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Some Aspects of the Biology of Invasive Fish Species from a Langat River Tributary, Selangor, Malaysia

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ABSTRACT

Invasive fish species pose several threats to aquatic biodiversity and health, necessitating a good understanding of their biology and ecology. This study aims to understand the biology of invasive fish species collected from a Langat River tributary, Selangor, focusing on their growth, reproduction, and feeding habits. Fish and water samples were collected between March and August 2022. A total of 171 specimens were recorded, including 71, 55, and 45 individuals of *Pterygoplichthys disjunctivus, P. pardalis,* and *Oreochromis* sp. The *b* values for length-weight relationships of *P. disjunctivus*, *P. pardalis,* and *Oreochromis* sp. were 2.79, 2.92, and 2.89, respectively. The mean condition factor for *Oreochromis* sp. was significantly ($p < 0.05$) higher than that of the other two species. There were no significant differences between the observed and expected number of males and females for all three species. The females had higher mean gonadosomatic index values compared to males. The mean fecundity for *P. disjunctivus*, *P. pardalis*, and *Oreochromis* sp. were 973 ± 596, 10562 ± 830, and 1052 ± 1068, respectively. The most important

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stomach contents of the three species were detritus, mineral particles, and diatoms, with a higher proportion of mineral particles found in the diets of *P. disjunctivus* and *P. pardalis*. The information on growth patterns, reproductive strategies, and dietary preferences provides valuable insights for controlling their invasion of local rivers.

Keywords: Feeding, fish ecology, food, gonadosomatic index, length-weight relationship, non-native species, water quality

INTRODUCTION

Invasive fish species pose a significant threat to native aquatic biodiversity, ecosystems, and fisheries worldwide because they can displace native species, alter habitats, and spread diseases (Xiong et al., 2023). These fish species might act as predators or rivals against indigenous species (Camacho-Cervantes et al., 2023), transmit parasites or pathogens (Šimková et al., 2019), or result in unexpected hybridization (Arndt et al., 2018). Thus, it may ultimately result in the loss of local biodiversity by eradicating indigenous species (Bezerra et al., 2019).

The Langat River is a crucial watercourse in Selangor, Malaysia, which ordinarily should be rich in diverse native fish species that have also been recorded in other adjoining water bodies. Native fishes are important because they can contribute to the river's ecological functioning (Wang et al., 2021). However, the presence of invasive fish species threatens the delicate balance and functioning of freshwater ecosystems (Nagelkerke et al., 2018).

Initially, alien fish species were imported to Malaysia for a variety of purposes, including the necessity to increase the nation's fish productivity and uses, such as ornamental fish keeping, sport fishing, and the biological control of undesirable species (Saba et al., 2020a). Unfortunately, when these fish are introduced into local waters, and their detrimental effects reach a tipping point, resulting in environmental dominance, alien fish become invasive (Havel et al., 2015; Piria et al., 2018). Besides that, they may spread to other water bodies, which may further increase their impact on the native ecosystem's biodiversity.

Alien fish species like tilapia (*Oreochromis* sp.) and sailfin catfishes (*Pterygoplichthys pardalis* and *P. disjunctivus*) have been imported intentionally and unintentionally for various purposes to Malaysia, including aquaculture, aquarium, recreational, and biological control purposes, resulting in their introduction and establishment of breeding populations in inland waters in Malaysia (Rahim et al., 2013; Saba et al., 2021). These invasive species can spread diseases, compete with native species for food and space, and predate on them, leading to population decline and the elimination of many native species (Ahmad et al., 2020). More so, some species have been categorized as invasive to Malaysia based on the risk assessment using the fish invasiveness screening kit (FISK) and the aquatic species screening kit (AS-ISK) (Saba et al., 2020b; Vilizzi et al., 2021).

Research on different aspects of the biology of fish species, including the length-weight relationship, condition factor, reproductive biology, and the food and feeding habits of fish, are crucial for understanding how different species are likely to interact with each other and their possible roles in their resident aquatic ecosystems (Tran et al., 2021). Despite numerous introduced fish species present in Malaysia's inland waterbodies and the growing research on their negative impacts on native species and the aquatic ecosystem, there still exists a dearth of information on the biology of non-native fish species recorded in many other waterbodies in Malaysia. Apart from Samat et al. (2016) and Saba et al. (2021), most of the previous studies have focused mainly on distribution and occurrence (Aqmal-Naser et al., 2023; Hamid et al., 2022; Khaleel et al., 2020), and invasion risk screening (Kiat & Rahim, 2023; Saba et al., 2020b; Vythalingam et al., 2022) of these species. To better understand the potential impacts of these invasive species in the inland waters of Malaysia, this study aims to explore some aspects of the biology of invasive fish species from a Langat River tributary, Selangor. The objectives are, therefore, to assess the length-weight relationships and condition factors of the three important invasive fish species, evaluate the sex ratio, gonadosomatic index, and fecundity of the species, and determine the food and feeding habits.

MATERIALS AND METHODS

Study Area

The study area refers to a stream that flows through a dense residential area of Sungai Merab and into the Langat River, Selangor. The stream's bottom is shallow and sandy, with a depth ranging from 0.2 to 1.2 m and a width of 2.5 to 10.0 m. The riverbank is densely vegetated with tall grasses and several crops, such as banana trees, sugar cane, and coconut trees.

The sampling was undertaken over six months at three different times, which coincided with 18th March 2022, 26th May 2022, and 25th August 2022. The rainfall patterns are significantly influenced by two distinct monsoon seasons: the northeast monsoon, which takes place between October and March, and the southwest monsoon, which typically starts in May and concludes in September (Amirudin et al., 2022). Fish sampling was conducted within 200 m along the stream at points A (2°55'03.6"N 101°45'13.6"E), B (2°55'01.1"N 101°45'12.5"E), and C (2°54'57.5"N 101°45'13.7"E) (Figure 1).

Water Quality Measurement

Water quality was measured at three different points along a 200 m stretch of the sampling site. During each of the three times of sampling, a total of three readings were taken. Water

