TEMPORAL POPULATION STRUCTURE OF FISH COMMUNITIES ALONG THE COASTAL WATERS OF UNIVERSITI MALAYSIA SABAH (UMS)

AMIR SYAZWAN SHAWEL[1], JOHN MADIN[1,2]*, EJRIA SALLEH[1,2], MABEL MANJAJI MATSUMOTO[1,2] AND SITTI RAEHANAH MUHAMAD SHALEH[1]

[1]*Borneo Marine Research Institute, Universiti Malaysia Sabah, Jalan UMS, 88400 Kota Kinabalu, Sabah, Malaysia.* [2]*Small Island Research Centre, Faculty of Science and Natural Resources, Universiti Malaysia Sabah, Jalan UMS, 88400 Kota Kinabalu, Sabah, Malaysia.*

*Corresponding author: jonmadin@ums.edu.my

Abstract: This study examines the temporal pattern of the population structure and community of fish along the coastline of Universiti Malaysia Sabah (UMS), Kota Kinabalu, Sabah. This area is known to have a productive seabed ecosystem to support fisheries, however fishes-related literature is limited and often focusing on specific species rather than communities. The present study fills this gap by providing crucial data on temporal pattern of community species, morphometric size, assemblages and population dynamics of fish caught in fishing net. Findings reveal 61 fish species across 27 families dominated by ponyfish of Leiognathidae including *Eubleekeria jonesi*, *Nuchequula flavaxilla*, *Photopectoralis bindus* and *Gazza minuta*. The diversity index is significantly ($p < 0.05$) high in December (H = 2.79) than other months with high contributions of ponyfish species. The smallest size in terms of standard length (SL) and weight (kg) is the species from the Engraulidae family with SL of 7.77 ± 1.46 cm and weigh at 0.007 ± 0.004 kg, in contrast Trichiuridae species is the largest in size with SL of 78.83 ± 25.62 cm and weigh at 0.285 ± 0.095 kg. There are at least two major recruitment peaks annually that linked to the monsoonal season, however natural mortality could cause the loss of nearly 20% populations during early stage while catches and fishing mortality increases drastically as fish grow larger. Fish assemblage and abundance are influenced by water parameters, where *Eubleekeria jonesi*, *Nuchequula nuchalis*, and *Scomberoides tol* correlates with high pH, dissolved oxygen, and salinity, while *Gazza minuta*, and *Nuchequula flavaxilla* with high temperature and turbidity. Continued efforts to monitor fish populations along coastal waters are essential to assess the impacts of human activities while future studies should consider effective fishing gear to optimise catch.

Keywords: Fish, coastline, diversity, marine, Sabah.

Introduction

Coastal waters are areas of the ocean located close to the coast with relatively shallow in depth extending from the high tide mark to deeper waters (Dipper, 2021) where relationships between biological, physical, and chemical elements further define this habitat (Mclusky, 2012). These waters are highly productive, rich in biodiversity, making it significantly important ecologically and economically. Ecologically, coastal waters support a vast array of marine life, including fish, invertebrates, seaweed, seagrass bed, and many more, contributes to the productivity of the ocean ecosystem in whole (Mann, 1982). Economically, these waters are

vital for various industries, particularly fisheries and tourism. Fisheries industries depend on the rich biodiversity as well as productivity of its coastal waters to maintain fish populations. Sustainably, this supporting the livelihoods of millions of people around the world, including Sabah waters which are well known for fisheries industry in Malaysia (Teh, 2016).

Interestingly, Sabah has the longest coastline in Malaysia, which further enhances the value and role of coastal waters for fishing activities, this in turn contribute to the socio-economic well-being of the local population (Selamat, 2017) as well as national economy

(Teh, 2016). Unfortunately, coastal waters are prone to destructive human activities, such as unregulated fishing activities and uncontrolled infrastructure developments, leading to the overexploitation of marine resources, disrupting populations dynamics and the balance of marine food web (Council, 1999). Destructive human activities affect everything from fish species ranges to coral growth rates, sculpting the distribution and behaviour of marine life (Mclusky, 2012). To date, such destructive human activities are often reported in Sabah waters involving the major coastal towns in the west and east coasts of the state.

A deeper understanding of biology and ecology of fish communities along coastal waters is essential for effective conservation measures. For example, studies on fish populations ecology in coastal waters are crucial to understand the spatial and temporal shifts in population dynamics as well as environmental factors that may influence it (Council, 2006). Indeed, such information is needed for effective conservation strategies in coastal waters that are constantly threatened by human activities (Vasilijevic, 2015). Coastal communities in Sabah are highly dependent on fishing for their livelihoods, and any disruption to fisheries stocks can have a lasting impact on their socio-economy (Teh, 2016). With a clear understanding of linkage between fish ecology and fishing activities, effective mitigation measures for sustainable fishing practices can be implemented to balance economic needs with ecological preservation (Korres, 2017).

This study investigated the temporal patterns of selected ecological fishery parameters of fish communities found along the coastal waters of Universiti Malaysia Sabah (UMS). It determines the temporal pattern of species occurrence, morphometric size, assemblages and population dynamics of fish caught in fishing net. The studied coastal waters areas are located within the busiest shipping route and other activities, that are expected to influence marine life, such as fish population structure. This study aspires to contribute valuable insights of coastal fishery resources and enrich understanding of the complex interplay between fish community and their surroundings in tropical ecosystem.

Materials and Methods

Study Area

The study was conducted along the coastal water areas of UMS [6.039022N,116.110481E]. These waters are important for various human activities including being a major shipping route centered in Sepanggar Bay, tourism and fishing as well as various beach activities in its surroundings (Figure 1). The water depth at nearshore area where sampling was conducted is less than 10 m and the sea bottom habitat consists of several types including sandy, rock, coral reefs, seagrass beds, and seaweed patches (Murshidi, 2018). It is important to note that the seabed ecosystems often mix, forming complex and interconnected habitats.

Field Sampling and Methods

A total of six fishing nets were placed randomly along the UMS coast in the subtidal zone near the shore. Each fishing net has a length of 15 m and a height of 1.5 m with a 4.45 cm mesh size (i.e. 1 inch 3 quarters). This net is commonly used by fishermen to catch pelagic fish in rocky seabed areas. The total length of the net used is 90 m arranged lengthwise and were deployed for an average of 60 minutes. Sampling was conducted for 12 months starting from November 2021 until October 2022. Sampling was usually carried out in the morning to avoid unsuitable weather conditions in the afternoon or evening. The fish samples obtained were taken to the laboratory for further analysis.

