Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2023.30016

315 (2023) 500–514
December

Eco-biology of Tinfoil barb *Barbonymus schwanenfeldii* in tropical Lake Kenyir, east coast Malaysia

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Received 30 June 2023; Accepted 9 September 2023

A B S T R A C T

The impact of large dams is a prevalent topic in environmental science, but the importance of altered water quality as a driver of eco-biological impacts in a lake ecosystem is often missing from the research in tropical aquatic environments. The sustainability of fishing in Lake Kenyir is becoming increasingly challenging due to overfishing and worrying levels of pollution in numerous riverine locations, which are detrimental to aquatic ecosystems and jeopardize aquatic life, particularly fish. These negative consequences have transformed lake ecosystems into dreadful obstacles that may significantly impair a species' capacity to carry out essential biological functions like development and reproduction. Based on the above perspectives, this study focused on some characteristics of water quality and reproductive biology (sexual dimorphism, age composition and gonad maturity) of Tinfoil barb *Barbonymus schwanenfeldii,* among one the popular fish in tropical man-made Lake Kenyir, Terengganu, Malaysia. The morphometric characteristics, meristic counts, age composition, and gonad maturity were investigated to examine the possible sexual size dimorphism, age, and the reproductive status of Tinfoil barb *B. schwanenfeldii* in Kenyir Lake, Terengganu, Malaysia. 8 morphometric characters showed significant differences within the sexes while meristic and otolith anatomy showed similar characteristics within the sexes. Males and females were of 5 and 1 y above, of age, respectively. Gonadosomatic index was between 3.84 ± 0.66 to 0.92 ± 0.13, and 6.50 ± 0.89 to 7.34 ± 1.11 while the hepatosomatic index ranged from 0.51 ± 0.17 to 0.59 ± 0.08, and 0.39 ± 0.04 to 0.70 ± 0.09 for males and females, respectively. 50% of the males were in the spent stage while 40% of the females were in Stage V, and 30% in Stage III. Thus, selected morphometrics parameters could be useful to differentiate within sexes of Tinfoil barb *B. schwanenfeldii*. The males *B. schwanenfeldii* were of older population compared to the female's population in Kenyir Lake. According to the Malaysia's National Water Quality Standards (NWQS), the water quality in Kenyir Lake Basin varied temporally and spatially and the most affected parameters were pH, dissolved oxygen, biochemical oxygen demand, chemical oxygen demand, and total suspended solids. The findings of this research may contribute to the further understanding of the eco-biology that aids in effective sustainable fisheries management in this fascinating man-made Lake Kenyir, Terengganu, Malaysia.

Keywords: Morphometrics; Meristics; Otolith; Reproduction; Tinfoil barb; Water quality Kenyir Lake

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1. Introduction

1.1. Tropical lake ecology

The nature of tropical aquatic ecosystems, stability and conservation with seasonality shaped by patterns of precipitation, more consistent temperatures, and often unique geological history. Most obvious is a general trend of higher species diversity and greater specialization and adaptive radiation among many aquatic groups. Dams are often criticized by ecologists and biogeochemists for fragmenting habitats. This raises speculation on whether this might also affect ecosystem functioning and stability. High species diversity and its relationship with trophic structure, coupled with limited detailed research, makes ecologically informed conservation of many tropical water bodies extremely difficult, and a solid base of eco-biological knowledge is often limited [1]. According to Kapasa and Cowx [2], some fishes can adapt to the new lacustrine habitat and exploit the abundant food resources in the flooded littoral zone during high-water periods. Another feature of the ecological transition from a riverine to a lacustrine environment is the ecological segregation of food and habitat [3,4] is shown in Fig. 1.

1.2. Lakes and reservoirs in Malaysia

Numerous reservoirs have been built because of the demand for hydroelectric power, irrigation, flood mitigation, drinking water, and recreational opportunities. In Malaysia, dams and reservoirs, the number of which is constantly rising, are crucial for maintaining fish diversity, as well as for providing the local population with a source of fish for research and sustainable aquaculture [5]. The main activity in lakes and reservoirs in Malaysia is, and always has been, fishing. Therefore, the fisheries and the fish resources of the lakes and reservoirs should be carefully maintained. In general, the fish stocks are degrading, and a concerted effort is required to maintain exploitable resources at a sustainable level [6,7].

1.3. Kenyir Lake

Lakes in Malaysia, natural or artificial, have multiple functions. Almost 90% of the nation's water supply comes from lakes and reservoirs. Lakes and reservoirs serve as the source of water for domestic, industrial and agriculture, hydroelectric power generation, flood mitigation, navigation, and recreation. The main activity in lakes and reservoirs in Malaysia is, and always has been, fishing. Therefore, the fisheries and the fish resources of the lakes and reservoirs should be carefully maintained. In general, the fish stocks are degrading and a concerted effort is required to maintain exploitable resources at a sustainable level [6].

Kenyir Lake is the largest artificial lake in the ASEAN region, is situated in Hulu Terengganu on the east coast of Peninsula Malaysia between the latitudes of 4°43'N and 5°15'N and the longitudes of 102°30'E and 102°55'E (Fig. 2).

In order to construct the Sultan Mahmud Hydro-Electric Power Plant, the Kenyir River was dammed in 1986, resulting in the creation of the lake, which has a surface area of 36,900 ha, a maximum depth of 145 m, an average depth of 37 m, and more than 340 islands. The lake is known as a unique tourist destination for its beautiful scenario of tropical forest and is widely known for its valuable flora and fauna species. It is believed that the area is the habitat of more than 8,000 species of flowers, 2,500 species of plants and trees, 8,000 species of orchids, 370 species of birds and 300 species of freshwater fish in 22 rivers (Table 1) [9,10].