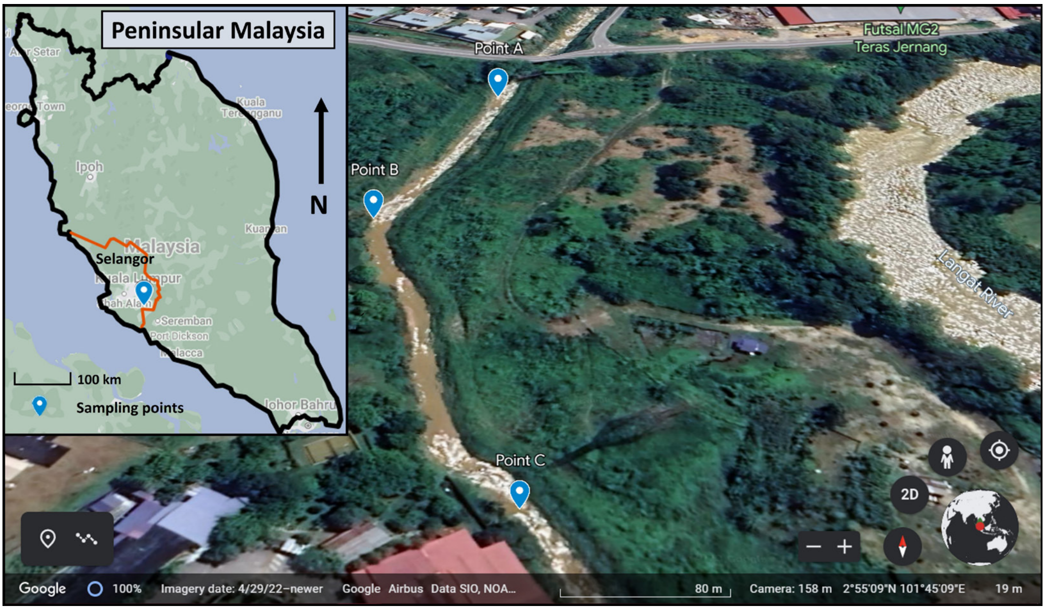

Figure 1. Map showing the location of the sampling points along the Langat River tributary, Selangor, Malaysia (*Source:* Google Earth)

quality parameters were measured, including dissolved oxygen, pH, water temperature, and total dissolved solids (TDS). On-site measurements were taken using a YSI 556 MPS probe (YSI, Yellow Springs, OH, USA). Additionally, chemical parameters, including ammonia, nitrite, nitrate, phosphate, and sulfate concentrations, were analyzed using a spectrophotometer (HACH, Loveland, CO, USA). The *ex-situ* measurements were conducted less than 24 hours after collecting the water samples using sterilized 500 mL polyethylene bottles.

Fish Sampling and Processing

Fish were sampled using a cast net with a length of 150 cm, a diameter of 305 cm, and a mesh size of 2 cm. The sampling activity was accomplished in 2 hours by four individuals for each sampling day, with the cast nets deployed approximately 24 times on each sampling day. All specimens collected were stored in a cool box containing ice cubes before being transported back to the laboratory for further assessment. Fishes were identified based on Zakaria-Ismail et al. (2019) and Saba et al. (2020c). All samples were dissected after the fish length and weight measurements were completed. The total length (TL), standard length (SL), and body weights (BW) of all collected specimens were measured to the nearest 0.1 cm and 0.1 g, respectively, by using a fish measuring board and a digital weighing scale. The ventral side of the fish was dissected to expose the viscera. The esophagus, intestine, stomach, and gonad (testis and ovary) were collected and separated from other visceral organs. The collected gut and gonad were then measured for length and weight to the nearest 0.1 cm and 0.1 g, respectively. The gut was preserved in 5% of formalin, while the gonad was preserved in 10% of buffered formalin. The gut and gonad were labeled and stored in a separate bottle.

Length-weight Relationship and Condition Factor

The relationship between fish weight and length may be shown using Equation 1 (Fakoya et al., 2019):

$$W = aL^b \qquad [1]$$

where: W = weight of the fish (g); L = total length of fish (cm); *a* = regression constant; and *b* = allometric coefficient.

Log-transformed data was utilized, and the least-square approach was used to estimate the values of constants *a* and *b* (Equation 2) (Zar, 1984).

$$\text{LogW} = a + b\text{LogL} \qquad [2]$$

Condition Factor

The Equation 3 for condition factor (K) is as follows:

$K = 100W/L^3$ (Mozsár et al., 2015) [3]

where: K= condition factor; W= weight (g); and L= total length of fish (cm).

Kruskal-Wallis's test was used to compare the well-being of the three invasive fish species at a $p < 0.05$.

Sex Ratio, Gonadosomatic Index and Fecundity

To statistically assess the sex ratio, Pearson's chi-square goodness of fit test in IBM SPSS, ver. 26.0 (IBM Corp., Chicago, IL, USA) was used based on Equation 4 for the chi-square statistic, which is:

$$X^2 = \sum [(O - E)^2 / E] \qquad [4]$$

where O is the observed frequency, and E is the expected frequency.

The gonadosomatic index (GSI) was determined after collecting ovaries from fish, blotting them, weighing them individually, and separating the eggs. Measurements of the weight of the fish gonad and the weight of the body without the gonad were then used to determine the GSI as in Equation 5:

$$GSI = 100 \times W_g / W \quad [5]$$

where: Wg = weight of wet gonad (g); and W = total wet body weight without gonad (g).

Small sub-samples from the posterior, middle, and anterior portions of the ovary were removed to calculate the fecundity. Then, each sub-sample was weighed to the nearest 0.1 g. The eggs within each sub-sample were counted using a dissecting microscope. The fecundity was, therefore, calculated according to Rahman and Samat (2021) as in Equation 6:

$$\text{Fecundity} = \frac{\text{Average number of eggs in sub-samples} \times \text{Weight of ovary (g)}}{\text{Weight of sub-sample (g)}} \quad [6]$$

Gut Content Extraction and Identification

Gut content analysis was performed by collecting the contents from the gut and transferring them to a petri dish containing 5 mL of distilled water to facilitate dilution. The occurrence frequency, volumetric approach, and index of preponderance were applied to obtain a more comprehensive perspective on dietary importance. The stomach contents were examined under a stereomicroscope using a 0.2 mm deep, 16 × 16 Fuchs Rosenthal counting chamber. The contents were then classified as multicellular green algae, unicellular green algae, red algae, plant parts, euglenoids, Xanthophyceae, Cyanobacteria, diatom, detritus, and mineral particles (Wickramaratne, 2021; Saba et al., 2021).

Frequency of Occurrence

The total number of stomachs containing prey items was expressed as a percentage of all non-empty stomachs to determine the frequency of occurrence (Hyslop, 1980). The frequency of occurrence method Equation 7 is as follows:

$$\%Oi = \frac{Ni}{N} \times 100 \quad [7]$$

where: $\%Oi$ = the frequency of occurrence of given food i ; Ni = number of stomachs containing prey I; and N = total number of stomachs with food.

Percentage Volume

The percentage volume was calculated using the volumetric method, where the volume of each food item was expressed as a proportion of the total volume of food in the stomach (Silveira et al., 2020). The following Equation 8 was used:

$$\%Vi = \frac{Vi}{Vt} \times 100 \quad [8]$$

where: $\%Vi$ = percentage of food items I; Vi = volume of item I; and Vt = total volume of food (gut content).

Index of Preponderance

The index of preponderance was used to determine the relative significance of each food category based on the percent volume and frequency of occurrence values (Santi et al., 2017). This index's Equation 9 is as follows:

$$I = \frac{ViOi}{\sum VtOt} \times 100 \quad [9]$$

where: I = index of preponderance; Vi = percentage volume of food component; Oi = Percentage of occurrence of food item; Vt = total percentage volume of food component; and O_t = total percentage of occurrence of food item.

