference in macroinvertebrate abundance among the three study sites. PK exhibited a significant difference compared to TP (p=0.0009) and MU (p=0.05). However, no significant difference in macroinvertebrate abundance was detected between the individual plots.

Sixteen gastropods identified until species level were recorded in overall study sites that belong to 10 families. Meanwhile, one gastropod was identified until genus level (*Onchidium* sp.) and one unidentified gastropod (named Gastropod A) was recorded (Table 4). Gastropod *Nerita articullata* A.Gould, 1847 (9.8%), *Cellana testudinaria* Linnaeus, 1758 (8.9%), and *Littorina* sp. (8.6%) were found to be the highest in terms of overall macroinvertebrate abundance. The high abundance of gastropods collected can be attributed to their mobile characteristics (Dewiyanti and Sofyatuddin 2012), enabling them to be widely distributed within the open mudflats. Although bivalves were the second most abundant class collected, only two species were found. *Anadara granosa* Linnaeus, 1758 and *Pharella javanica* Lamarck, 1818 species are highly consumed by local people as protein sources and are commercially cultivated in East Asian and Southeast Asian regions (Sari et al. 2020). *Anadara granosa* prefers large soft mudflat areas that border the landward margin of mangrove forests (Faulkner 2009), which explains their absence in all studied plots of PK, where mangrove forests are lacking.

Meanwhile, polychaeta species were the least recorded class with one identified genus, *Glycera* sp., and two unidentified Polychaetes, namely Polychaete A and Polychaete B. Polychaetes were underrepresented in these results, possibly due to limitations in the methods used for benthic macroinvertebrate collection. The flexible bodies of polychaetes may have allowed them to escape from the sampling cores, and their identification was challenging as they were often found in fragments due to sampling and handling. Furthermore, polychaete bodies are extremely delicate and prone to breakage during examination (Górska et al. 2019).

Relationship between waterbirds and prey availability

A simple linear regression was conducted to predict the abundance of waterbirds based on the abundance of benthic macroinvertebrates in each study plot. The regression analysis revealed a significant relationship (F (1, 7)=7.033, p<0.05) with an R^2 value of 0.501. The results demonstrated a positive correlation between the abundance of waterbirds and the abundance of benthic macroinvertebrates (Figure 6). This suggests that as the abundance of benthic macroinvertebrates increases, the abundance of waterbirds also tends to increase. Previous studies have also shown similar positive relationships between waterbirds and prey abundance or biomass, although the strength of the relationship may vary across different studies (Jing et al. 2007; Nachuha and Mwima 2020). In this study, a numerical relationship between waterbirds and benthic macroinvertebrate prey within the three study sites was confirmed. However, the relationship was not particularly strong, as indicated by the moderate R^2 value of 50.1%. This could be attributed to the relatively small sample size used in the study. Additionally, relying solely on a sampling method that focuses exclusively on collecting macroinvertebrates may inadvertently overlook other potential prey items, such as fish. Moreover, limitations associated with the sampling and handling of macroinvertebrates could result in an inadequate sampling of prey species, particularly due to the high mobility of certain species and the fragility of others, which may easily break during examination.

Table 3. The comparison of waterbird diversity in three study sites using three diversity indices

Sites	Species	Individuals	Shannon (H')	Simpson (D)
TP 1	10	89	1.992	0.839
TP 2	15	996	1.468	0.634
TP 3	5	921	0.315	0.121
PK 1	10	130	0.952	0.773
PK 2	10	37	2.150	0.871
PK 3	9	143	0.660	0.660
PL 1	14	1350	1.365	0.641
PSM 1	6	34	1.708	0.801
PSM 2	5	33	1.395	0.730

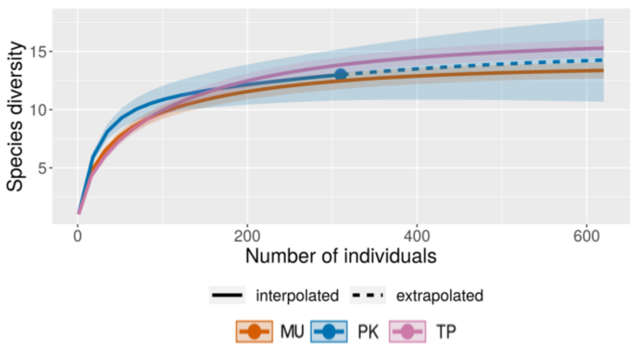

Figure 5. Waterbird accumulation curve, based on rarefaction for each study site along the South-west Johor Coast. MU: Muar, PK: Pontian Kechil, TP: Tanjung Piai

Table 4. Summary of the abundance of benthic macroinvertebrates in each study site