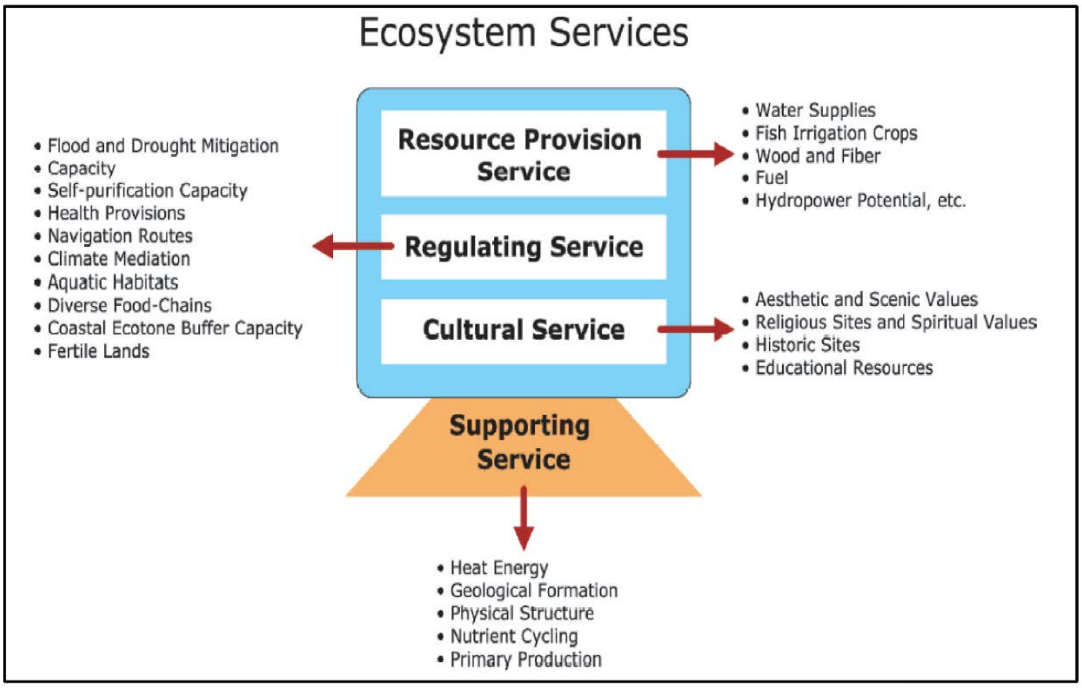


Fig. 1. Ecosystem service provided by lakes and reservoir.

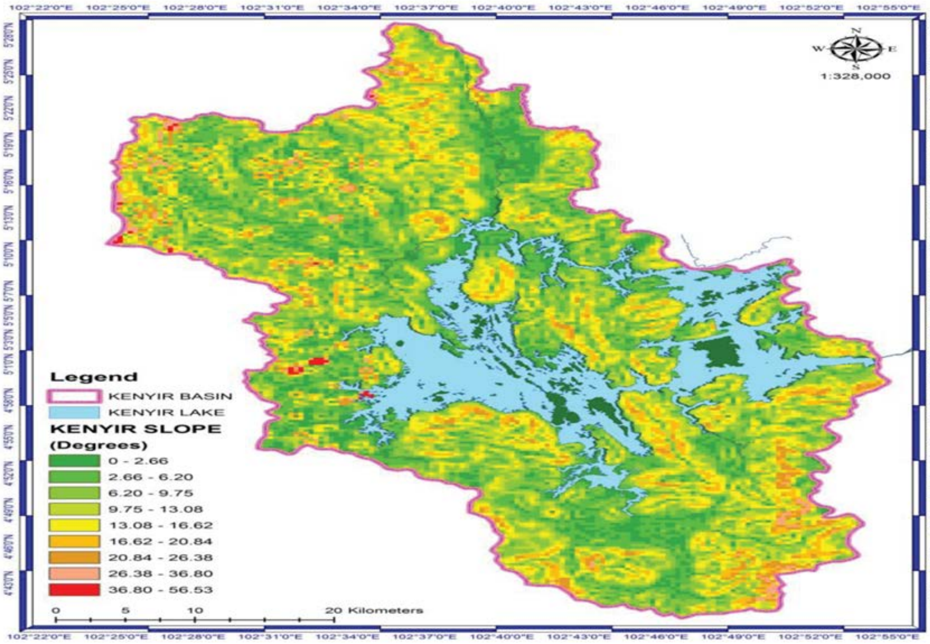


Fig. 2. Kenyir Lake catchment areas, Hulu Terengganu, Terengganu, Malaysia [8].

Table 1
Locations of rivers (Sg.) Lake Kenyir [11]

Location	River name
102° 42′42.602″E 05° 11′01.064″N	Sungai Siput
102° 39′49.705″E 5° 17′42.360″N	Sungai Petuang
102° 38′19.879″E 5° 12′57.393″N	Sungai Tembat
102° 37′46.486″E 5° 11′24.258″N	Sungai Terengganu
102° 33′17.735″E 5° 03′30.462″N	Sungai Ketiar
102° 34′15.044″E 04° 58′03.613″N	Sungai Besar
102° 33′09.379″E 04° 56′16.506″N	Sungai Lepar
102° 35′13.374″E 4° 54′38.067″N	Sungai Lawit
102° 42′04.9″E 04° 52′32.0″N	Sungai Cenana
102° 41′24.427″E 04° 50′36.340″N	Sungai Bewah
102° 44′30.707″E 04° 47′42.302″N	Sungai Cicir
102° 44′31.9″E 04° 47′16.9″N	Sungai Perepek
102° 45′00.244″E 04° 46′28.235″N	Sungai Terenggan
102° 42′32.595″E 04° 48′17.089″N	Sungai Cacing
102° 48′00.5″E 04° 55′26.2″N	Sungai Pertang
102° 50′22.510″E 04° 57′54.633″N	Sungai Lasir
102° 45′03.621″E 05° 02′21.528″N	Sungai Leban Terengganu
102° 46′42.443″E 05° 04′58.079″N	Sungai Sauk
102° 20′6.25″E 05° 07′34.463″N	Sungai Mandak
102° 54′5.18″E 05° 0′40.01″N	Sungai Kenyir
102° 54′40.34″E 05° 1′2.36″N	Sungai Berangan
Sungai = River	

Department of Environment (DOE) has classified lakes into a few classes such as Classes I, II, III, IV and V. To measure the quality of water and detect the water pollution, it is one of the indicators that can be used. Based on 6 significant pollutants, the water quality index (WQI) parameters measured which is dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), ammoniacal nitrogen (AN), total suspended solids (TSS) and pH (Table 2).

1.4. Reproductive biology

Fishing is one of the earliest pursuits that has guaranteed human survival. Fishing can lead to financial success and employment. It can improve nutritional health by supplying halieutic protein. Every month of the year, fishing is allowed in the man-made Lake Kenyir as it is one of the most potential eco-tourism spots in the east coast of Malaysia. Due to the extended fishing season, these aquatic habitats are overfished. Over-exploitation is indicated by the loss of large individuals, a reduction in average fish size compared to the size of the same species found in other pools, and a rapid decline in daily catches despite greater fishing efficiency. utilized fishing equipment. Thus, over-exploitation due to fishing and pollution of numbers of riverine areas and their aquatic environments endanger aquatic fauna, particularly the fishes, and therefore the sustainability of fishing in Lake Kenyir happened to an expanding issue [11–14].

The abusive exploitations of these lake ecosystems constitute serious obstacles that could have a deep impact on the normal biological functions of species such as growth and reproduction. In response to stresses, due to overexploitation, certain fish populations develop adaptive strategies, notably the regulation of growth and reproduction. The reproductive strategy used by fish species is a set of characteristics that the species must exhibit to reproduce successfully.