Data Analysis

Microsoft Excel spreadsheet software (Office 365, Version 2016, Microsoft Corp., Berkshire, UK) was used for record-keeping purposes and analyzed to obtain descriptive statistics. Data collected from the condition factor and length-weight relationship was analyzed using simple linear regression from the log equation. All inferential statistics were done in IBM SPSS, ver. 26.0 (IBM Corp., Chicago, IL, USA).

RESULTS

Water Quality Assessment

From March to August 2022, temperature, dissolved oxygen, and ammonia levels showed declining patterns, whereas pH, conductivity, and TDS demonstrated increasing tendencies. Phosphate and sulfate declined over time, with March showing the greatest average values for both parameters, while August had the lowest average values. The nitrate concentration gradually rose from March to May and declined from May to August. The nitrite concentration declined from March to August (Table 1).

Table 1
Summary of water quality parameter measurements from the three sampling months

	Readings (Mean ± SD)		
Parameters	**March**	**May**	**August**
Temperature (ºC)	28.8 ± 0.2	27.8 ± 0.2	27.7 ± 0.3
Dissolve oxygen (mg/L)	4.5 ± 0.3	4.9 ± 1.1	5.6 ± 0.8
Conductivity (µS/cm)	0.1 ± 0.0	0.2 ± 0.0	0.2 ± 0.0
Total dissolved solids (mg/L)	80.4 ± 0.4	90.1 ± 2.7	93.0 ± 0.7

Table 1 *(continue)*

	Readings (Mean ± SD)		
Parameters	**March**	**May**	**August**
pH	7.63 ± 0.10	7.70 ± 0.00	8.00 ± 0.10
Phosphate (mg/L)	12.7 ± 0.8	11.6 ± 0.9	1.1 ± 0.4
Sulphate (mg/L)	20.2 ± 3.3	9.4 ± 1.9	7.3 ± 1.3
Nitrate (mg/L)	5.2 ± 0.7	7.2 ± 1.6	5.2 ± 0.6
Nitrite (mg/L)	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0
Ammonia (mg/L)	0.3 ± 0.0	0.2 ± 0.0	0.1 ± 0.0

Fish Length and Weight

A total of 171 specimens were collected, including 71, 55, and 45 individuals of *P. disjunctivus*, *P. pardalis,* and *Oreochromis* sp., respectively. The overall mean lengths and weights for the three species spanning the study duration are presented in Table 2, while Figure 2 shows the invasive species sampled.

Table 2
Overall length and weight information of the invasive fish species

Species		**Mean ± SD**	**Min**	**Max**
P. disjunctivus	Length (cm)	22.9 ± 6.8	12.3	46.1
	Weight (g)	125.7 ± 20.0	15.0	665.0
P. pardalis	Length (cm)	24.5 ± 6.2	11.6	42.6
	Weight (g)	149.9 ± 113.6	15.0	550.0
***Oreochromis* sp.**	Length (cm)	16.3 ± 3.4	8.9	24.0
	Weight (g)	96.0 ± 59.3	15.0	275.0

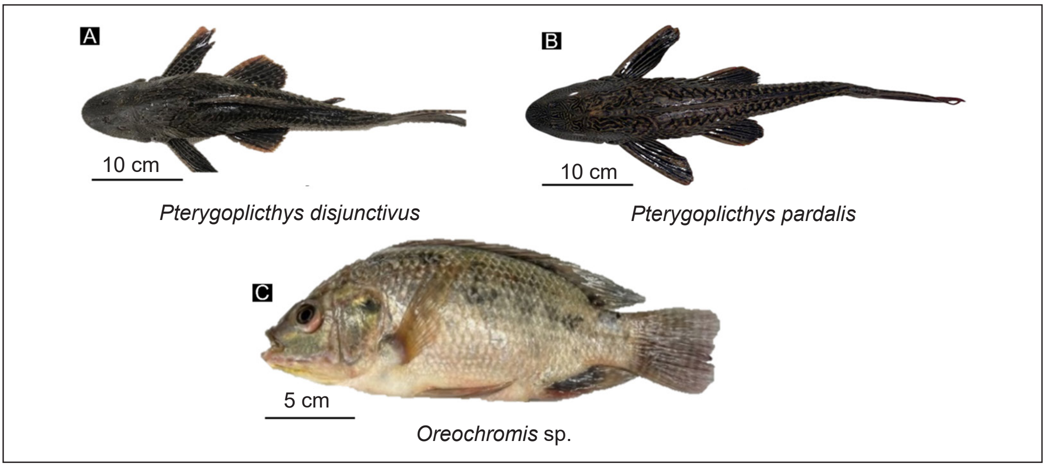

Figure 2. Invasive fish specimens: (A) *Pterygoplichthys disjunctivus*, (B) *P. pardalis*, and (C) *Oreochromis* sp.

A summary of length and weight information for the three different sampling months is presented in Table 3. In March, the average body weight of *P. disjunctivus* was 287.4 ± 215.5 g, with the highest recorded weight being 1125.0 g. In May, the weight reduced to 165.5 ± 135.9 g, while in August, it decreased even further to 72.4 ± 42.9 g. In March, the average body weight of *P. pardalis* was 146.0 ± 120.8 g, with the highest recorded weight being 550.0 g. In May, the weight rose to 176.2 ± 137.3 g and in August, it dropped to 126.8 ± 58.5 g. The average body weight of *Oreochromis* sp. was 72.7 g ± 41.6 g in March, ranging from 15.0 g to 180.0 g. The average body weight in May rose to 133.5 g ± 70.8 g, ranging from a minimum of 40.0 g to a maximum of 275.0 g. The average body weight in August declined to 94.8 g ± 57.6 g, ranging from a minimum of 25.0 g to a maximum of 220.0 g.

Table 3
Monthly length and weight information of the invasive fish species

Month	Species	N	Mean BW (g) ± SD	Min BW (g)	Max BW (g)	Mean TL (cm) ± SD	Min TL (cm)	Max TL (cm)
March	*P. disjunctivus*	30	287.4 ± 215.5	15.0	1125.0	43.2 ± 6.9	12.3	41.1
May	*P. disjunctivus*	23	165.5 ± 135.9	45.0	665.0	26.4 ± 6.9	16.7	46.1
August	*P. disjunctivus*	18	72.4 ± 42.9	20.0	170.0	19.6 ± 4.6	12.4	28.4
March	*P. pardalis*	25	146.0 ± 120.8	15.0	550.0	24.2 ± 7.0	11.6	42.5
May	*P. pardalis*	16	176.2 ± 137.3	35.0	475.0	25.5 ± 6.8	16.0	40.2
August	*P. pardalis*	14	126.8 ± 58.5	45.0	235.0	23.9 ± 3.6	17.6	31.7
March	*Oreochromis* sp.	15	72.7 ± 41.6	15.0	180.0	15.1 ± 2.9	8.9	21.0
May	*Oreochromis* sp.	10	133.5 ± 70.8	40.0	275.0	18.8 ± 3.1	12.8	24.0
August	*Oreochromis* sp.	20	94.8 ± 57.6	25.0	220.0	16.0 ± 4.0	10.0	23.0

Length-frequency Distribution

The highest number of individuals in any size class for the entire sampling period was 34, as recorded for *P. disjunctivus* in the 15.0–19.9 cm size class. *Pterygoplichthys pardalis* recorded the largest number of individuals in the 20.0–24.9 cm and 25–29.9 cm size classes, while *Oreochromis* sp. recorded the largest number of individuals in the 15.0–19.9 cm size class (Figure 3).

