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Length-Weight Relationship and Condition Factor of Malaysian Mahseer (*Tor* sp.) from Selected Wild and Cultured Populations Across Peninsular Malaysia

(Hubungan Panjang-Berat dan Faktor Keadaan Mahseer Malaysia (*Tor* sp.) daripada Populasi Liar dan Ternak Terpilih di Seluruh Semenanjung Malaysia)

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ABSTRACT

Biometric data is essential for effective fisheries management, particularly for the Malaysian mahseer (*Tor* sp.), a potential aquaculture species currently listed as 'Data Deficient'. Wild populations are declining due to habitat degradation, while current aquaculture practices fall short of meeting market demand. This study investigates the length-weight relationship (LWR) and condition factor (K) of Malaysian mahseer populations, with samples categorized by origin (wild: n=25; cultured fish: n=29) based on their respective sampling locations. Wild fish ranged from 12.00 to 46.00 cm in length and 22.00 to 1060.00 g in weight, while cultured fish ranged from 15.30 to 41.30 cm in length and 63.71 to 559.22 g in weight. Separate LWR regression analyses showed hypoallometric growth in both populations (b_{wild} = 2.614, $b_{cultured}$ = 1.779), with wild fish exhibiting stronger length-weight correlations ($R^2 = 0.96$) compared to cultured fish ($R^2 = 0.52$). The K-values were higher in the cultured population ($K_{cultured}$ = 1.891 vs K_{wild} = 1.203), highlighting the controlled environment's positive influence on growth. By distinguishing the biometric characteristics of wild and cultured populations, this study provides critical insights for enhancing aquaculture practices and conserving wild mahseer populations in Peninsular Malaysia.

Keywords: Fish biometric; Fulton's condition factor; growth pattern; length-weight relationship; Malaysian mahseer

ABSTRAK

Data biometrik penting bagi pengurusan perikanan yang berkesan seperti spesies Ikan Kelah dengan potensi akuakultur yang kini tersenarai sebagai 'Kekurangan Data'. Bilangan populasi ikan liar semakin menyusut kesan daripada kemerosotan habitat, manakala amalan akuakultur sedia ada tidak berjaya memenuhi permintaan pasaran. Penyelidikan ini mengkaji hubungan panjang-berat (LWR) dan faktor keadaan (K) bagi populasi Kelah dengan sampel dikategorikan mengikut asal-usul (liar: n=25; ternak: n=29) berdasarkan lokasi persampelan masing-masing. Ikan liar berjulat panjang antara 12.00 ke 46.00 cm dan berat 22.00 ke 1060.00 g, manakala ikan ternak berjulat panjang antara 15.30 ke 41.30 cm dan berat 63.71 ke 559.22 g. Analisis regresi LWR berasingan bagi kedua-dua populasi liar dan ternak menunjukkan tumbesaran hipoalometrik (b_{liar} = 2.614, b_{ternak} = 1.779), yang mana korelasi panjang-berat ikan liar lebih kuat (R2 = 0.96) berbanding ikan ternak (R2 = 0.52). Nilai K lebih tinggi dalam populasi ternak (K_{ternak} = 1.891 berbanding K_{liar} = 1.203), menonjolkan pengaruh positif persekitaran terkawal terhadap pertumbuhan. Dengan membezakan ciri biometrik populasi ikan liar dan ternak, kajian ini menyediakan maklumat penting dalam penambahbaikan pengurusan akuakultur serta usaha pemeliharaan Ikan Kelah liar di Semenanjung Malaysia.