Reproductive strategy is also an overall model of species-specific reproduction and covers a range of life cycle

Table 2
Water quality index [12,13]

Parameter	Class					
	Unit	I	II	III	IV	V
pH	–	>7	6–7	5–6	<5	>5
Dissolved oxygen	mg/L	>7	5–7	3–5	1–3	<1
Biochemical oxygen demand	mg/L	<1	1–3	3–6	6–12	>12
Chemical oxygen demand	mg/L	<10	10–25	25–50	50–100	>100
Total suspended solids	mg/L	<25	25–30	50–150	150–300	>300
Ammoniacal nitrogen	mg/L	<0.1	0.1–0.3	0.3–0.9	0.9–27	>2.7
Water quality index (WQI) (%)		<92.7	76.5–92.7	51.9–76.5	31.0–51.9	>31.0

characteristics including age, size at first sexual maturity, gonadal development, fecundity, oocyte size, reproductive period, and oviposition period. Some life cycle characteristics can be influenced by the amount of food, fishing pressure, and environmental conditions [15–17].

1.5. Reproductive biology of Tinfoil barb or Barbonymus schwanenfeldii

Tinfoil barb or *Barbonymus schwanenfeldii* is classified under the family of Cyprinidae. In Malaysia, it is locally known as "Lampam Sungai" [18]. This species is also synonymous to *Barbus schwanenfeldii* or *Puntius schwanenfeldii* [19]. It is widely distributed in the Chao Phraya Basin of Thailand, Cambodia, Laos, Vietnam, the Malay Peninsula, Borneo as well as Sumatra [18,20,21]. As the largest man-made lake, Kenyir Lake provides a suitable environment for Tinfoil barb to thrive. Kamaruddin et al. [9] reported that 35.8% of the total fish caught in Pengkalan Gawi-Pulau Dula section of the Kenyir Lake were Tinfoil barbs; thus, solidifying its reputation as the most abundant fish species in the area. Tinfoil barbs have economic importance as they are readily accepted by locals due to their tasty meat [22] and have potential for aquaculture, especially in ponds, lakes or tanks. Nevertheless, due to high anthropogenic activities in Kenyir Lake, the population status of many native fish species including *B. schwanenfeldii* is at risk and has been reported to decline over the past few years [23]. Yet, the biology of Tinfoil barbs in Malaysia has been poorly studied with little biological information is currently available [24–26]. Therefore, the biological information on this species is crucial for efficient inland fisheries management for restocking and conservation purposes.

Various fish taxa display remarkable sexual size dimorphism (SSD) in both male and female such as in Anjak fish, *Schizocypris brucei* [27], European seabass, *Dicentrarchus labrax* [28], Tule perch, *Hysterocarpus traskii* [29] and *Semiplotus semiplotus* [30], *Cheilinus lunulatus* and *Halichoeres hortulanus* [31] as well as cichlids in Lake Melawi [32]. SSD occurs because of natural and sexual selection, and thus, quantifying the variation in morphological characters and external features may help us to understand its ecological and adaptive significance [33] other than it is vital for taxonomic identification [34]. As such, the morphometric of fish can be used to assess the well-being of individuals while the meristic observation helps to determine any possible differences within fish sex; based on the shape of the fish [35–38].

In addition, knowledge on the fish age is imperative for assessing the status of fish stocks while proposing effective fisheries management actions to ensure their sustainability [39]. The use of otolith ring has become popular to obtain information about the taxon, age, growth and size of fishes [40–43]. Otoliths are calcified structures, found in the inner ear cavity of teleost fish that serve as a balance organ and aid in hearing [44].

While the age of the fish is important, other life history parameters such as reproductive status offer an insight into their future sustainability. The reproductive status of fishes can be identified based on gonadosomatic index (GSI), as well as gonadal macroscopic observation while the energy status which is comprised of the ability of fishes to store fatty substances is evaluated through the hepatosomatic index (HSI). GSI represents the simplest way to measure changes in the size and weight of gonads in relation to the total weight of the organism that is responding to environmental drivers [45] while HSI is influenced by the feeding habits and reproductive behaviors of the fish [46]. The differences in morphological characters between the male and female wild Tinfoil barb stocks have not yet been studied and as such, this could be the first of its kind that has focused on examining the extent of their morphological variations in the wild.

Based upon the above perspectives this study aims to assess potential water quality parameters along with some reproductive characteristics of the focal fish species caught Sg. in Lake Kenyir, Terengganu, Malaysia. More specifically, the aim was to determine sexual size dimorphism, age, and the reproductive status of Tinfoil barb *B. schwanenfeldii* in Kenyir Lake It is expected that these findings will allow us to propose a plan of management of the lakes for sustainable fishing. Hence, this study was performed to evaluate whether Tinfoil barbs, *B. schwanenfeldii*, display morphometric and meristic sexual dimorphism as well as to determine the age compositions of this fish population and their reproductive status in Kenyir Lake ecosystems.

2. Materials and methods

B. schwanenfeldii largely dominates at Kenyir Lake, Terengganu (N = 5°12.902′, E = 102°38.306′, Fig. 3) as well

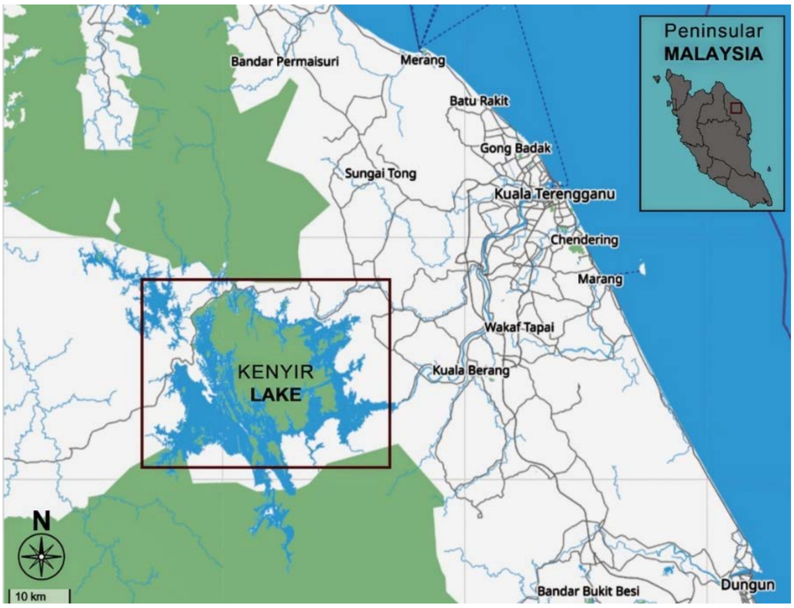


Fig. 3. Study area map showing the Kenyir Lake, Terengganu, Malaysia.