Length-weight Relationship and Condition Factor

The results of the length-weight relationships (LWR) and condition factors (CF) are presented in Table 4. The *b* values for *P. disjunctivus, P. pardalis,* and *Oreochromis* sp. were 2.79, 2.92, and 2.89, respectively. *Oreochromis* sp. had the highest mean condition factor (1.97 ± 0.23) while the sailfin catfishes (*P. disjunctivus* and *P. pardalis*) recorded CF values less than 1.

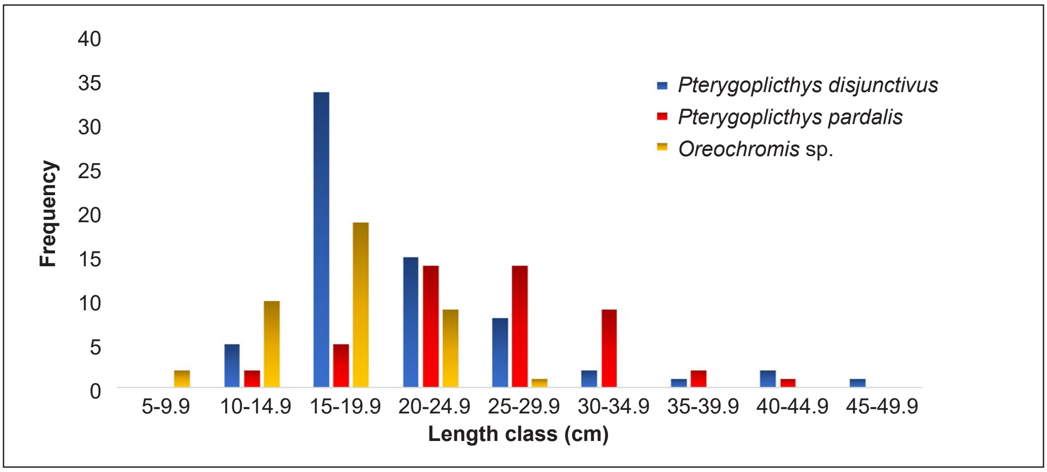

Figure 3. Length frequency distribution of invasive fish species

Table 4

The three invasive species' length-weight relationship and condition factor values over the entire sampling period

Species	N	Equation	R^2	Mean CF ± SD	Min CF	Max CF
P. disjunctivus	71	y = 2.7939x - 1.7909	0.9705	0.86 ± 0.14^a	0.50	1.16
P. pardalis	55	y = 2.9232x - 1.9586	0.9785	0.86 ± 0.11^a	0.80	1.12
***Oreochromis* sp.**	45	y = 2.8942x - 1.5834	0.9761	1.97 ± 0.23^b	1.42	2.53

Note. Means with different superscripts indicate significant differences at $p < 0.05$

Throughout the study period, the *b* values recorded for *P. disjunctivus* in March (2.93), May (2.89), and August (2.61) were found to be less than 3. *Pterygoplichthy pardalis* recorded *b* values of 2.91, 2.87, and 2.93 in March, May, and August, respectively, while *Oreochromis* sp. was 2.95 in March, 3.09 in May, and 2.85 in August. All the *b* values were less than 3, indicating negative allometric growth, except for May, where *Oreochromis* sp. recorded a *b* value of 3.09, exhibiting positive allometric growth.

Sex Ratio, GSI and Fecundity

There were no significant differences between the observed and expected number of males and females for *P. disjunctivus* X^2 (1, N = 45) = 0.56, $p = 0.456$, *P. pardalis* X^2 (1, N = 49) = 0.67, $p = 0.184$ and *Oreochromis* sp. X^2 (1, N = 53) = 0.17, $p = 0.680$. Therefore, the proportion of males and females was not significant ($p > 0.05$). The females had higher mean GSI values for all three species than males. However, female *Oreochromis* sp. had a lower mean GSI compared to the females of the two sailfin catfishes (Table 5).

The temporal variation in GSI for the three invasive species is presented in Figure 4. The highest GSI values for female *P. disjunctivus* were recorded in August (2.09), and the lowest GSI values were in March (0.61) during the study period. For the males, the highest

Table 5
Gonadosomatic index (GSI) values of the three invasive fish species

Species	Sex	N	Mean ± SD	Min GSI	Max GSI
P. disjunctivus	Male	19	1.18 ± 2.62	0.12	11.85
	Female	24	9.63 ± 6.50[a]	0.19	21.29
	Total	43	5.90 ± 6.59	0.12	21.29
P. pardalis	Male	26	0.41 ± 0.64	0.08	3.22
	Female	23	8.06 ± 5.32[a]	0.35	19.11
	Total	49	4.47 ± 5.46	0.08	19.11
Oreochromis sp.	Male	19	0.38 ± 0.52	0.03	2.22
	Female	18	1.72 ± 1.32[b]	0.23	4.93
	Total	37	1.03 ± 1.19	0.03	4.93

Note. The same superscript for female *P. disjunctivus* and *P. pardalis* indicates no significant difference ($p > 0.05$) in their GSI values. GSI values were computed only for specimens with identifiable gonads

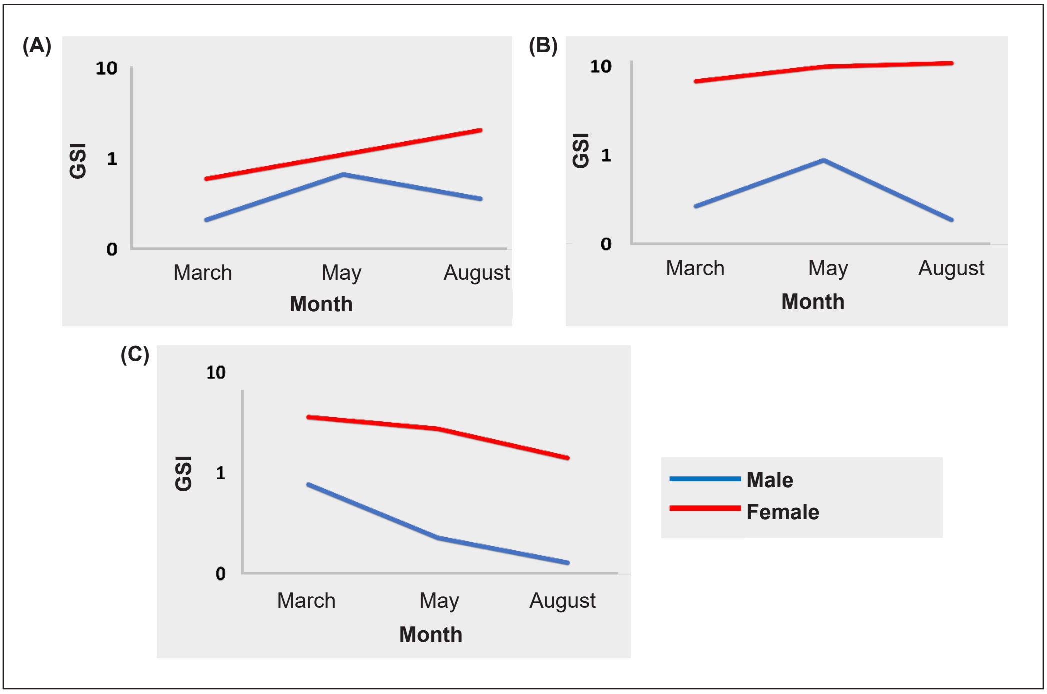

Figure 4. Temporal variation of the gonadosomatic index (GSI) for males and females of (A) *Pterygoplichthys disjunctivus,* (B) *Pterygoplichthys pardalis,* and (C) *Oreochromis* sp.