Environmental parameters such as temperature, salinity, pH, and dissolved oxygen (DO) were measured using a YSI-multiparameter while turbidity was measured with a turbidity meter. Water parameters were taken at the depth of 1 m below water surface, and recorded monthly during fish sampling. However, results are not fully reported here.
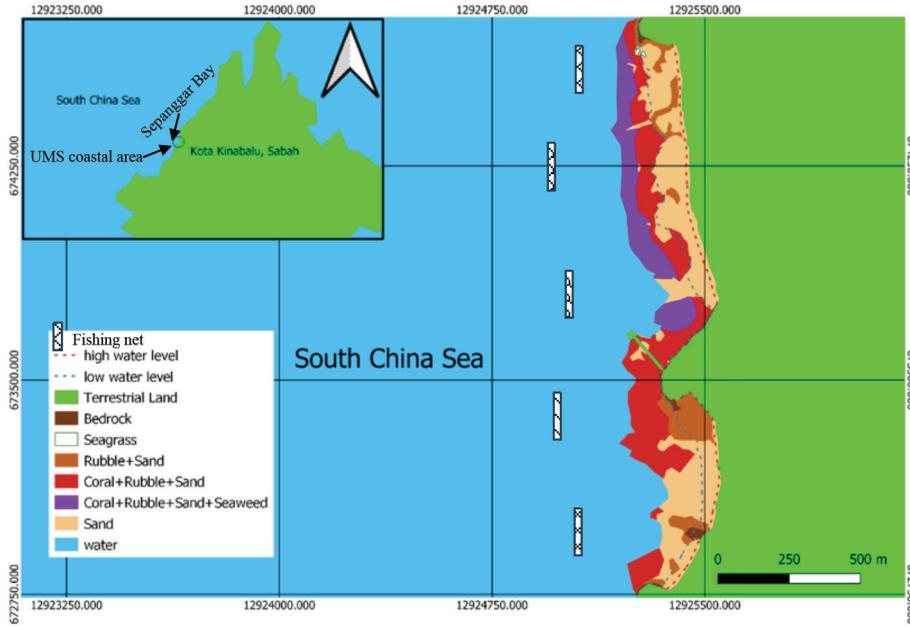
Figure 1: Geographical location of the sampling site at UMS coastal area. The nets are installed randomly near the shore considering the suitability of the seabed topography to prevent nets entanglement

Laboratory Treatments and Analysis

In the laboratory, fish samples were identified to the lowest taxa possible (i.e. species), and enumerated for species abundance as well as morphometric measurements namely weight (kg), and standard length (SL). Detailed records including, categorising fish individuals by month, and species were created as raw data in an excel file. In addition, the total number of individuals, the total number of individuals per species, and the total number of species found were also determined.

Computation and Statistical Analysis

The CPUE and WPUE was estimated as follow:

Catch per unit effort (No. ind./h),

$$CPUE = \frac{No.\ of\ fish}{No.\ of\ nets \times Surface\ area\ of\ net \times Time\ Imins)}$$

The weight per unit effort (kg/h),

$$WPUE = \frac{Total\ weight}{No.\ of\ nets \times Surface\ area\ of\ net \times Time\ Imins)}$$

where
Number of fishing nets = 6 units
Surface area of fishing nets = 15 m X 1.5 m
Fishing time = 60 minutes (1 hour)

The Shannon-Weiner diversity index (H) was computed based on Shannon, (1984);

$$p_i = \frac{n_i}{N}$$

$$H_i = -\Sigma(p_i)(\ln p_i)$$

where

H = diversity index
p_i = proportion of individuals in the ith species
n_i = number of individuals of species i
N = total number of individuals

The log transformation [log10(x+1)] was applied to the computed raw data of abundance (CPUE), Shannon-Weiner diversity index and environmental parameters to address the non-normality and to stabilise variance. The Shapiro-Wilk test results indicated normality and homogeneity of data and thus permitted further statistical analysis. One-Way ANOVA

analysis was used to investigate the effects of month (Nov-21, Dec-21, ... and Oct-22) on the dependent variables namely the CPUE, environmental parameters, ecological indices, and morphological size of fish. To further determine the significant level of differences identified by the ANOVA, the post-hoc comparisons using Tukey's Honestly Significant Difference (HSD) test was performed. This test assesses specific differences between months, providing a more nuanced understanding of the data. The significance level was set at $p < 0.05$. All statistical analysis for ANOVA were performed in RStudio, a statistical computing and graphics software, downloaded from Posit website.

The hierarchical clustering analysis was conducted to illustrate the assemblage of fish species based on the similarity of the distribution pattern in their abundance over the 12 months sampling [i.e., (Nov-21, Dec-21, ... and Oct-22)]. The selection of species for analysis was based on the total abundance of the most contributing individuals as well as the frequency of occurrence. The degree of similarity was set at 20% and the step-by-step procedure for the analysis followed the methods provided in Aghababyan (2016). The analysis was performed in RStudio.

The Canonical Correspondence Analysis (CCA) is used to explore the relationships between the monthly abundance (Nov-21, Dec-21, ... and Oct-22), and water parameters such as temperature, salinity, pH, dissolved oxygen, and turbidity. The dataset was imported into PAST 4.03 and the step-by-step procedure for the analysis are based on Hammer (2020).

The FiSAT II was used to analyse the recruitment, mortality and growth parameters of *Eubleekeria jonesi*, *Atule mate*, *Netuma thalassina*, and *Trichiurus lepturus*. These species were selected based on their relatively high abundance with more frequent monthly catches. Electronic Length Frequency Analysis (ELEFAN I) was performed by employing a length frequency interval of 2 mm. The asymptotic length (L∞) and growth coefficient (K) for each species were estimated. The Growth Performance Index (GPI) was then calculated using the equation GPI = log(K) + 2 * log(L∞). The von Bertalanffy growth curve and the length frequency distribution graph were plotted for the species. The natural mortality was calculated using Pauly's M empirical equation log(M) = -0.0066 – 0.279 log(L∞) + 0.6543 log(K) + 0.4634 log(T) where L∞ = data of asymptotic length, K = growth coefficient, and T is the average temperature (i.e., 30.06°C) (Pauly, 1983). Total mortality (Z) was derived as Z = M + F, where Z represents the combined effects of natural mortality (M) and fishing mortality (F). The exploitation rate (E) was estimated using the equation E = F/Z. The recruitment pattern was then analysed where the L∞ and K were inputted into the software (Gayanilo, 2005). The length-structured Virtual Population Analysis (VPA) was conducted by inputting the L∞, K, M, and F to estimate population abundance, fishing mortality, survivors, natural losses, and catches.

Results

List of Species and Ecological Indices

A total of 61 species of fish from 27 families were recorded (Table 1). The families Carangidae and Leiognathidae each have the highest number of species (i.e., 10) and make up 33% of the total fish species found. The families with the fewest number of representative species were Apogonidae, Lactariidae, Lutjanidae, Oostraciidae, Paralichthyidae, Pempheridae, Platycephalidae, Sciaenidae, Sphyraenidae, Terapontidae, Tetraodontidae, and Trichiuridae, with only one species each. The family with the highest total catch is Leiognathidae with 220 individuals, followed by Carangidae (72), and Gerreidae (37) while Apogonidae, Lutjanidae, Paralichthyidae, Platycephalidae, Terapontidae, and Tetraodontidae, each of with only one individual. The average of 14 different fish species were recorded every month, with the highest in December 2021 (25), January 2022 (22), and February 2022 (20) while the lowest was in June 2022 (8) and September 2022 (9).