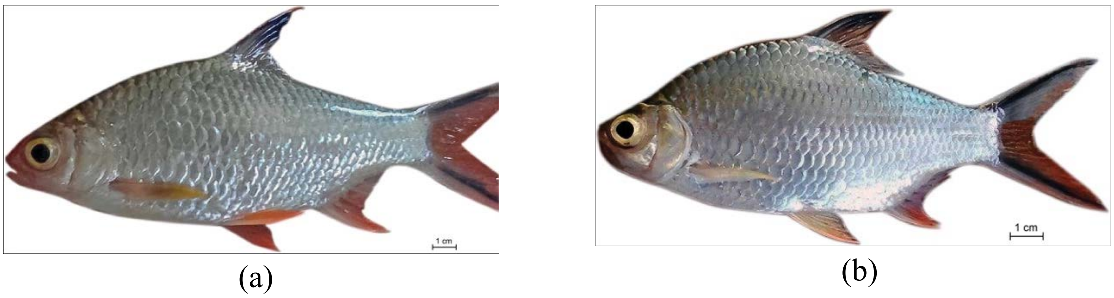


Fig. 4. Male (A) and female (B) Tinfoil barb *Barbonymus schwanenfeldii* collected from the Kenyir Lake.

as in the riverine waters of Peninsular Malaysia. The lake is a well-known man-made lake that is surrounded by tropical forest. It covers 260 km^2 and contains 340 small islands, more than 14 waterfalls, numerous rapids, and rivers [47].

For this study, a total of twenty adult *B. schwanenfeldii* (Fig. 4) with body sizes ranging from 19.5 to 28.3 cm of total length and 120.06 to 389.07 g of body weight were sampled from Kenyir Lake from August to October 2016 using casting nets and gillnets (Table 3). The samples obtained were humanely euthanized by overdosing them with tricaine methanesulfonate (MS-222) in 0.6 g/5 L of water and immediately transported in iceboxes to the freshwater hatchery laboratory unit of the Faculty of Fisheries and Food Science, Universiti Malaysia Terengganu for further biological measurements and otolith extraction.

2.1. Morphological identification

2.1.1. Morphometric characteristics

The fresh specimens were measured to the nearest 0.01 cm using a vernier caliper and biometry board. The sexes of the fish were determined based on their body shapes — the males are slender with distinctive rough tubercles (sandpaper-like bumps) on their scales while the females can be identified based on their wider body shape with swollen abdominal region and smooth scales [48]. Thirty-nine morphometric measurements (Fig. 5) were studied for each fish and compared between males and females. The association between the morphometric measurements to the total length of the fish was calculated as a percentage.

Table 3
Average total length (mean ± SD) and body weight (mean ± SD) of Tinfoil barb, *Barbonymus schwanenfeldii* collected from Kenyir Lake

	Total length range (cm)	Body weight range (g)
Male,	21.5–24.5	120.06–163.32
n = 10	(22.76 ± 1.13)	(141.62 ± 17.37)
Female,	19.5–28.3	189.49–398.07
n = 10	(26.08 ± 1.31)	(267.71 ± 58.62)

2.1.2. Meristic count

For the meristic parameters, the counts included the scale of the lateral line (LLS), scale above the lateral line (ALLS)

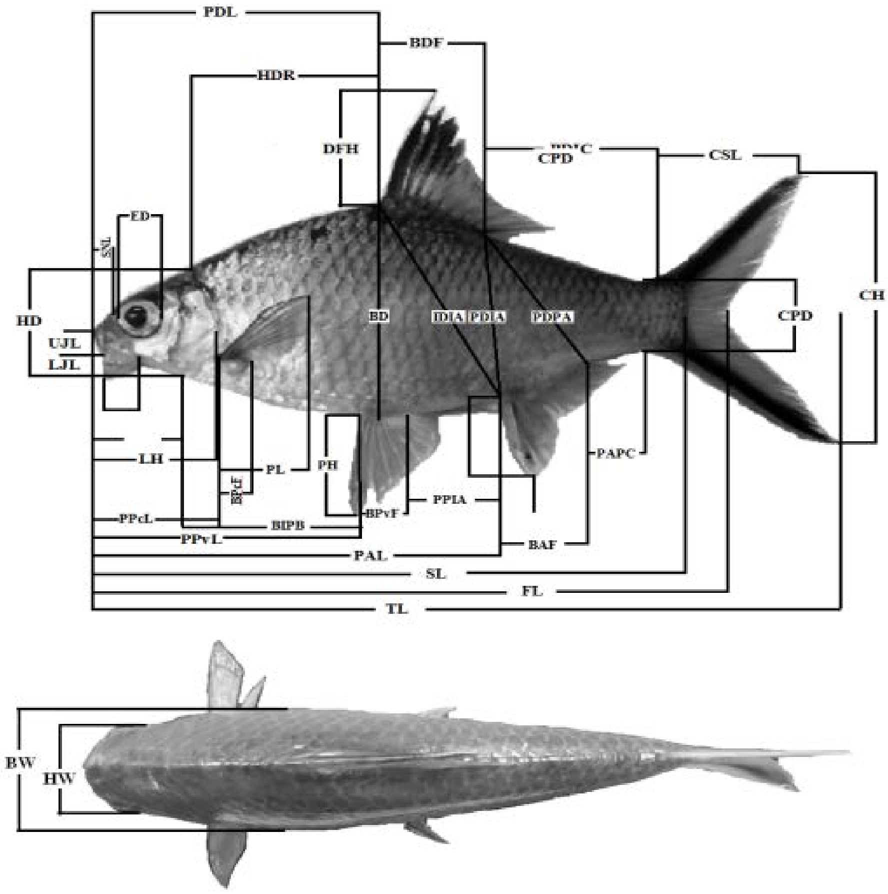


Fig. 5. Morphometric characters used in the morphological determination on the males and females of *Barbonymus schwanenfeldii*: total length (TL), fork length (FL), standard length (SL), snout length (SNL), upper jaw length (UJL), lower jaw length (LJL), branchiostegal length (BL), head depth (HD), length of the head (LH), head to first dorsal fin (HDR), base length of dorsal fin (BDF), dorsal fin height (DFH), posterior end of the dorsal to insertion of the caudal fin (PDIC), caudal fin spine length (CSL), caudal fin height (CH), caudal fin length (CL), caudal peduncle depth (CPD), posterior end of the anal fin to posterior end of the caudal fin (PAPC), base length of anal fin (BAF), anal fin height (AFH), posterior end of the pelvic fin to insertion of the anal fin (PPIA), base length of pelvic fin (BPvF), pelvic fin height (PH), branchios to insertion pelvic fin base (BIPB), base length of pectoral fin (BPcF), pectoral fin length (PL), branchios to insertion dorsal fin base (BIDB), body depth (BD), insertion dorsal fin base to insertion of the anal fin base (IDIA), posterior dorsal fin base to insertion of the anal fin base (PDIA), posterior dorsal fin base to posterior anal fin base (PDPA), eye diameter (ED), head width (HW), pre-pectoral length (PPcL), pre-pelvic length (PPvL), pre-anal length (PAL), pre-dorsal length (PDL), body width (BW) [Ambak et al. [24]].

and scale below lateral line (BLLS). The scale of lateral line involves the counting of the scale along the lateral line while the scale above the lateral line was counted from the scale at the lateral line until the last scale at the base of the dorsal fin. The scale below the lateral line was counted from the scale at the lateral line until the last scale at the base of the ventral fin. Number of fin rays dorsal (DFR), pectoral (PFR), pelvic/ventral (VFR) and anal fin rays (AFR) were also counted with spine or hard rays [49]. An abdominal incision was made to further confirm the sex based on gonad identification.