GSI values were recorded in May (0.68), and the lowest GSI values recorded were in March (0.21). For *P. pardalis,* the highest GSI value for males was in May (0.89), whereas the highest GSI value recorded for females was in August (11.01). The lowest GSI value for males was detected in August (0.19), whereas the lowest GSI value for females was recorded in March (6.88) for *P. pardalis.* The GSI for female *Oreochromis* sp. was found to be the highest (2.87) in March and the lowest (1.30) in August. On the other hand, male GSI was highest (0.78) in March and the lowest (0.13) in August.

The mean fecundity for *P. disjunctivus*, *P. pardalis,* and *Oreochromis* sp. were 972.5 ± 595.7, 10562.0 ± 829.6, and 1052.3 ± 1068.1, respectively. For *P. disjunctivus,* the highest fecundity was observed in May.

Food and Feeding Habits

Overall Stomach Contents

Details of food items found in the stomachs of the three invasive fish species throughout the study period are presented in Table 6. The food categories most important to *P. disjunctivus* and *P. pardalis* based on percentage frequency of occurrence, FO (%), and percentage index of preponderance, IP (%) were detritus, mineral particles, and diatoms. In contrast, detritus, mineral particles, and unicellular green algae were the most important factors for *Oreochromis* sp.

By percentage volume, VO (%), detritus, mineral particles, diatoms, and plant parts were the most important stomach contents to *P. disjunctivus* and *P. pardalis*, respectively, while by IP (%) detritus, mineral particles, diatoms were the most important for *P. disjunctivus* and *P. pardalis.* Detritus, mineral particles, and unicellular green algae were the most important stomach contents for *Oreochromis* sp. by IP (%).

Table 6
Summary of overall food items of three invasive species

	FO (%)			VO (%)			IP (%)		
Stomach content	**PD**	**PP**	**OR**	**PD**	**PP**	**OR**	**PD**	**PP**	**OR**
Mineral particles	95.56	100	86.67	22.66	29.82	6.84	4.68	34.59	0.89
Detritus	100	100	100	51.50	27.2	63.53	10.59	31.56	10.41
Diatom	61.80	81.57	56.67	5.11	9.59	2.49	0.71	9.09	0.23
Cyanobacteria	23.59	77.56	76.67	1.48	9.38	6.23	0.08	8.50	0.71
Unicellular green algae	55.27	30.32	77.78	5.81	1.96	6.74	0.65	0.69	0.82
Multicellular green algae	54.96	54.39	56.11	4.18	6.63	3.53	0.45	4.45	0.30
Red algae	0.00	63.01	43.33	1.91	3.99	1.32	0.00	2.90	0.10
Xanthophyceae	0.00	27.19	31.37	0.00	1.24	0.00	0.12	0.39	0.00
Euglenoids	18.21	41.92	0.00	1.23	2.18	0.06	0.00	1.11	0.00
Plant parts	58.17	70.43	90.00	6.13	8.01	5.98	0.70	6.72	0.82
Insect part	0.00	0.00	50.56	0.00	1.99	0.00	0.00	0.00	0.15
Zooplankton	0.00	41.11	0.00	0.00	1.36	0.00	0.00	0.00	0.09

Note. FO% = percentage frequency of occurrence, VO% = percentage volume, IP% = Percentage index of preponderance, PD = *P. disjunctivus*, PP = *P. pardalis*, OR = *Oreochromis* sp.

Monthly Stomach Contents

The feeding habits of the three invasive species over the sampling months indicated that detritus is the primary food source for all organisms (Table 7). *Pterygoplichthys disjunctivus* exhibits a debris predilection and a minimal inclination towards euglenoids. *Pterygoplichthys pardalis* mostly ingest mineral particles and shows minimal attraction towards Xanthophyceae. *Oreochromis* sp. exhibits a preference for debris; however, there is a transition to diatoms in March and August, and there is a minimal intake of unicellular algae in May.

Table 7
Most and least important stomach content in invasive fish species by sampling months

Species	Month	The most important food items	FO (%)	VO (%)	IP (%)
P. disjunctivus	March	Detritus	100	48.4	9.2
	May	Detritus	100	61.9	12.4
	August	Detritus	100	47.4	11.1
P. pardalis	March	Mineral particles	100	32.8	37.9
	May	Mineral particles	100	27.6	32.6
	August	Mineral particles	100	29.1	33.9
Oreochromis sp.	March	Detritus	100	52.6	7.5
	May	Detritus	100	57.8	6.7
	August	Detritus	100	80.2	17.1
Species	**Month**	**Least important food items**	**FO (%)**	**VO (%)**	**IP (%)**
P. disjunctivus	March	Euglenoids	31.1	1.1	0.1
	May	Euglenoids	13	0.4	0
	August	Euglenoids	6.6	0.3	0
P. pardalis	March	Xanthophyceae	28	1.1	0.4
	May	Xanthophyceae	25	1.5	0.5
	August	Xanthophyceae	28.6	1.1	0.4
Oreochromis sp.	March	Diatoms	40	1.7	0.1
	May	Unicellular Algae	0.9	0.5	0.2
	August	Diatoms	0.9	0.2	0.2

Note. FO% = percentage frequency of occurrence, VO% = percentage volume, IP% = Percentage index of preponderance

DISCUSSION

This study assessed some aspects of the biology of invasive fish species in the Langat River tributary, Selangor, Malaysia, based on growth, reproduction, and feeding habits over six months. Selangor, Malaysia, experiences considerable climatic variability throughout the year, which allowed the possibility of documenting aspects of fish biology during different seasons within the sampling duration.

Water Quality Assessment

Most physico-chemical parameters observed in this study were within the recommended ranges for the survival of tropical freshwater fish (Towers, 2015). However, it is worth noting that some parameters exhibited a high standard deviation, indicating the presence of readings that may not be optimal for fish. However, invasive fish species are known for their hardiness and may thrive in suboptimal water quality conditions.