Species that are frequently encountered includes *Eubleekeria jonesi*, *Secutor megalolepis*, *Photopectoralis bindus*, *Nuchequula flavaxilla* of Leiognathidae, *Netuma thalassina* (Ariidae), *Caranx ignobilis* and *Scomberoides tala* of Carangidae as well as *Gerres subfasciastus* (Gerreidae). These species were recorded for at least more than five different sampling months, and present in either small or large numbers.

The Shannon-Weiner diversity index was significantly ($p < 0.05$) high in December 2021 (2.79) and was lowest in September 2022 (1.81) [Figure 2 (a)]. The diversity index was significantly ($p < 0.05$) higher from December 2021 until February 2022 (2.62 ± 0.18), the highest diversity average for three months, compared to May 2022 until July 2022 (2.08 ± 0.19) with the lowest diversity average for consecutive three months.

The Catch Per Unit Effort (CPUE) was highest during March 2022 with 13 ind./h, and the lowest was during July 2022, September 2022, and October 2022 with 4 ind./h (Figure 2b). The CPUE was significantly ($p < 0.05$) higher from February 2022 until April 2022 (9.67 ± 2.36 ind./h). It recorded the highest average CPUE for three months, compared to August 2022 until October 2022 (4.33 ± 0.47 ind./h), the lowest average CPUE for three months.

The Weight Per Unit Effort (WPUE) was the highest during May 2022, with 0.48 kg/h, and the lowest was during June 2022, July 2022, August 2022, and October 2022 with 0.18 kg/h [Figure 2 (c)]. There was a significant ($p < 0.05$) difference between the highest average WPUE for three months from November 2021 until January 2022 with 0.36 ± 0.05 kg/h and the lowest average WPUE for three months from June 2022 until August 2022 with 0.18 ± 0 kg/h.

The most contributing species in term of total catch is *E. jonesi*, a species from the family Leiognathidae with 81 individuals contributing 16.01% of the total fish abundance (Table 2). This is followed by *Gazza minuta*, another species from the family Leiognathidae with 31

Table 1: List of fish found in the UMS coastline showing the months (i.e., during month of 11 and 12 in year 2021, and from month of 1 to 10 in year 2022) in which the species were caught, their total abundance (CPUE), standard length (cm) and weight (kg)

Family	Species	Common Name	Month (s) (11-12 2021, 1-10 2022)	Abundance (CPUE per hour fishing)	Standard Length (cm)	Weight (kg)
Apogonidae	*Ostorhinchus griffini*	Cardinalfish	1	1	11.3 ± 0	0.044 ± 0
Ariidae	*Hexanematichthys sagor*	Sagor Catfish	5	1	29 ± 0	0.337 ± 0
	Netuma thalassina	Giant Catfish	2, 3, 5, 6, 7, 8, 10	14	14.68 ± 0.73	0.064 ± 0.005
Caesionidae	*Caesio teres*	Yellow-tail fusilier	1	2	13.5 ± 1.3	0.068 ± 0.017
Carangidae	*Alepes djedaba*	Shrimp Scad	5	5	14.1 ± 1.07	0.052 ± 0.012
	Alepes melanoptera	Blackfin Scad	3, 8	4	13 ± 2.8	0.041 ± 0.02
	Atule mate	Yellowtail scad	11, 12, 7, 9, 10	19	15 ± 1.26	0.061 ± 0.01
	Carangoides hedlandensis	Bumpnose Trevally	12, 2, 3	5	8.13 ± 0.31	0.018 ± 0.001
	Caranx ignobilis	Giant Trevally	11, 2, 4, 5, 7, 10	9	12.2 ± 1.03	0.05 ± 0.01

Family	Species	Common name				
	Caranx melampygus	Bluefin Trevally	12, 1, 2	7	14.37 ± 0.45	0.067 ± 0.007
	Parastromateus niger	Black Pomfret	6, 8	3	7.55 ± 0.05	0.016 ± 0.001
	Scomberoides lysan	Queenfish	12, 2, 5	4	18.3 ± 0.03	0.068 ± 0.003
	Scomberoides tala	Barred Queenfish	11, 12, 4, 6, 7, 10	7	18.67 ± 1.65	0.087 ± 0.032
	Scomberoides tol	Queenfish	11, 12, 1, 2, 3	9	16.85 ± 2.46	0.065 ± 0.008
Dorosomatidae	*Amblygaster leiogaster*	Blue Sardine	8	1	9.5 ± 0	0.011 ± 0
	Sardinella fimbriata	Sardine	12	1	7.1 ± 0	0.007 ± 0
Engraulidae	*Stolephorus commersonnii*	Teri Anchovy	12, 2	2	9 ± 0	0.01 ± 0.001
	Stolephorus indicus	Indian Anchovy	11	1	5.1 ± 0	0.001 ± 0
Gerreidae	*Gerres erythrourus*	Short Silverbelly	12, 1, 2	7	8.73 ± 0.52	0.023 ± 0.005
	Gerres subfasciatus	Silverbelly Roach	11, 12, 1, 2, 4, 10	30	11.72 ± 0.82	0.044 ± 0.006
Labridae	*Cheilinus chlorourus*	Floral Wrasse	1	1	13.9 ± 0	0.08 ± 0
	Halichoeres chloropterus	Green Wrasse	1, 5	8	12.38 ± 0.6	0.056 ± 0.004
	Halichoeres nigrescens	Bubblefin Wrasse	12	1	10 ± 0	0.021 ± 0
Lactariidae	*Lactarius lactarius*	False Trevally	4, 6, 7, 8, 10	16	11.67 ± 0.55	0.041 ± 0.004
Leiognathidae	*Aurigequula fasciata*	Striped Ponyfish	7, 8	2	7.2 ± 1	0.011 ± 0.004
	Deveximentum insidiator	Pugnose Ponyfish	4, 5, 7, 9, 10	16	9.6 ± 0.12	0.024 ± 0.002
	Eubleekeria jonesi	Jones' Ponyfish	11, 12, 1, 2, 3, 4, 5, 8, 9, 10	81	8.13 ± 0.76	0.018 ± 0.004
	Gazza minuta	Toothpony	3, 4, 6, 8	31	9.5 ± 0.29	0.028 ± 0.003
	Leiognathus equula	Ponyfish	9	1	7.4 ± 0	0.012 ± 0
	Leiognathus longispinis	Longspine Ponyfish	12, 1, 3, 4	19	9.93 ± 0.46	0.028 ± 0.002
	Nuchequula flavaxilla	Yellowspotted Ponyfish	11, 12, 1, 2, 3, 4	21	9.13 ± 0.34	0.021 ± 0.002
	Nuchequula nuchalis	Spotnape Ponyfish	11, 12, 1, 2	14	7.98 ± 0.44	0.018 ± 0.003
	Photopectoralis bindus	Orangefin Ponyfish	12, 2, 3, 6, 8, 9	25	6.72 ± 0.44	0.008 ± 0.002
	Secutor megalolepis	Bigscale Ponyfish	3, 4, 5, 6, 7, 8, 9, 10	10	7.2 ± 0.21	0.014 ± 0.001
Lutjanidae	*Lutjanus biguttatus*	Two-spot Snapper	8	1	10 ± 0	0.02 ± 0