Class	Family	Species	Abundance of benthic macroinvertebrate			
			TP	PK	MU	Total
Bivalvia	Pharidae	*Pharella javanica* Lamarck, 1818	37	24	44	105
Bivalvia	Arcidae	*Anadara granosa* Linnaeus, 1758	53	0	49	102
Gastropoda	Batillariidae	*Batillaria zonalis* Bruguière, 1792	28	27	0	55
Gastropoda	Chilodontidae	*Euchelus alabastrum* Reeve, 1858	70	0	40	110
Gastropoda	Ellobiidae	*Cassidula aurisfelis* Bruguière, 1789	46	18	27	91
Gastropoda		*Laemodonta punctigera* H.Adams & A.Adams, 1854	35	30	18	83
Gastropoda	Littorinidae	*Littorina undulata* Gray, 1839	50	38	67	155
Gastropoda	Muricidae	*Ergalatax contracta* Reeve, 1846	38	0	36	74
Gastropoda		*Thais gradata* Jonas, 1846	53	0	40	93
Gastropoda	Nacellidae	*Cellana testudinaria* Linnaeus, 1758	69	52	40	161
Gastropoda	Neritidae	*Nerita articulata* A.Gould, 1847	74	72	32	178
Gastropoda		*Nerita lineata* Gmelin, 1791	17	20	27	64
Gastropoda		*Nerita undata* Linnaeus, 1758	23	0	0	23
Gastropoda	Onchidiae	*Onchidium* sp.	35	0	33	68
Gastropoda	Planaxidae	*Planaxis sulcatus* Born, 1778	13	0	42	55
Gastropoda	Potamididae	*Cerithidea obtusa* Lamarck, 1822	16	0	47	63
Gastropoda		*Telescopium telescopium* Linnaeus, 1758	34	33	0	67
Gastropoda	Trochidae	*Chrysostoma paradoxum* Born, 1780	24	17	0	41
Gastropoda		*Monodonta labio* Linnaeus, 1758	29	20	0	49
Gastropoda		Gastropod A	40	18	41	99
Polychaeta	Glyceridae	*Glycera* sp.	17	0	7	24
Polychaeta		Polychaete A	21	0	9	30
Polychaeta		Polychaete B	8	4	1	13
Total			830	373	600	1,803

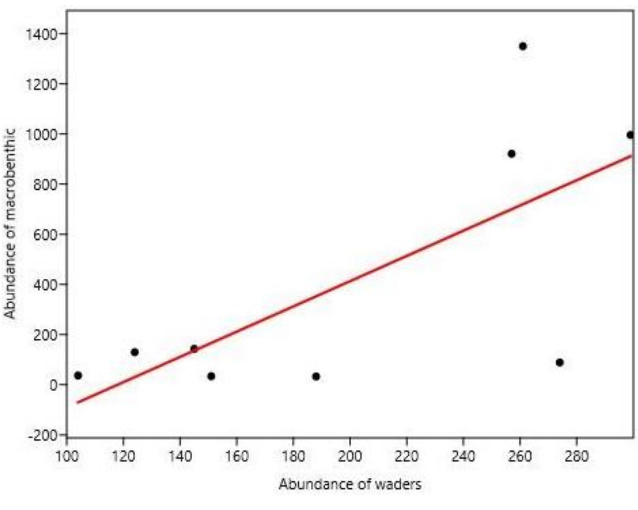

Figure 6. Significant linear regression between the abundance of waterbirds and the abundance of macroinvertebrates

In conclusion, a total of 17 waterbird species were recorded successfully. Tanjung Piai National Park, among the study sites, exhibited the highest species richness, waterbird abundance, and prey abundance. These findings emphasize the importance of considering the specific habitat requirements and ecological traits of different bird species when assessing the impacts of habitat degradation and land reclamation activities on waterbird populations. The study highlights the differential responses of migrant and resident species to habitat changes and underscores the need for conservation efforts that address the specific needs of each species group. Notably, the presence of adjacent mangrove forests was found to have a clear impact on the abundance of waterbirds and prey in the studied mudflat areas. These findings underscore the importance of mangrove habitats in supporting diverse waterbird populations and their potential role in mitigating the impacts of disturbance. Healthy mangrove forests in proximity to mudflat areas can contribute to the availability of food resources, provide shelter and nesting sites, and offer protection from disturbances, ultimately influencing the abundance and composition of waterbird species. Therefore, conservation efforts should prioritize the preservation and restoration of mangrove ecosystems to maintain and enhance waterbird populations in coastal areas. Furthermore, the study observed a positive relationship between the abundance of waterbirds and the availability of prey. These findings suggest that the availability of prey plays a crucial role in supporting waterbird populations. The findings presented can inform future plans for the area in light of the upcoming land reclamation projects. Decision-makers can use this information to advocate for conservation measures within the project plans, such as buffer zones or protected areas that preserve coastal habitats. The data can also support comprehensive environmental impact assessment to evaluate potential risks to waterbird populations and their habitats along the South West Johor Coast.

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