Length-weight Relationship and Condition Factor

Although *P. pardalis* had the highest overall *b* value in this study, all three species exhibited negative allometry. *Oreochromis* sp., however, exhibited a positive allometry in May. More so, compared to *P. disjunctivus* and *P. pardalis*, *Oreochromis* sp., which had the highest mean CF, exhibited better well-being. It may translate to the fact that *Oreochromis* sp., despite a drop in some water quality parameters, could flourish, underscoring the significantly higher CF values for this species compared to its invasive counterparts. This competitive advantage could contribute to the outcompeting of the native species by *Oreochromis* sp. (Beatty et al., 2022; Saba et al., 2021). The invasive species' ability to flourish under suboptimal water quality conditions, coupled with their higher CF, may give them an upper hand in resource utilization and potentially lead to the displacement or decline in the diversity and abundance of native species.

Sex Ratio, GSI and Fecundity

The sex ratio in the three invasive species is not influenced by any factor that would lead to a non-random distribution of males and females. More so, for all three species, the female sex had higher mean GSI values compared to the males, indicating active reproduction. The significantly higher GSI values of *P. disjunctivus* and *P. pardalis* than *Oreochromis* sp. suggest better reproductive capacity. It is also indicated in the fecundity values. The highest GSI values for the female of each of the sailfin catfishes were recorded in August, while that of female *Oreochromis* sp. was in March. The highest fecundity for each of the three species was recorded in May, which coincides with the southwest monsoonal season (Amirudin et al., 2022).

The differences in LWR, CF, and reproductive biology among the invasive fish species in this Langat River tributary suggest that the sailfin catfishes have different life history strategies compared to tilapia, which may impact the native ecosystem in different ways. For example, species with a higher growth rate and CF may have a competitive advantage over native species for resources, while species with active reproduction may have a greater potential for population growth and expansion (Hudina et al., 2015; Paula et al., 2014).

Food and Feeding Habits

Detritus, mineral particles, and diatoms were the most important contents found in the stomachs of sailfin catfishes. Detritus is a significant carbon source in the global carbon cycle and serves as a food supply for detritivores, which are prominent elements of almost all ecosystems. The high percentage of mineral particles (mud and sand) in this species may be explained by a suction-type ventral mouth adapted to erode food from a rough surface, such as sand and mud at the base of rivers and lakes (Samat et al., 2016). This finding aligns with Iskandar (2021), who found a higher proportion of detritus and mineral particles in the stomach of *P. pardalis* collected from the Pusu River, Selangor.

Although detritus is difficult to digest for some fishes, *P. disjunctivus* and *P. pardalis* have well-developed gizzard-shaped pyloric stomachs, which helps them to digest the detritus (Samat et al., 2016). Besides, the preference for diatom (Bacillariophyta) as the essential natural diet of *P. pardalis* indicates that it is abundant in this area. In addition, it is an epilithic kind of microalgae, thus making it ideal for *P. pardalis*. Morphologically, *P. disjunctivus* and *P. pardalis* have ventrally oriented triangular mouth that supports their feeding habits (Elfidasari et al., 2020). Therefore, evidence suggests that *P. disjunctivus* and *P. pardalis* might be categorized as herbivores and detritivores. It agrees with the findings of Wickramaratne (2021) for the Victoria and Kalawewa reservoirs in Sri Lanka and Stolbunov et al. (2021) in Vietnam, detritus was the most important food found in the stomachs of loricariid fishes such as *P. disjunctivus* and *P. pardalis.*

Similarly, the most important food of *Oreochromis* sp. was detritus, coinciding with the finding of Shalloof and Khalifa (2009), who found a high proportion of detritus in the diet of *Oreochromis* sp. from Zabaal Lakes, Egypt. The findings of this study are also supported by Iskandar (2020), who found a high amount of detritus (48.99%) in the gut of *O. niloticus* from Pusu River, Selangor. Contrarily, Saba et al. (2021) found that diatoms were the most commonly occurring food item in the diet of *Oreochromis* sp. From the Gombak River, Selangor by occurrence, volume, and preponderance, and from the Klang River, diatoms and detritus were the most significant food items by volume. In the Langat River, detritus was the most important food item by volume and preponderance, followed by worms, suggesting that *Oreochromis* sp. from various Malaysian rivers have a diverse diet, with detritus and diatoms being the most essential components.

The high proportion of mineral particles indicates that *Oreochromis* sp. are bottom grazers, which agrees with Oso et al. (2006), while an abundance of detritus indicates their omnivorous nature (Shalloof et al., 2020). Also, the diet composition of fish species may be influenced by the abundance of specific food categories in the water body, making the fish explore what is available (Whitfield et al., 2022). According to Idowu et al. (2019), cichlids may adapt to numerous tropical functions, such as having a detritivorous, herbivorous, and planktivorous diet, and they could act as predators.

CONCLUSION

This study provides valuable information on the LWR, CF, reproductive biology, and food preferences of invasive fish species collected from a stream that flows into the Langat River in Selangor, Malaysia. During sampling for alien fish species, some samples of two native fish species, the blunt-snout barb *Mystacoleucus obtusirostris* and marble goby *Oxyeleotris marmorata*, were encountered. In this study, tilapia *Oreochromis* sp. recorded a better condition and well-being compared to the sailfin catfishes (*P. disjunctivus* and *P. pardalis*), which are likely to contribute more to the negative impact on native fish species through their prolific reproductive capacity. The results highlight the importance of understanding the life history traits of invasive fish species for their management and control and serve as a preliminary investigation of the potential of these species to impact the ecosystem of the Langat River. More so, the information gathered in this study serves as a baseline for further research and conservation efforts. It can guide informed decisions in managing invasive species by controlling their invasion of local rivers and preserving native fish populations.

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REFERENCES

Ahmad, A. K., Nur-Hazwani, M. N. R., Omar, S. A. S., Aweng, E. R., & Taweel, A. (2020). Preliminary study on invasive fish species diffusion in selected Malaysian freshwater ecosystems. *Pakistan Journal of Biological Sciences*, *23*(11), 1374-1379. http://hdl.handle.net/123456789/1004

Amirudin, A. A., Salimun, E., Zuhairi, M., Tangang, F., Juneng, L., Mohd, M. S. F., & Chung, J. X. (2022). The importance of cumulus parameterization and resolution in simulating rainfall over peninsular Malaysia. *Atmosphere*, *13*(10), Article 1557. https://doi.org/10.3390/atmos13101557

Aqmal-Naser, M., Ali, N., Azmi, N., Fahmi-Ahmad, M., Rizal, S., & Ahmad, A. (2023). Freshwater fishes (Actinopterygii) of Kenyir Reservoir, Peninsular Malaysia: Updated checklist, taxonomic concerns and alien species. *Biodiversity Data Journal*, *11*, Article e100337. https://doi.org/10.3897/BDJ.11.e100337

Arndt, E., Marchetti, M. P., & Schembri, P. J. (2018). Ecological impact of alien marine fishes: Insights from freshwater systems based on a comparative review. *Hydrobiologia*, *817*, 457-474. https://doi.org/10.1007/s10750-018-3511-5