| Family	Species	Common Name				
Mullidae	*Parupeneus indicus*	Indian Goatfish	12, 2	2	16.5 ± 0.5	0.130 ± 0.05
	Upeneus vittatus	Yellowstriped Goatfish	12, 2	2	11.5 ± 0.8	0.038 ± 0.005
Nemipteridae	*Nemipterus furcosus*	Rosy Threadfin Bream	11, 3	2	12.55 ± 0.55	0.048 ± 0.008
	Scolopsis affinis	Bridled Monocle Bream	3	1	17.5 ± 0	0.163 ± 0
	Scolopsis ciliata	Saw-jawed Monocle Bream	12	1	12.8 ± 0	0.062 ± 0
Ostraciidae	*Rhynchostracion nasus*	Shortnose Boxfish	12, 2	2	9.1 ± 0.2	0.046 ± 0.003
Paralichthyidae	*Pseudorhombus argus*	Peacock Flounder	1	1	9.5 ± 0	0.014 ± 0
Pempheridae	*Pempheris oualensis*	Blackspot Sweeper	1	22	11.24 ± 0.57	0.035 ± 0.005
Platycephalidae	*Platycephalus indicus*	Indian Flathead	1	1	22.6 ± 0	0.107 ± 0
Pomacentridae	*Abudefduf bengalensis*	Bengal Seargent	12, 2	4	10.1 ± 0.3	0.059 ± 0.006
	Abudefduf sexfasciatus	Scissortail Seargent	12, 1, 2, 5	23	9.76 ± 1.01	0.035 ± 0.007
	Stegastes obreptus	Western Gregory	1	4	9.75 ± 0.48	0.036 ± 0.002
Scaridae	*Leptoscarus vaigiensis*	Marbled Parrotfish	1, 5	5	16.33 ± 1.25	0.137 ± 0.034
	Scarus ghobban	Blue-barred Parrotfish	12	1	17.5 ± 0	0.128 ± 0
Sciaenidae	*Nibea soldado*	Soldier Croaker	7, 10	4	14.75 ± 0.75	0.06 ± 0.013
Scombridae	*Rastrelliger brachysoma*	Short Mackerel	8, 9	10	14.74 ± 0.57	0.059 ± 0.008
	Rastrelliger faughni	Island Mackerel	12, 2, 5	3	16.2 ± 1.2	0.077 ± 0.017
	Scomberomorus commerson	Spanish Mackerel	3, 8, 9	5	24.7 ± 7.69	0.16 ± 0.097
Serranidae	*Cephalopholis boenak*	Chocolate hind	1	1	11.5 ± 0	0.05 ± 0
	Epinephelus quoyanus	Longfin Grouper	1	1	13.4 ± 0	0.067 ± 0
Siganidae	*Siganus canaliculatus*	White-spotted Rabbitfish	12, 1	19	12.42 ± 0.64	0.047 ± 0.006
	Siganus virgatus	Doublebar Rabbitfish	3	1	15.3 ± 0	0.137 ± 0
Sphyraenidae	*Sphyraena putnamae*	Chevron	1, 8	4	27 ± 7.18	0.157 ± 0.081
Terapontidae	*Pelates quadrilineatus*	Fourlined Terapon	6	1	12 ± 0	0.042 ± 0
Tetraodontidae	*Chelonodontops patoca*	Milkspotted Puffer	11	1	8.3 ± 0	0.036 ± 0
Trichiuridae	*Trichiurus lepturus*	Beltfish	2, 4, 5, 9	6	78.83 ± 25.62	0.285 ± 0.095
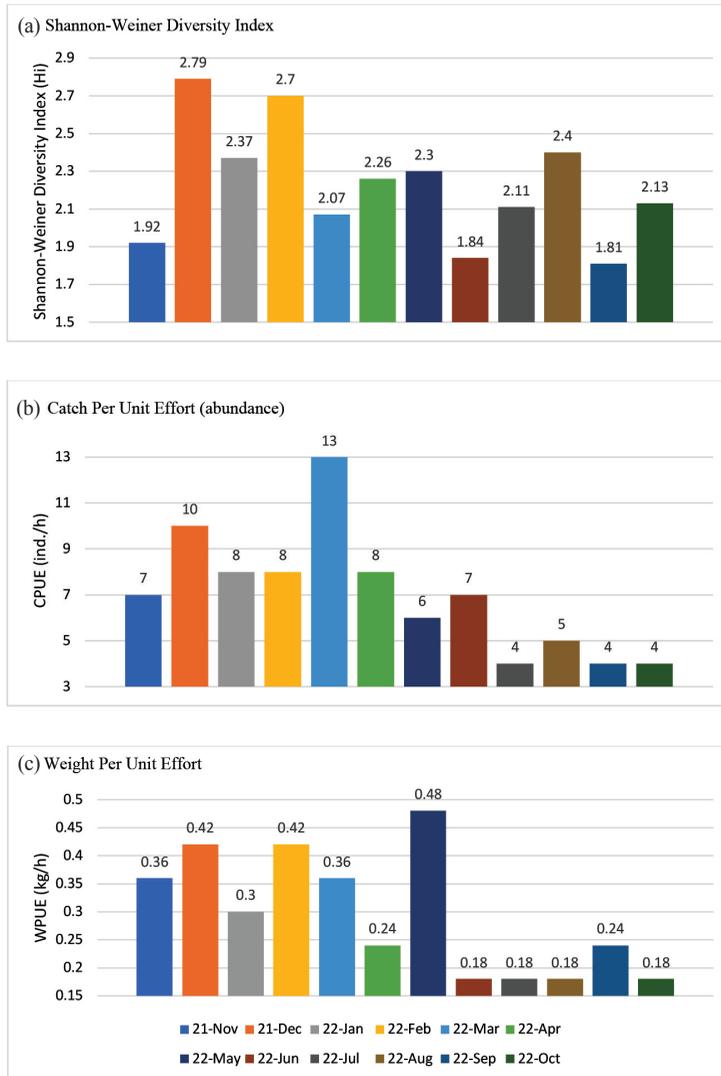
Figure 2: Temporal pattern of Shannon-Weiner Diversity Index (a), CPUE (abundance) (b), and weight (c) of fish found in the UMS coastline

Table 2: The most contributing species in term of total catch, and percentage of total contributions as well as cumulative

Family	Species	Total Catch	Percentage (%)	Cum. (%)
Leiognathidae	*Eubleekeria jonesi*	81	16.01	16.01
Leiognathidae	*Gazza minuta*	31	6.13	22.14
Gerreidae	*Gerres subfasciastus*	30	5.93	28.07
Leiognathidae	*Photopectoralis bindus*	25	4.94	33.01
Pomacentridae	*Abudefduf sexfasciatus*	23	4.55	37.56
Pempheridae	*Pempheris oualensis*	22	4.36	41.92

individuals making up for 6.13% of the total abundance. Other families such as Gerreidae, Pomacentridae, Pempheridae, Carangidae and Siganidae also with relatively high abundance.

Morphometric Size and Temporal Variations

The smallest fish in term of SL size is *Stolephorus indicus*, an anchovy from the family Engraulidae, with only 5.1 ± 0 cm (Table 1). Meanwhile, the largest was *T. lepturus*, a cutlassfish from the family Trichiuridae, with a SL of 78.83 ± 25.62 cm. In term of size by family group, Engraulidae is the smallest with 7.77 ± 1.46 cm in SL while the largest was among Trichiuridae with 78.83 ± 25.62 cm.