2.1.3. Age estimation

The "open-the-hatch" technique was applied to remove the otolith from *B. schwanenfeldii* following Secor et al. [52]. The otoliths were extracted with forceps and cleaned with distilled water. All excess tissues were carefully removed, and the otoliths were air-dried before being stored in paper envelopes while awaiting further analysis. Otoliths were placed individually in a plastic tray ice block (Jenke [52]), embedded in clear epoxy resin and hardener with a ratio of 5:1 [50]. The epoxy was left to dry for approximately 3 d at room temperature [51].

Each ice block containing the otolith was sectioned using a diamond-coated, straight-edged Buehler precision saw which cut a thin section (300 μm) through the nucleus. Three thin transverse sections (0.5 mm) near the otolith center were taken [50], ground using twin variable speed grinder-polisher machine (Model BETA 8), cleared of the excess resin using the CarbiMet paper discs 300 μm until the focus of the otolith appeared which includes all rings and the nucleus [50–52] while providing a polished face for viewing. The otolith section was mounted on the glass slide using Buehler mounting wax crystal bond on a hot plate at

121°C [50] and read under Nikon compound microscope. The sectioned otoliths were read independently twice with no reference to the previous readings.

2.1.4. Reproductive parameters

The fish was carefully dissected to remove the gonad and liver. The gonad analysis for each sex was carried out based on macroscopic observation such as coloration, shape and size. Both gonad and liver were weighted for GSI and HSI value whereby GSI = [Gonad weight (g)/body weight (g)] × 100% and HSI = [Liver weight (g)/body weight (g)] × 100 [53]. The maturity stages of the gonad were determined based on their external appearance as well as the colours of the gonad which were classified as translucent, greenish, and light greenish [54].

2.1.5. Statistical analyses

The parameters of the morphometric ratios between total length (TL) and 39 morphometric measurements were taken as the independent variable, according to the morphometric model. All morphometrics measurement were rounded-off to the nearest 0.01 mm. Statistical analysis was performed by using paired *T*-test (PASW statistics version 18) for all morphometric parameters, GSI and HSI with a significant value set at $p < 0.05$. Values were presented as mean ± standard deviation (SD).

3. Results

3.1. Water quality

The water quality data were adapted from secondary data [55] as observed in Tables 4 and 5 [9,56,57].

Increased BOD levels are indicative of receiving a substantial load of organic matter discharge along with a high volume of agricultural and sewage discharge from various sources. It might be connected to the vicinity of the sewage discharges from the boathouse areas, which dump food waste directly into the lake. The shipload of

Table 4
Mean value, range and %RSD of physico-chemical parameters and metals concentration [56]

Parameter	Mean ± SD	Range	%RSD
Temp. (°C)	31.14 ± 0.16	30.91–31.40	0.51
Total dissolved solids (mg/L)	16.29 ± 10.23	15.93–16.71	1.41
COND (μS/cm)	27.79 ± 10.67	25.94–28.82	2.41
Dissolved oxygen (mg/L)	4.75 ± 1.54	2.28–6.88	32.42
pH	7.03 ± 0.08	6.84–7.13	1.14
TUR (NTU)	1.33 ± 0.19	1.08–1.71	14.29
Biochemical oxygen demand (mg/L)	0.96 ± 0.14	0.77–1.13	14.58
Chemical oxygen demand (mg/L)	6.48 ± 1.29	4.70–8.20	19.91
Ammoniacal nitrogen (mg/L)	0.11 ± 0.07	0.05–0.30	63.64
Total suspended solids (mg/L)	2.17 ± 0.84	1.28–4.44	38.71
ORP (mV)	227.10 ± 20.58	186.24–270.50	9.06
Al (μg/L)	23.0845 ± 2.71	18.2748–28.6776	11.74
As (μg/L)	0.2983 ± 0.03	0.2564–0.3556	10.00
B (μg/L)	4.1711 ± 0.06	4.0637–4.2826	1.44
Ba (μg/L)	5.0655 ± 0.28	4.7235–5.5569	5.52
Ca (μg/L)	2,033.4024 ± 90.51	1,911.6911–2,247.0230	4.45

Table 5
Water classes and uses [56]

Class	Uses
Class 1	Conservation of natural environment
	Water supply 1 – Practically no treatment necessary
	Fishery 1 – Very sensitive aquatic species
Class IIA	Water supply II – Conventional treatment
	Fishery II – Sensitive aquatic species
Class IIB	Recreational use body contact
Class III	Water supply III – Extensive treatment required
	Fishery III – Common, of economic value and tolerant species; livestock drinking
Class IV	Irrigation
Class V	None of above

bacterial and detrimental microbial activities and consequences were also reflected in other studies conducted on lake water quality and cage aquaculture [58–61].

On the other hand, an alkaline situation is caused by the pH value being influenced by the presence of carbonate magnesium and calcium in the water [62]. While the calcium concentrations are higher than the Maliau Basin [63], the magnesium concentrations are lower than the baseline values observed from the Kota Marudu River [64], which shows that they are the result of natural weathering. Any body of water will typically have a pH range between 6.0 and 8.5 in its natural state, which is the ideal pH range for the survival of fish [59].

There are higher values of BOD, COD, TSS, and NH_3–N at the middle and downstream portions of the lake basin as compared to the upstream, according to a few preliminary water quality level assessments in the Kenyir Lake Basin. The pH and DO levels have shown the opposite level. The water quality of Kenyir Lake, which is influenced by hydrological characteristics and potential sources from anthropogenic activities, was assessed in this study using the DOE-WQI program. Additionally, the classification based on the Malaysia's National Water Quality Standards (NWQS) was contrasted with the beneficial use of the water. The water of the Kenyir Lake Basin (upstream to downstream) was designated as Class II yet most of the areas indicated WQI levels not below 60%. which is suitable for eco-tourism activities and conducive to fish habitat [56,57].

3.2. Reproductive biology

The body of *B. schwanenfeldii* is silvery in colour with red dorsal fins that have a black blotch at the tip, red pectoral, pelvic and anal fins, and caudal fin with white margin and a black sub-marginal stripe along each lobe.

3.2.1. Morphometric characteristics

The sex dimorphic characters used to differentiate between male and female *B. schwanenfeldii* in Kenyir Lake (Table 6). From the data, eight (21.62%) of the morphometric characters shows significant differences ($p < 0.05$) based on the total body length between male and female *B. schwanenfeldii*, which were snout length (SNL), lower jaw length (LJL), posterior end of the dorsal to insertion of the caudal fin (PDIC), caudal fin length (CL), caudal peduncle depth (CPD), anal fin height (AFH), body depth (BD), and eye diameter (ED).