Beatty, S. J., Lear, K. O., Allen, M. G., Lymbery, A. J., Tweedley, J. R., & Morgan, D. L. (2022). What factors influence fin-nipping damage by the invasive *Gambusia holbrooki* (Poeciliidae) on native fishes in riverine systems? *Freshwater Biology*, *67*(2), 325-337. https://doi.org/10.1111/fwb.13843

Bezerra, L. A. V., Freitas, M. O., Daga, V. S., Occhi, T. V. T., Faria, L., Costa, A. P. L., Padial, A. A., Prodocimo, V., & Vitule, J. R. S. (2019). A network meta-analysis of threats to South American fish biodiversity. *Fish and Fisheries*, *20*(4), 620-639. https://doi.org/10.1111/faf.12365

Brewer, S. K., Rabeni, C. F., & Papoulias, D. M. (2008). Comparing histology and gonadosomatic index for determining spawning condition of small-bodied riverine fishes. *Ecology of Freshwater Fish, 17*(1), 54-58. https://doi.org/10.1111/j.1600-0633.2007.00256.x

Camacho-Cervantes, M., Keller, R. P., & Vilà, M. (2023). Could non-native species boost their chances of invasion success by socializing with natives? *Philosophical Transactions of the Royal Society B*, *378*(1878), Article 20220106. https://doi.org/10.1098/rstb.2022.0106

Elfidasari, D., Wijayanti, F., & Sholihah, A. (2020). Trophic level and position of *Pterygoplichthys pardalis* in Ciliwung River (Jakarta, Indonesia) ecosystem based on the gut content analysis. *Biodiversitas*, *21*(6), 2862-2870. https://doi.org/10.13057/biodiv/d210665

Fakoya, K. A., Anetekhai, M. A., & Saba, A. O. (2019). Length-weight relationship and relative condition factor of Gorean snapper, *Lutjanus goreensis* (Valenciennes, 1830) in the coastal zone of Lagos, south-west Nigeria. *Zoologist (The)*, *17*, 20-25. https://doi.org/10.4314/tzool.v17i1.4

Hamid, M. A., Sahb, A. S. R. M., Nor, S. A. M., & Mansor, M. (2022). The distribution of invasive tilapia throughout a tropical man-made lake with special reference to Temengor Reservoir, Malaysia. *Indonesian Journal of Limnology*, *3*(1), 47-57. https://doi.org/10.51264/inajl.v3i1.26

Havel, J. E., Kovalenko, K. E., Thomaz, S. M., Amalfitano, S., & Kats, L. B. (2015). Aquatic invasive species: Challenges for the future. *Hydrobiologia*, *750*, 147-170. https://doi.org/10.1007/s10750-014-2166-0

Hudina, S., Žganec, K., & Hock, K. (2015). Differences in aggressive behaviour along the expanding range of an invasive crayfish: An important component of invasion dynamics. *Biological Invasions*, *17*, 3101-3112. https://doi.org/10.1007/s10530-015-0936-x

Hyslop, E. J. (1980). Stomach contents analysis - A review of methods and their application. *Journal of Fish Biology*, *17*(4), 411-429. https://doi.org/10.1111/j.1095-8649.1980.tb02775.x

Idowu, A. A., Ipadeola, A., Nwekoyo, V. E., & Popoola, O. C. (2019). Food and feeding habit of *Sarotherodon galilaeus* in Opeji River of Ogun State Nigeria. *Nigerian Journal of Agriculture, Food and Environment*, *15*(2), 104-110.

Iskandar, Z. R. (2020). *Community structures, well being, and gut contents of Alien Fishes in Pusu River, Gombak, Selangor* [Unpublished Bachelor Thesis]. Universiti Putra Malaysia.

Khaleel, A. G., Nasir, S. A., Ismail, N., & Ahmad-Syazni, K. (2020). Origin of invasive fish species, peacock bass Cichla species in Lake Telabak Malaysia revealed by mitochondrial DNA barcoding. *Egyptian Journal of Aquatic Biology and Fisheries*, *24*(3), 311-322. https://dx.doi.org/10.21608/ejabf.2020.92251

Kiat, C. H., & Rahim, K. A. A. (2023). Risk screening of introduced African Catfish (Clarias gariepinus) (Burchell, 1822) in Sarawak using the fish invasiveness screening kit (FISK v2). *Borneo Journal of Resource Science and Technology*, *13*(2), 151-160. https://doi.org/10.33736/bjrst.5705.2023

Mozsár, A., Boros, G., Sály, P., Antal, L., & Nagy, S. A. (2015). Relationship between Fulton's condition factor and proximate body composition in three freshwater fish species. *Journal of Applied Ichthyology*, *31*(2), 315-320. https://doi.org/10.1111/jai.12658

Nagelkerke, L. A., Onselen, E. V., Kessel, N. V., & Leuven, R. S. (2018). Functional feeding traits as predictors of invasive success of alien freshwater fish species using a food-fish model. *PLoS One*, *13*(6), Article e0197636. https://doi.org/10.1371/journal.pone.0197636

Oso, J. A., Ayodele, I. A., & Fagbuaro, O. (2006). Food and feeding habits of *Oreochromis niloticus* (L.) and *Sarotherodon galilaeus* (L.) in a tropical reservoir. *World Journal of Zoology*, *1*(2), 118-121. http://idosi.org/wjz/wjz1(2)2006/8.pdf

Paula, A. F. D., Pires, D. D. O., & Creed, J. C. (2014). Reproductive strategies of two invasive sun corals (Tubastraea spp.) in the southwestern Atlantic. *Journal of the Marine Biological Association of the United Kingdom*, *94*(3), 481-492. https://doi.org/10.1017/S0025315413001446

Piria, M., Simonović, P., Kalogianni, E., Vardakas, L., Koutsikos, N., Zanella, D., Ristovska, M., Apostolou, A., Adrović, A., Mrdak, D., Tarkan, A. S., Milošević, D., Zanella, L. N., Bakiu, R., Ekmekçi, F. G., Povž, M., Korro, K., Nikolić, V., Škrijelj, R., … & Joy, M. K. (2018). Alien freshwater fish species in the Balkans - Vectors and pathways of introduction. *Fish and Fisheries*, *19*(1), 138–169. https://doi.org/10.1111/FAF.12242

Rahim, K. A. A., Esa, Y., & Arshad, A. (2013). The influence of alien fish species on native fish community structure in Malaysian waters. *Kuroshio Science*, *7*(1), 81-93.