As expected, the smallest fish in term of weight is *S. indicus*, an anchovy of only 0.001 ± 0 kg while *Hexanematichthys sagor*, a catfish of Ariidae is the largest with 0.337 ± 0 kg (Table 1). In term of family group, Engraulidae is the

smallest with an average weight of 0.007 ± 0.004 kg while the largest is Trichiuridae, with an average of 0.285 ± 0.095 kg.

The temporal pattern of fish size (i.e., SL and weight) shows notable fluctuations over time among Trichiuridae which can reach 113.5 cm in length during February and May 2022 [Figure 3 (a)]. The highest weight within this family group also recorded during February and May 2022 with 0.367 kg [Figure 3 (b)]. For most other fish species, the size is much smaller (i.e., < 40 cm) compared to Trichiuridae. For example, the highest SL for Sphyraenidae and Scombridae are 31 cm and 24.1 cm, respectively, with the former recorded in January and the latter in March 2022. Both of these families can reach highest weights of approximately 0.199 kg and 0.157 kg for Sphyraenidae and Scaridea, respectively while most other families weigh less than 0.10 kg.
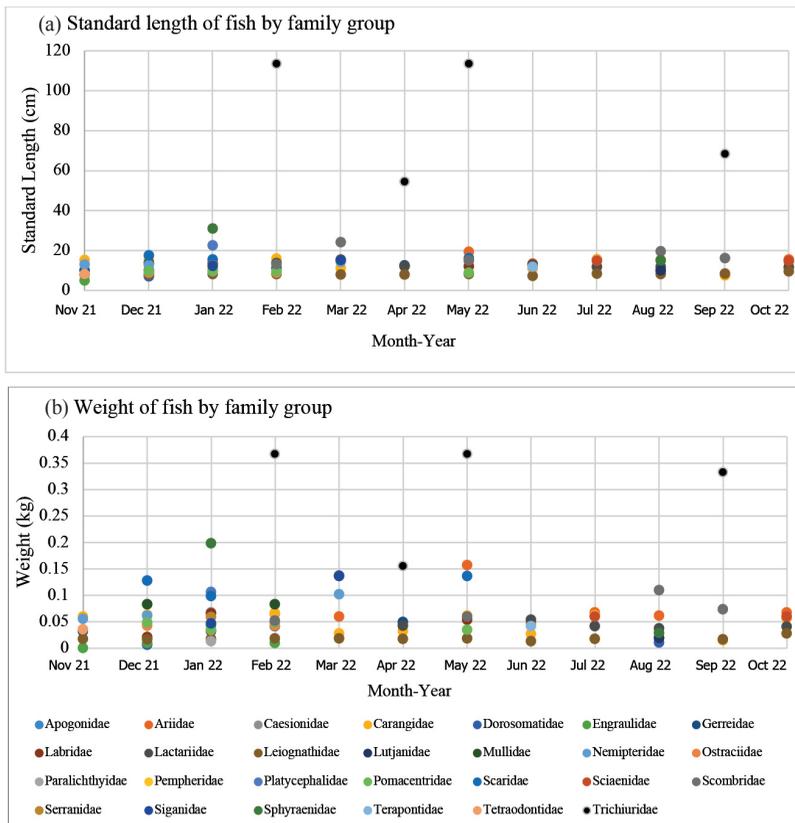

Figure 3: Monthly variations of standard length (a) and weight (b) of fish community by family group

Temporal Pattern of Growth, Recruitment, and Virtual Population

The von Bertalanffy growth curve, and length frequency distribution graphs were plotted for the most abundance species namely *E. jonesi*, *A. mate*, *N. thalassina*, and *T. lepturus*. The growth performance index GPI (Ø) for *E. jonesi* is 3.87, with estimated maximum length of 9.98 cm (Table 3). The maximum length reached in November and December 2021 as well as in February and March 2022 [Figure 4 (a)]. For *A. mate*, the GPI is 2.05 with an estimated maximum length of 19.43 cm (Table 3), mostly in April 2022 [Figure 4 (b)]. The GPI for *N.*

thalassina is 3.8 with an estimated maximum length of 16.2 cm (Table 3) also in April 2022 [Figure 4 (c)], while *T. lepturus* have a GPI of 4.1 and an estimated maximum length of 116.55 cm (Table 3) in February and May 2022 ([Figure 4 (d)].

The recruitment rates of *E. jonesi* over one year period is less than 15%. The highest is in April with 13.72% and gradually decreased thereafter with only slight increase in October [Figure 5 (a)]. *A. mate* has a peak recruitment in March and April, reaching nearly 20%. The

(a) *Eubleekeria jonesi*
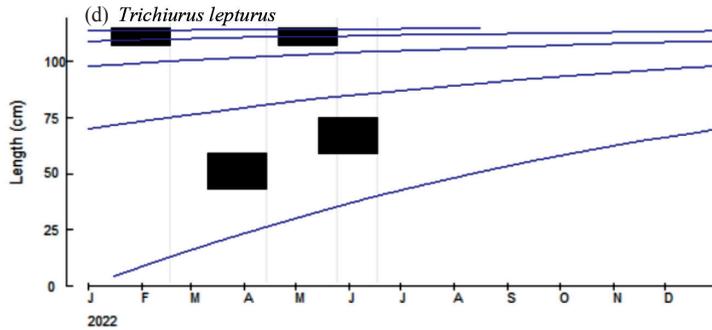
(b) *Atule mate*

(c) *Netuma thalassina*
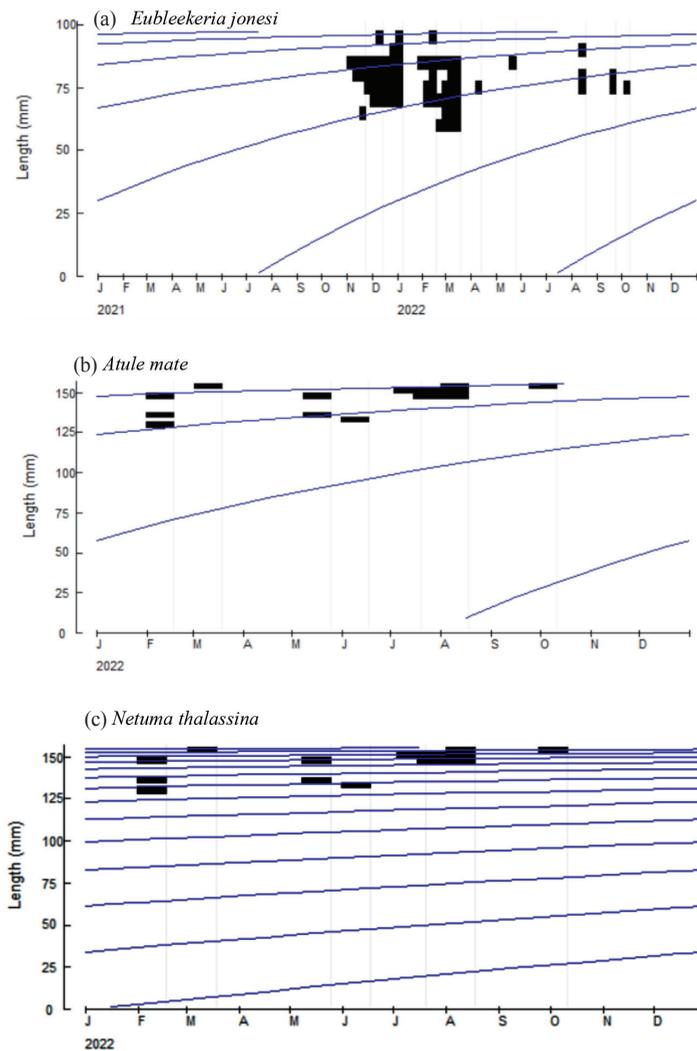
Figure 4: Length frequency distribution with growth curve output from FiSAT II of four most abundance species namely *Eubleekeria jonesi* (a), *Atule mate* (b), *Netuma thalassina* (c), and *Trichiurus lepturus* (d). Growth parameters are shown in Table 3