3.2.2. Meristic counts

The meristic counts were similar between males and females of *B. schwanenfeldii* (Table 7).

3.2.3. Age

Observation of otolith characteristics between sexes of *B. schwanenfeldii* did not show any significant differences on their morphologies. The age of the *B. schwanenfeldii* was determined after sectioning and polishing process (Fig. 6) based on the annual growth rings, that is, opaque zones (Fig. 7). The mean length of the otolith was 4.9 mm (4.51–5.3 mm) for males and 3.76 mm (2.56–4.81 mm) for females. The age distribution of *B. schwanenfeldii* for males are: 5 y old (5 fish), 6 y old (2 fish) and 7 y old (3 fish). While for the females, it was determined that there were two 1-y-old fish, three 2-y-old, three 4-y-old, one 5-y-old and one 7-y-old.

3.2.4. Reproductive status

The GSI and HSI in the Tinfoil barbs *B. schwanenfeldii* ranged from 0.81% to 13.95%, and 0.15% and 1.21%, respectively. GSI were significantly different between males and females ($p < 0.05$) with a 3-fold higher GSI observed for females compared to males (Table 8). On the other hand, no significant difference was found for the HSI within males and females.

Both sexes display paired gonads. In males (Table 9), 50% of the samples were within Stage IV, and 30% were in Stage I. While for females (Table 10), 40% of the samples were found in Stage V, and 30% were in Stage III, that is, advance maturing stage.

4. Discussion

Sexual size dimorphism exists among vertebrates and can aid in understanding fish body structure and adaptation capacity, along with species identification. It has been widely used by fish taxonomists to distinguish the male from the female of a species [65]. The reason behind SSD is not clear, but it has been recorded that males are found to be larger than females, that is, approximately 20.0% larger in protogynous reef species with external fertilization and paternal care, where male–male competition is predicted to be most intense [33]. Some authors, however, argue that SSD is caused by sex-specific growth and longevity patterns [66]. In freshwater fish, males outgrowing females has been reported in *Semiplotus semiplotus* [30] and commonly occurs in tilapia [67–69]. Wan et al. [70] suggested that the *pro-opiomelanocortin* (*Pomc*) *gene* contributes to SSD, and suggested that the high estrogen level in females promotes the expression of *Pomc* that suppresses feeding in female tilapias which then leads to the slower growth of female tilapias. However, in a majority of the fish species, females are larger than males as demonstrated in perches, *Perca fluviatilis* [71] and in electric rays, *Narcine entemedor* [72]. Size differences between sexes can also be attributed to the varying ages at maturity and to the divergence of the energy investment during gonad development and maturation [73].

The cause of variation in the morphometric and meristic characters can be partly attributed to intraspecific variability which is under the influence of environmental parameters [74]. In this study, eight morphometric characteristics showed sexual dimorphism thus can be used for sex determination in *B. schwanenfeldii*. The results of the investigation of measuring characters within sexes of marine medaka, *Oryzias dancena* showed that both dorsal fin and anal fin lengths are longer in males than females [36]. Additionally, Libovarsky and Bishara [75] demonstrated that sexual differences of snout length and eye diameter, pre-dorsal length and maximum body depth in *Oreochromis niloticus*, and snout length, and eye diameter, head depth and maximum

Table 6
Morphometric characteristic for male and female Tinfoil barb

Morphometric characteristic (% TL)	Male (value ± SD)	Female (value ± SD)
FL	82.48 ± 0.5	82.17 ± 0.37
SL	74.12 ± 3.14	77.26 ± 0.85
*SNL	2.61 ± 0.19	2.9 ± 0.29
UJL	6.23 ± 0.46	6.43 ± 0.74
*LJL	4.69 ± 0.34	5.62 ± 0.61
BL	11.53 ± 0.68	12.43 ± 0.67
HD	16.42 ± 0.6	16.9 ± 0.65
LH	17.98 ± 0.36	17.98 ± 0.66
HDR	27.43 ± 0.67	28.05 ± 0.73
BDF	13.16 ± 0.46	12.8 ± 0.61
DFH	18.34 ± 0.97	19.41 ± 0.72
*PDIC	25.62 ± 1.06	24.44 ± 0.56
CSL	26.65 ± 1.05	26.63 ± 1.35
CH	42.98 ± 0.62	39.71 ± 1.52
*CL	5.93 ± 0.94	5.286 ± 0.48
*CPD	10.42 ± 0.36	10.25 ± 0.57
PAPC	10.36 ± 0.97	10.61 ± 0.56
BAF	10.31 ± 0.54	10.78 ± 0.37
*AFH	12.12 ± 1.23	9.95 ± 0.58
PPIA	14.34 ± 0.55	14.55 ± 0.9
BPvF	4.17 ± 0.2	4.29 ± 0.24
PH	15.31 ± 0.65	15.02 ± 0.7
BIPB	25.74 ± 0.58	24.82 ± 0.8
BPcF	3.56 ± 0.22	3.35 ± 0.21
PL	15.94 ± 0.36	15.67 ± 0.72
BIDB	36.4 ± 1.43	37.1 ± 1.45
*BD	31.3 ± 0.75	35.58 ± 1.49
IDIA	34.02 ± 1.38	34.48 ± 1.22
PDIA	24.83 ± 1.01	25.84 ± 1.04
PDPA	22.6 ± 1.14	23.51 ± 1.46
*ED	7.07 ± 0.3	6.44 ± 0.14
HW	12.82 ± 0.6	11.94 ± 0.35
PPcL	19.14 ± 0.5	19.98 ± 1.01
PPvL	38.08 ± 0.48	37.96 ± 1.3
PAL	55.15 ± 0.92	55.09 ± 1.94
PDL	40.6 ± 0.76	40.79 ± 1.24
BW	11.45 ± 0.47	11.86 ± 0.45

*Significantly different at $p < 0.05$.

body depth in Tilapia zillii. Nwani et al. [76] reported that sexual dimorphism related to dorsal fin base length among mormyrids in the Anambra River System, Nigeria. In *Semiplotus semiplotus*, differences in anal fin height, caudal peduncle depth, and caudal fin length were observed between males and females [30].

According to Gante et al. [25], the number of lateral line scales was 36, dorsal fin rays (iv,9) pectoral fin rays (i,13) and anal fin rays (iii,6) for tinfoil bard elsewhere. Our findings are in consistent with Gante et al. [25], and since all the meristic parameters remained constant in fish with different body lengths, therefore, we can conclude that meristic count is independent of body length [77]. However, some variation in meristic characteristics among similar species of fish from different geographic locations may occur and have been reported to be influenced by environmental variables. For instance, Perazzo et al. [78] demonstrated that individuals of *Bryconamericus iheringii* in lotic environments have a more hydrodynamic shape, as well as a larger operculum compared to the same species found in the reservoir.