Rahman, M. M., & Samat, A. F. (2021). Reproductive cycle, sexual maturity and fecundity of *Nemipterus furcosus* (Valenciennes, 1830). *Aquaculture and Fisheries, 6*(4), 424-431. https://doi.org/10.1016/j.aaf.2020.07.006

Saba, A. O., Ismail, A., Zulkifli, S. Z., Ghani, I. F. A., Halim, M. R. A., Ibrahim, M. A., Mukhtar, A., Aziz, A. A., Wahid, N. A. A., & Amal, M. N. A. (2021). Invasion risk and potential impact of alien freshwater fishes on native counterparts in Klang Valley, Malaysia. *Animals*, *11*(11), Article 3152. https://doi.org/10.3390/ani11113152

Saba, A. O., Ismail, A., Zulkifli, S. Z., Shohaimi, S., Jamil, N. R., Nawi, N. M., Ghani, I. F. A., Halim, M. R. A., & Amal, M. N. A. (2020a). Checklists, production trends, and potential ecological and socioeconomic impacts of non-native freshwater fishes in Malaysia: A review. *Aquatic Invasions*, *15*(4), 646-670. https://doi.org/10.3391/ai.2020.15.4.07

Saba, A. O., Ismail, A., Zulkifli, S. Z., Halim, M. R. A., Wahid, N. A. A., & Amal, M. N. A. (2020b). Species composition and invasion risks of alien ornamental freshwater fishes from pet stores in Klang Valley, Malaysia. *Scientific Reports*, *10*(1), Article 17205. https://doi.org/10.1038/s41598-020-74168-9

Saba, A. O., Rasli, N. F., Ismail, A., Zulkifli, S. Z., Ghani, I. F. A., Muhammad-Rasul, A. H., & Amal, M. N. A. (2020c). A report on introduced Amazon sailfin catfish, Pterygoplichthys pardalis in Gombak Basin, Selangor, with notes on two body patterns of the species. *Pertanika Journal of Tropical Agricultural Science*, *43*(4), 693-703. https://doi.org/10.47836/pjtas.43.4.19

Samat, A., Yusoff, F. M., Arshad, A., Ghaffar, M. A., Nor, S. M., Magalhaes, A. L. B., & Das, S. K. (2016). Reproductive biology of the introduced sailfin catfish *Pterygoplichthys pardalis* (Pisces: Loricariidae) in Peninsular Malaysia. *Indian Journal of Fisheries, 63*(1), 35-41.

Santi, E. P., Rahardjo, M. F., & Sulistiono, S. (2017). Diet of scalloped perchlet, Ambassis nalua (Hamilton, 1822) in Pabean Bay, West Java. *Jurnal Iktiologi Indonesia*, *17*(1), 45-53. https://doi.org/10.32491/jii.v17i1.303

Shalloof, K. A. S., & Khalifa, N. (2009). Stomach contents and feeding habits of *Oreochromis niloticus* (L.) from Abu-Zabal lakes, Egypt. *World Applied Sciences Journal*, *6*(1), 1-5.

Shalloof, K. A. S., Alaa, M., & Aly, W. (2020). Feeding habits and trophic levels of cichlid species in tropical reservoir, Lake Nasser, Egypt. *The Egyptian Journal of Aquatic Research*, *46*(2), 159-165. https://doi.org/10.1016/j.ejar.2020.04.001

Silveira, E. L. D., Semmar, N., Cartes, J. E., Tuset, V. M., Lombarte, A., Ballester, E. L. C., & Vaz-dos-Santos, A. M. (2020). Methods for trophic ecology assessment in fishes: A critical review of stomach analyses. *Reviews in Fisheries Science & Aquaculture*, *28*(1), 71-106. https://doi.org/10.1080/23308249.2019.1678013

Šimková, A., Řehulková, E., Rasoloariniaina, J. R., Jorissen, M. W., Scholz, T., Faltýnková, A., Mašová, Š., & Vanhove, M. P. (2019). Transmission of parasites from introduced tilapias: A new threat to endemic Malagasy ichthyofauna. *Biological Invasions*, *21*, 803-819. https://doi.org/10.1007/s10530-018-1859-0

Stolbunov, I. A., Gusakov, V. A., Dien, T. D., & Thanh, N. T. H. (2021). Food spectrum, trophic and length-weight characteristics of nonindigenous suckermouth armored catfishes *Pterygoplichthys spp*. (Loricariidae) in Vietnam. *Inland Water Biology*, *14*, 597-605. https://doi.org/10.1134/S1995082921050163

Towers, L. (2015, June 2). *Water quality: A priority for successful aquaculture.* The Fish Site. https://thefishsite.com/articles/water-quality-a-priority-for-successful-aquaculture

Tran, H. D., Nguyen, H. H., & Ha, L. M. (2021). Length–weight relationship and condition factor of the mudskipper (*Periophthalmus modestus*) in the Red River Delta. *Regional Studies in Marine Science*, *46*, Article 101903. https://doi.org/10.1016/j.rsma.2021.101903

Vilizzi, L., Copp, G. H., Hill, J. E., Adamovich, B., Aislabie, L., Akin, D., Al-Faisal, A., J., Almeida, D., Amal, M. N. A., Bakiu, R., Bellati, A., Bernier, R., Bies, J. M., Bilge, G., Branco, P., Thuyet, B., Canning-clode, J., Cardoso Ramos. H. A., Costellanos-Gallindo, G. A., … & Semenchenko, V. (2021). A global-scale screening of non-native aquatic organisms to identify potentially invasive species under current and future climate conditions. *Science of the Total Environment*, *788*, Article 147868. https://doi.org/10.1016/j.scitotenv.2021.147868

Vythalingam, L. M., Raghavan, R., Hossain, M., & Bhassu, S. (2022). Predicting aquatic invasions in a megadiverse region: Maximum-entropy-based modelling of six alien fish species in Malaysia. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *32*(1), 157-170. https://doi.org/10.1002/aqc.3729

Wang, J., Chen, L., Tang, W., Heino, J., & Jiang, X. (2021). Effects of dam construction and fish invasion on the species, functional and phylogenetic diversity of fish assemblages in the Yellow River Basin. *Journal of Environmental Management*, *293*, Article 112863. https://doi.org/10.1016/j.jenvman.2021.112863

Whitfield, A. K., Able, K. W., Blaber, S. J., Elliott, M., Franco, A., Harrison, T. D., & Houde, E. D. (2022). Feeding ecology and trophic dynamics. In A. K. Whitfield, K. W. Able, S. J. M. Blaber, M. Elliott (Eds.), *Fish and fisheries in estuaries: A global perspective (pp.255-331).* Wiley. https://onlinelibrary.wiley.com/doi/abs/10.1002/9781119705345.ch5

Wickramaratne, I. U. (2021). Food habits of *Pterygoplichthys disjunctivus* (Vermiculated sailfin catfish) and coexisting fish species in Victoria and Kalawewa reservoirs, Sri Lanka. *Journal of Agriculture and Value Addition*, *4*(2), 57-75. https://doi.org/10.4038/java.v4i2.28

Xiong, W., Guo, C., Gozlan, R. E., & Liu, J. (2023). Tilapia introduction in China: Economic boom in aquaculture versus ecological threats to ecosystems. *Reviews in Aquaculture*, *15*(1), 179-197. https://doi.org/10.1111/raq.12710

Zakaria-Ismail, M., Fatimah, A., & Khaironizam, M. Z. (2019). *Fishes of the freshwater ecosystems of Peninsular Malaysia*. Lambert Academic Publishing.

Zar, J. H. (1984). Simple linear regression. In *Biostatistical Analysis* (pp. 324-359). Prentice Hall.