Table 3: Growth parameters of the four most dominant species. L∞: asymptotic length; K: growth coefficient and GPI (Ø): Growth Performance Index. The month in which maximum length reached for each species are shown in Figure 3

Species	L∞ (cm)	K	GPI(Ø)
*Eubleekeria jones*i	9.98	0.75	3.87
Atule mate	19.43	0.3	2.05
Netuma thalassina	16.2	0.24	3.8
*Trichiurus lepturu*s	116.55	0.92	4.1

number decreases significantly to less than 5% in July, however increases to nearly 15% in October [Figure 5 (b)]. Both *N. thalassina* and *T. lepturus* has relatively high recruitment rates over one year period reaching nearly 30% (February) and 40% (May), respectively, compared to less than 20% for both *E. jonesi* and *A. mate*.

For most species, the number of surviving fish decreases exponentially with increasing group length. Both *E. jonesi* [Figure 6 (a)] and *T. lepturus* [Figure 6 (d)] experience mortality from catches and fishing as they grow larger. For example, E. jonesi experienced mortality due to fishing starting at the size of 6 cm (60 mm) and increasing drastically at the size group of 8.5 cm (85 mm) with F = 1.7. On the other hand, *T. lepturus* experience high fishing mortality at the group size of 103 cm with F = 0.6. Interestingly, both *A. mate* [Figure 6 (b)] and *N. thalassina* [Figure 6 (c)] have almost no mortality of catches whereas fishing mortality was minimal (F = 0.1) at their largest length group.

Species Assemblage in Relation to Water Parameters

Based on cluster analysis of species that contribute to 90% of the total abundance, they can be classified into six groups with 20% similarity (Figure 7). Two horsefish species (*Deveximentum insidiator* and *E. jonesi*) and yellowtail (*A. mate*) are in their own cluster, namely group A, B and C, respectively. Group D comprised of ponyfishes, such as *G. minuta*, *Leiognathus longispinis*, and *Nuchequula flavaxilla*. Group E is the largest cluster with a total 13 species comprises of ponyfishes (*Leiognathus equula* and *Nuchequula nuchalis*), damselfishes (*Abudefduf bengalensis*, *Abudefduf sexfasciatus*, and *Segastes obreptus*), rabbitfishes (*Siganus canaliculatus* and *Siganus virgatus*), blackfin scad (*Alepes melanoptera*), trevallies (*Caranx hedlandensis* and *Caranx melampygus*), queenfishes (*Scombroides lysan* and *Scombroides tol*) and sagor catfish (*Hexanematichthys sagor*). Group F consist of eight species including
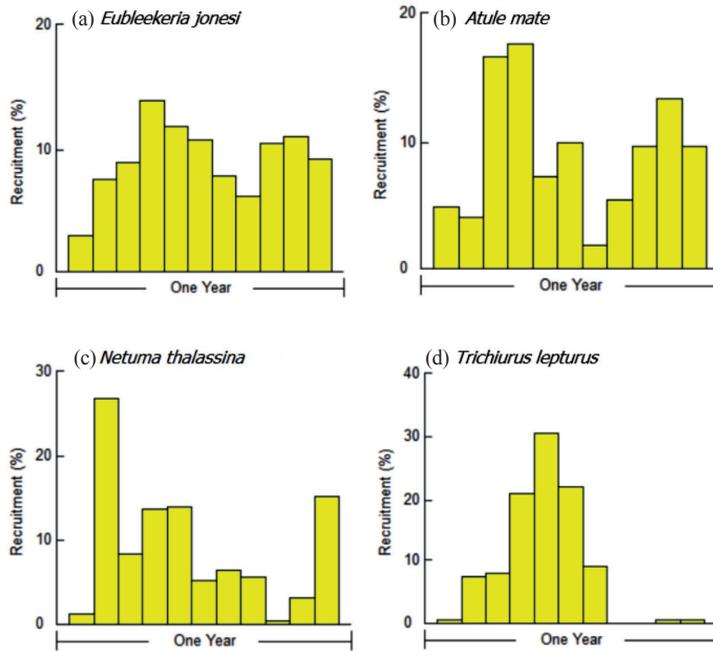
Figure 5: Recruitment percentage of *E. jonesi* (a), *A. mate* (b), *N. thalassina* (c), and *T. lepturus* (d) over the one year period
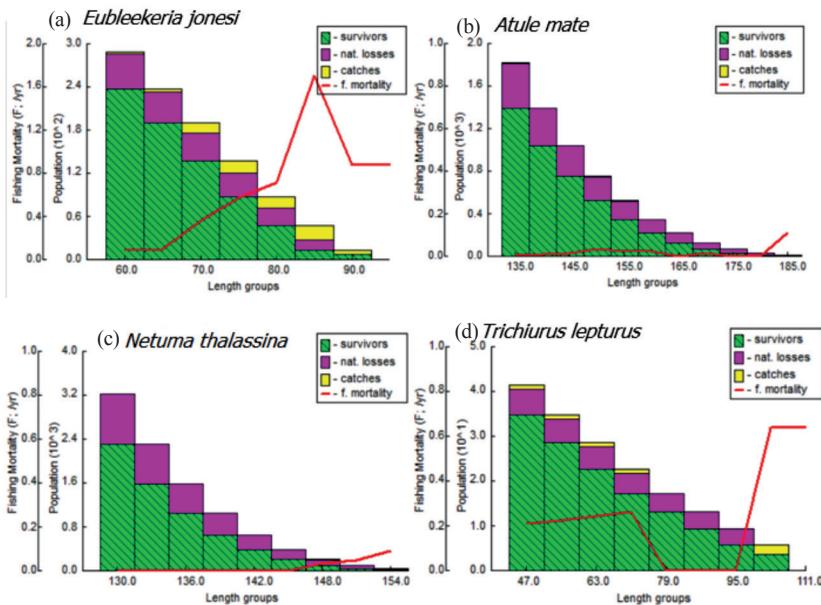

Figure 6: Length-structured Virtual Population Analysis (VPA) of fish population dynamics estimating survivors, natural losses, catches and fishing mortality of *E. jonesi* (a), *A. mate* (b), *N. thalassina* (c), and *T. lepturus* (d)

ponyfishes (*Photopectoralis bindus* and *Secutor megalolepis*), barred queenfish (*Scombroides tala*), black pomfret (*Parastromateus niger*), ribbonfish (*T. lepturus*), giant trevally (*Caranx ignobilis*), giant catfish (*N. thalassina*) and shrimp scad (*Alepes djedaba*).