In the present study, eight morphometric characters showed significant differences within sexes ($p < 0.05$). Among the most significant differences between male and

Table 7
Meristic count in male (n = 10) and female (n = 10) Tinfoil barb *Barbonymus schwanenfeldii*

Meristic parameter	Male	Female
Lateral line scale, LLS	36	36
Scale above lateral line, ALSS	9	9
Scale below lateral line, BLSS	6	6
Dorsal fin rays, DFR	iv,9	iv,9
Pectoral fin rays, PFR	i,13	i,13
Anal fin rays, AFR	iii,6	iii,6
Ventral fin rays, VFR	i,8	i,8

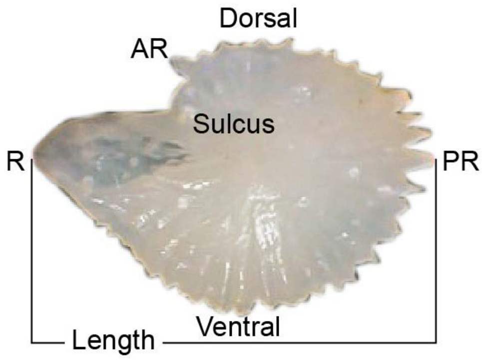


Fig. 6. Otolith from a male *Barbonymus schwanenfeldii*. AR = antirostrum; PR = postrostrum; R = rostrum.

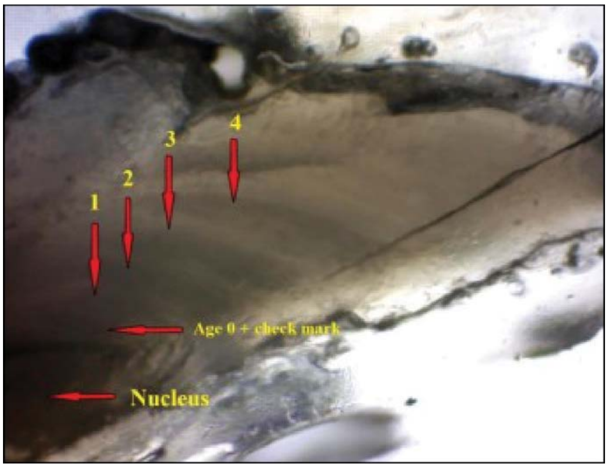


Fig. 7. Opaque zones show the ages of *Barbonymus schwanenfeldii* (4-y-old) under light microscope.

female *B. schwanenfeldii* morphometrics were their snout length (SNL), lower jaw length (LJL), and body depth (BD) with the females showing longer measurements than the males. Conversely, the posterior end of the dorsal to insertion of the caudal fin (PDIC), anal fin height (AFH), caudal fin length (CFL), caudal peduncle depth (CPD) and eye diameter (ED) in the males are longer than those in the females. Larger fins in male fish probably are advantageous during courtship displays [79]. Hence, the mentioned differences in

Table 8
Mean gonadosomatic index and hepatosomatic index of Tinfoil barb *Barbonymus schwanenfeldii*

Organosomatic indices (%)	Male	Female
GSI	2.30 ± 1.96^a	6.94 ± 2.99^b
HSI	0.55 ± 0.38^a	0.55 ± 0.27^a

Different superscript letters in the data columns indicate significant difference.

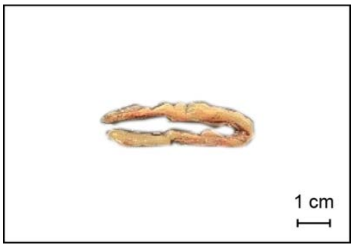
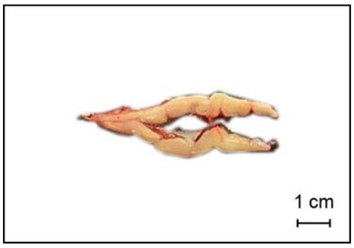
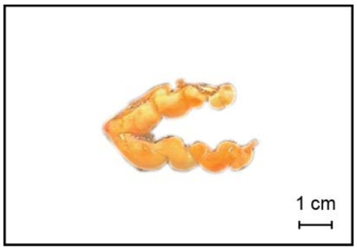
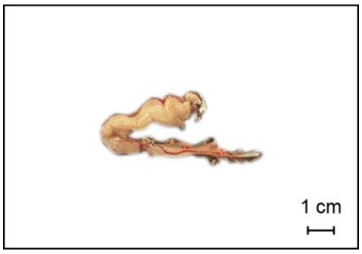
the morphometric characters noted for males and females of *B. schwanenfeldii* may be considered as a sexually dimorphic feature of this species.

The largest fish in this study was a 7-y-old female with the body weight of 398.67 g and a total length of 28.28 cm. Comparatively, the biggest males were two 5-y-old that reached lengths within 22.1–23 cm. In the 1–4-y-old age classes, only females were identified. The average length of *B. schwanenfeldii* has been reported to be within 10–25 cm and weight of about 200–600 g [80]. Bailey and Cole [48] reported that this fish can reach a length greater than 40 cm and often live more than 10 y in captivity. Whether *B. schwanenfeldii* could reach a greater age of more than 7 is not known from this study. In this study, the fish that have been caught were mostly more than 1 y old and weighed more than 140 g. Efizon et al. [81] reported that the first maturity occurs at 7.3 and 8.5 cm, for males and females, respectively. This clearly shows that all of *B. schwanenfeldii* sampled from Kenyir Lake were already matured.

Studies on age and sex determination in fish are important both for ecologists and aquaculturists. The shape and otolith morphology of *B. schwanenfeldii* are similar to other perciform fishes. The otolith length is consistently between 4 and 6 mm. This is a moderate-sized otolith according to the categories given by Paxton [82] except for 2 females with otolith sizes that were less than 4 mm as the fishes were still young (1-y-old). There does not appear to be any sexual dimorphism based on the shape and morphology of otolith between males and females of *B. schwanenfeldii*. The otolith method to determine the ages of male and female fish has also been reported by Donabauer and IGC-SOUTH [83] on walleye in Brookville Reservoir and by Verónica et al. [42] on *Diapterus auratus* from Mexico. However, they only examined the age and did not make any attempt to compare within the sexes. Only studies by McPherson [84] and Buckworth [85] analyzed the otolith data for males and females, separately.