The fish community can be divided into two groups based on their affinity with water parameters and the sampling month. Group 1 (i.e., circle on the left) includes *Eubleekeria jonesi* (ejon)*, Nuchequula nuchalis* (nnuc), *Scomberoides tol* (stol) and others are mostly found during Nov-21, Dec-21, Jan-22, and Feb-22 (Figure 8). This group are strongly correlated with pH, dissolved oxygen, and salinity. On the other hand, Group 2 (circle on the right) are include Gazza *minuta* (gmin), *Nuchequula flavaxilla* (nfla) and other are mostly found during Mar-22, Apr-22, Jun-22, Aug-22, Sep-22 and with a strong correlation with temperature and turbidity. The number of species and their abundance is relatively high in group 1 with 24 species compare with only 12 species in group 2. There are at least eight species of fish to occur randomly without clear correlations with water parameters and sampling months.

Discussion

A total of 61 fish species were identified in the UMS coastal areas, which is nearly two times higher than the 36 species recorded in Marudu Bay by Khatib (2015) and comparable to the 66 species found in Darvel Bay by Farhana-Azmi *et al*. (2022). It is also comparable to the 70 species reported in one of the highest diversity locations in Sabah, Sarawak, and Brunei waters reported in Vidthayanon (1998). The relatively high species count in the UMS coastline compared to Marudu Bay (e.g., Khatib, 2015) can be attributed to the diverse marine habitats including coral reefs, seagrass and rocky seabed of its subtidal zones, unlike the estuarine environment of Marudu Bay. Despite having slightly fewer species number than Darvel Bay, the UMS coastline exhibited a higher average Shannon-Weiner diversity index (2.23) than in Darvel Bay (2.05).

Two of the most abundance families in the present study are Leiognathidae (ponyfishes) and Carangidae (scads, queenfish, trevallies, and pomfrets). Ponyfishes are typically considered bycatch due to their limited edible flesh and high bone count (Hendrayana, 2020).
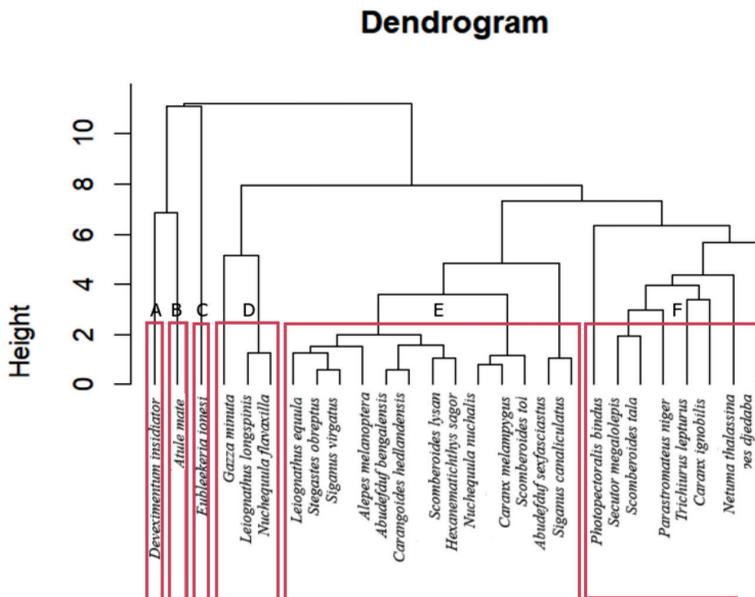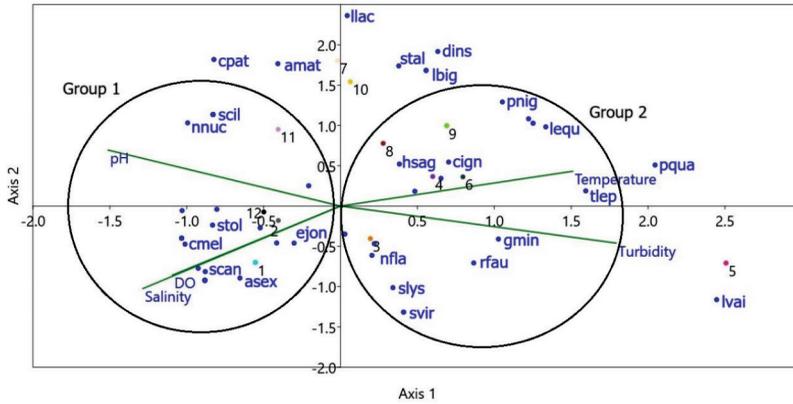
Dendrogram

Figure 7: Cluster analysis of 27 species accounted for 90% of the total abundance. Each species in the similar group (i.e., red boxes A, B, C, D and F) are with 20% similarity in terms of their monthly abundance pattern

Species	Abbreviation	Species	Abbreviation
Hexanematichthys sagor	hsag	*Eubleekeria jonesi*	ejon
Atule mate	amat	*Gazza minuta*	gmin
Caranx ignobilis	cign	*Leiognathus equula*	lequ
Caranx melampygus	cmel	*Nuchequula flavaxilla*	nfla
Parastromateus niger	pnig	*Nuchequula nuchalis*	nnuc
Scomberoides lysan	slys	*Lutjanus biguttatus*	lbig
Scomberoides tala	stal	*Scolopsis ciliata*	scil
Scomberoides tol	stol	*Abudefduf sexfasciatus*	asex
Lactarius lactarius	llac	*Leptoscarus vaigiensis*	lvai
Deveximentum insidiator	dins	*Rastrelliger faughni*	rfau
Pelates quadrilineatus	pqua	*Siganus canaliculatus*	scan
Trichiurus lepturus	tlep	*Siganus virgatus*	svir

Figure 8: CCA ordination of species contributed 90% of total abundance in relation to sampling month and water parameters, such as disolved oxygen, pH, temperature, turbidity, and salinity. Group 1 is on the left while Group 2 is on the right (circled). The species abbreviations is shown in the table

In contrast, Carangids are highly valued as a food source, ranking fourth among the most important pelagic fish resources (Kasim, 2003). The abundance of these families is likely due to the complex habitats of the UMS coastline that may provide food and protection from predators during their juvenile stages (Charbonnel, 2002). This habitat complexity may explain the lower species count in Marudu Bay, which lacks coral reefs, compared to the UMS coastline and Darvel Bay, which have coral reefs (Khatib, 2015; Farhana-Azmi, 2022). Notably, Marudu Bay also had Leiognathidae and Carangidae as the most abundant families. In contrast, Darvel Bay had no Leiognathidae species and only one Carangidae species, indicating these families are not dependent on coral reefs. Leiognathidae are opportunistic omnivores feeding on fish, invertebrates, and algae, contributing to their high diversity (10 species) and abundance (43.48%) in the study area. In contrast, Carangidae primarily feed on smaller fish, resulting in their 10 species and 14.22% abundance.

The study showed an interesting trend of the length and weight of fishes, it steadily increases until the appearance of large predatory families, such as Trichiuridae, Sphyraenidae, and Ariidae,

likely causes the average length and weight of other fish group to be significantly lower than the month before. The largest fish species are of the family Trichiuridae namely *T. lepturus*, commonly known as the ribbonfish and is a commercially valuable fish species that can be found worldwide, usually on continental shelves and slopes (Ahangar, 2009). Ribbonfish exhibit diurnal migration, feeding on smaller fish at night and returning to deeper waters during the day (Rao, 1977; Kudale, 2023). Note that the ribbonfish observed in the present study were likely sexually mature, as their average length (78.83 cm) exceeded the estimated maturity length for females of 70.9 cm (Taghavimotlagh, 2021).

Several studies have reported that larger predatory fishes have size preferences for prey, which often indirectly controls the average size of fish in an ecosystem (Martins, 2005; Colloca, 2009; Li, 2013). The presence of these predators as fish reach a certain size could be influenced by the substrate composition of the study area. Smaller fish use coral reefs for protection, hiding in crevices and caves that larger predators cannot access (Johansson, 2012). As fish grow larger, they lose these hiding spots, increasing their vulnerability to predation.

The growth coefficient (K) for *E. jonesi, A. mate, N. thalassina,* and *T. lepturus* differed from other studies. Specifically, *A. mate* and *N. thalassina* had lower growth coefficients compared to findings by Azim *et al.* (2017) for Marudu Bay (K = 1.5 for *A. mate*) and Wahyuono *et al.* (1985) for Sampit Bay, Kalimantan (K = 0.267 for *N. thalassina*) where the present study reported K = 0.3 for *A. mate* and K = 0.24 for *N. thalassina*. The opposite is true for *T. lepturus*, where the present study had higher growth coefficient with K = 0.92 compared to a study done in the peninsular west coast of Malaysia, with K = 0.850 (Ahmad, 2003). Meanwhile, the growth coefficient for *A. mate* was significantly lower compared to other studies, and the GPI (Ø) was relatively similar to Marudu Bay (Azim, 2017). The GPI (Ø) of both *N. thalassina* (Ø = 3.8) and *T. lepturus* (Ø

= 4.1) was higher as compared to other studies, for example, Wahyuono *et al.* (1985) recorded Ø = 2.87 for *N. thalassina* in Sampit Bay, Kalimantan and Ahmad *et al.* (2003) recorded Ø = 3.97 in peninsular Malaysia. The exploitation rate of fish in the present study is also low, indicating the under-exploitation of these three species. In contrast, the exploitation rate for *E. jonesi* (0.45) was closer to the optimum exploitation rate (0.5). This suggests that fishing methods may be less effective, especially in areas with rocky seabed or coral reefs where the efficiency of using fishing nets may be limited. However, further studies should focus on the reasoning behind the under exploitation of these fish species, since *A. mate* and *T. lepturus* are highly valuable economically.

Fish recruitment in the UMS coastline followed patterns similar to those in other regions. *A. mate* exhibited two major recruitment peaks annually, consistent with studies in Marudu Bay and Kerala, India (Reuben, 1992; Azim, 2017). Similarly, *T. lepturus* exhibits a recruitment pattern akin to a study conducted on the Veraval coast (Avinash, 2014). In this similar tropical area, the peak recruitment period occurred from May to July, closely resembling the findings of our current study. Environmental factors such as temperature, pH, salinity, and DO significantly influence fish spawning (de Vlaming, 1972; Omori, 1978). This suggests that species prefer recruitment periods with low temperature and turbidity and high salinity, pH, and DO levels.

Mortality rates for *E. jonesi*, *A. mate*, *N. thalassina*, and *T. lepturus* decreased as the fish grew larger and older, with juveniles more susceptible to predation (Frenette, 1984; Kingsford, 1994; Hulsmann, 2002). Notably, *A. mate* and *N. thalassina*, which experienced almost no fishing mortality, had higher natural mortality rates in smaller class sizes compared to *E. jonesi* and *T. lepturus*. This higher mortality rate may be linked to their slower growth rates, as *A. mate and N. thalassina* had growth coefficients of K = 0.3 and K = 0.24, respectively, versus K = 0.75 and K = 0.92 for *E. jonesi* and *T. lepturus*. Slower growth rates result in prolonged

periods in smaller, more vulnerable size classes, increasing predation risk. Conversely, species with higher growth rates, such as *E. jonesi* and *T. lepturus*, showed higher fishing mortality, with *E. jonesi* fishing mortality peaking at the 85 mm class size and *T. lepturus* at 103 cm, thus, the relationship between growth coefficients and fishing mortality warrants further investigation.

The UMS coastline exhibited a diverse fish community, with Leiognathidae and Carangidae being the most abundant families. This finding aligns with Khatib *et al.* (2014) study in Marudu Bay, who reported similar species counts for these families. Leiognathidae were present in all six cluster or groups identified in the study, while Carangidae were found in three different cluster. This shows that even though fish are in the same family, the distribution pattern of abundance are different. The cause of the separate species clusters of the same fish family group is not clearly understood, however different timing of peak recruitment times, diet and specific habitats may influence species clusters of fish community.

The fish species in the present study formed two main assemblages based on correlation with environmental factors and seasonal changes monthly. These assemblages showed temporal division: Group 1 (Nov-21 to Feb-22) was highly correlated with pH, DO, and salinity, favourable for groups C, E, and F. Meanwhile, Group 2 (Mar-22 to Sep-22) had higher correlation temperatures and turbidity. As mentioned before, May to September is the southwest monsoon, and November to March is the Northeast monsoon for Malaysia, leading to the change in temperature of marine environments throughout the year (Suhaila, 2010).

Conclusions

The total number of fish species found along the UMS coastline is comparable to the number reported from other studies indicate that the coastal waters support large species diversity. The fish community is dominated by pony fishes (*E. jonesi*, *G. minuta*) and other commercially important species such as scads

(*A. mate*), queenfish (*S. tol*), and cutlassfish (*T. lepturus*). The growth rates of small-sized fish such as *A. mate* and *N. thalassina* in the present study are relatively low compared to the rates reported from other studies. However, this is much higher for large-sized species such as *T. lepturus* and *T. lepturus* compared to the rates reported from other study in Malaysia and Indonesia. Interactions among fish communities, particularly effect of predation, are apparent, and likely to influence species recruitment patterns. For example, the occurrence of larger predatory fish such as cuttlefish causes the abundance of small-sized fish such as ponyfishes to decrease significantly in the following months. Continued efforts to monitor fish populations along coastal waters are essential to assess the impacts of human activities and ensure the resilience of marine ecosystems to the critical impacts of climate change. Future studies should consider the use of more effective fishing gear with nighttime sampling as to maximize fishing effort in fish population studies.

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Conflict of Interest Statement

The authors declare that they have no conflict of interest.

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