Female fish have paired ovaries that produce eggs, and male fish have paired testes that produce sperm. The female Tinfoil barbs become sexually mature from May through July in Sumatra during the onset of rising water temperatures from 25°C to 27°C (77°–81°F) [81]. Generally, many fish naturally spawn during seasonal changes, such as during an increase in temperature or the availability of natural feeds (phytoplankton and zooplankton) for the developing fry. Organosomatic indices such as GSI and HSI vary within fish species. GSI is measured based on the gonad and body weight of species and the value is directly proportional to the maturity stages as it correlates with the growth of ovaries and testes. There are several classifications for GSI value

Table 9
Testes maturity stages of Tinfoil barb *Barbonymus schwanenfeldii*

Testes stage	Description
	Stage I (Immature stage) Testes are thin, elongated and pale in colour. Thirty percent (3 out of 10) of the samples were at this stage.
	Stage II (Maturing stage) Testes increase in weight and volume; thin, translucent and white in colour. One out of ten of the samples was at this stage.
	Stage III (Mature stage) Testes increase in weight and volume; large, turgid and white in colour. One out of ten of the samples was at this stage.
	Stage IV (Spent stage) Testes become thin and translucent. The weight and volume of the testes decrease. Five out of ten of the samples were at this stage.

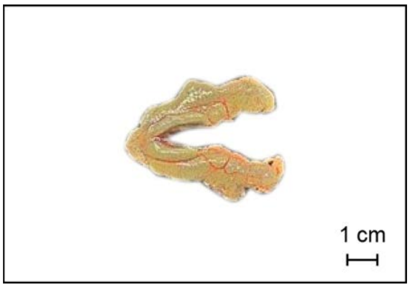
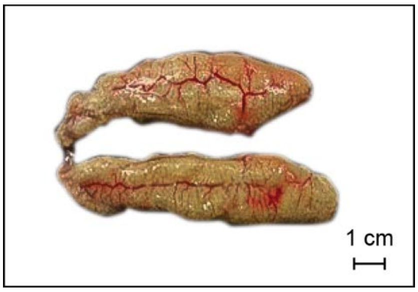
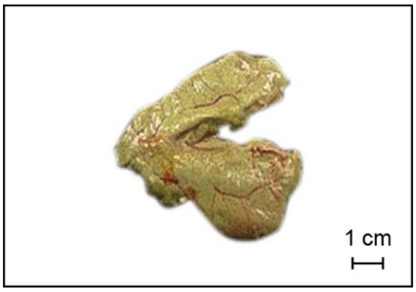
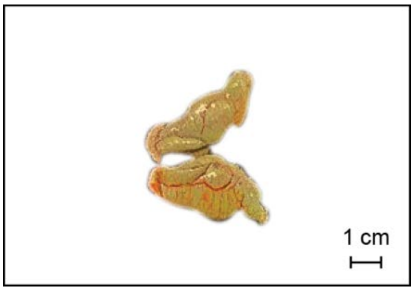
depending on the maturity stages: immature, mature and post spawning. According to McAdam et al. [86], the value of GSI based on growth stages is less than 2.23% for immature, GSI for mature is between 2.43% and 10.46%, and for post spawning is less than 2.43%. In the present study, mean GSI for females showed significantly 3-fold higher values compared to males due to the size of the ovaries. Haryono et al. [87] stated that the GSI values vary according to seasons where a higher GSI was observed during the dry season. Meanwhile, HSI value provides information on the condition of fish and also the quality of water. Comparatively, in *Notopterus notopterus*, HSI was gradually decreased along with ovarian maturation [88] due to the used of energy stored in liver for the development of the ovaries. However, in the present study, HSI values were not affected in both sexes. Delahunty and de Vlaming [89] mentioned that HSI does not change over the range of body weight suggesting that HSI is an appropriate expression of liver size.

5. Conclusion

The finding of this study could be highly useful as a basis for conducting future taxonomic and identification studies on Tinfoil barb *B. schwanenfeldii* populations. Morphometric study on Tinfoil barb in Kenyir Lake can be used as applications for sex identification. Further in-depth studies on the biology of *B. schwanenfeldii* and the enactment of strict conservation strategies for protection of this population in Kenyir Lake are warranted.

In fish biology, knowledge of reproduction is important for the rational utilisation of fish stocks and their sustainable production. The reproductive aspects of fish can be used to provide sound scientific advice in fishery management since the data give a better understanding of the fluctuations in the population. The findings of this study call for an increasing focus on effective management setup, regular stakeholder's follow-up and further monitoring program to ensure the sustainability of the resources.

Table 10
Ovarian maturity stages of Tinfoil barb *Barbonymus schwanenfeldii*

Ovarian stage	Description
	Stage II (Early maturing stage) The ovaries increase in weight and volume. The ovaries become thicker, opaque and pale green in colour. One out of ten of the samples was at this stage.
	Stage III (Advance maturing stage) The ovaries increase in weight and volume. The ovaries are yellowish in colour with many blood vessels. Three out of ten samples were at this stage.
	Stage IV (Mature stage) The ovaries occupy the whole-body cavity with increase in weight and volume. The ovaries are opaque and slightly green in colour. Ova can be identified individually. One out of ten of the samples was at this stage.
	Stage V (Spawning stage) The ovaries are light greenish in colour. The ovaries burst due to spawning process and decrease in weight and volume. Four out of ten samples were at this stage.
	Stage VI (Spent stage) The ovaries reduce in size and greenish in colour. One part of ovary becomes smaller after the spawning process. One out of ten of the samples was at this stage.

*Note: None of the ovaries in Stage I.

The Natural Resources interprets conservation as “the achievement of the highest sustainable quality of living for mankind by the natural utilization of the environment”. Water resources management particularly in the basins of Kenyir Lake is a very important aspect that should be noted and improved by the relevant. Overall, the water in the Kenyir Lake classified under Class I during the dry season and a few sampling stations are recorded under Class II especially nearby active development and climate changes during the wet season. All stakeholders should work together in maintaining water quality and improving water resources management, especially in the Kenyir Lake Basin. There are many initiatives have been implemented by the government to manage water resources in Malaysia. Among the initiatives or measures undertaken by the government are improving distribution systems and water management as well as water smart campaign use to users. Besides that, authorities such as the Department of Environment (DOE) need to play an important role in guiding the water resources regularly.

It will make water resources management in Kenyir Lake Basin can be carried out effectively and produce good quality and clean water to the community without any pollution. In this study we have proposed some measures or steps in the management of water resources in the Kenyir. This option involves the formation of fisheries co-management committees with fishers and other stakeholders from the riverside community. The committee can ensure responsible fishing practices by formulating relevant regulations for the sustainable exploitation of fishery resources. Fishing communities or organizations should be partners in planning, designing, and implementing fishing regulations. Indeed, when these communities or fishermen's organizations are involved in habitat protection and are part of the process of drafting management policies, they give full legitimacy to the regulations, being the strongest advocates, controllers, and implementers of management decisions. Consequently, a community co-management committee would ensure that a closed period, reduced fishing effort, and regulations on minimum mesh size for gillnets are respected, in the interest of protecting fish stocks and ensuring sustainable exploitation of the resource.

Acknowledgements

The authors are grateful for the technical support received from the Faculty of Fisheries and Food Science, Universiti Malaysia Terengganu. Thanks to Dr. M.K.A. Bhuiyan, University of Cadiz, Spain for graphical supports, editing photos and making study area map.

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