Kata kunci: Biometrik ikan; Faktor keadaan Fulton; corak tumbesaran; hubungan panjang-berat; kelah Malaysia

INTRODUCTION

Fish represent the most speciose group of vertebrates, with more than 32,500 species classified as teleost, comprising marine and freshwater fishes under 515 families (Keat-Chuan et al. 2017; Nelson 2006). Remarkably, almost 40% of these species inhabit just 1% of global freshwaters ecosystems, such as rivers, lakes, and streams. This underscores the immense diversity, high endemism, and critical importance of the freshwater ecosystems (Collen et al. 2014; Gleick 1998). However, freshwater fish species face significant threats due to anthropogenic activities, including deforestation, dam construction, large-scale fish harvesting, and pollution, leading to declines in populations and increased risk of extinction (Chong, Lee & Lau 2010; Keat-Chuan et al. 2017). Despite their ecological and socioeconomic significance, many aspects of the biology, ethology, ecology, and physiology of these species remain poorly understood. This is particularly true for fish species of conservation concern, where a lack of data has hindered effective taxonomic management and conservation efforts (Lau et al. 2021).

The length-weight relationship (LWR) is a vital biological parameter in fisheries science, providing critical information about the growth pattern and condition of fish populations. LWR data, combined with population and environmental parameters, help inform conservation strategies and fisheries management (Abdellatif et al. 2022; Froese 2006). For instance, LWR analysis allow researchers to estimate fish biomass, assess growth across different habitats or environments (wild vs farm settings), and data on LWR can be further used to develop improved feeding and farming strategies (Karna et al. 2020; Kuriakose 2017). This relationship is beneficial to assist in achieving the ideal growth surroundings for the studied species (Baek et al. 2020). Deviations from expected weight data obtained during sampling can be assessed, and variables (sex, fish geographic distribution) attributed to such discrepancies in observation can be further disentangled (Kuriakose 2017).

Another supplemental biometric tool is Fulton's condition factor (CF, represented by the letter "K"), which evaluate whether fish stock is in optimal health and growth condition. Through quantification of CF, fish farmers and managers can identify suboptimal growth conditions and implement corrective measures, such as adjusting feed formulation or improving fish rearing practices (Ighwela, Ahmed & Abol-Munafi 2011; Jisr et al. 2018).

An iconic Malaysian mahseer (*Tor* spp.) from *Cyprinidae* family has emerged as a promising aquaculture species due to its nutritional, ornamental, and recreational value. Unfortunately, wild mahseer populations are rapidly declining due to over-exploitation and habitat degradation (Esa & Abdul Rahim 2013; Lau et al. 2021; Pinder et al. 2019). Two mahseer species, known as *Tor tambra* (Valenciennes, 1842) and *Tor tambroides* (Bleeker, 1854), are found in Peninsular Malaysia, with both species deemed as data deficient by the IUCN Red List (Lau et al. 2021; Pinder et al. 2019; Walton et al. 2017). Additionally, they exhibit extensive morphological variations and are tetraploidy in chromosomal number, leading to difficulties in species identification and phylogenetic data interpretation (Pinder et al. 2019; Walton et al. 2017). Habitat destruction from land clearing, development, river impoundment, sedimentation, and pollution has further intensified the difficulties in conserving wild fish populations (Chong, Lee & Lau 2010; Keat-Chuan et al. 2017).

Effort to reduce harvesting pressure on the declining wild *Tor* spp. populations through fish farming face significant challenges. A major issue is the lack of population-level data, particularly for wild populations, as well as limited understanding of their fundamental biological and ecological factors. This gap undermines efforts to optimize growth and developmental processes in farming (Abdul Salam & Gopinath 2006; Keat-Chuan et al. 2017). While the economical and biological significance of Malaysian mahseer is widely recognized, essential biometrical data such as the LWR remain unavailable to support growth assessment. Meanwhile, LWR has been studied in several other fish species, such as the mudskipper, *Periophthalmus chrysospilos* (Abdoli et al. 2009; Zain & Abdullah 2019), twelve species of Philippine mullets (Guino-o 2012), archerfish, *Toxotes chatareus* and *Toxotes jaculatrix* (Das & Mazlan 2008), and several other local fish species in Malaysia riverine (Zulkafli et al. 2016). These knowledge gaps hinder efficient fish farming practices and limit effort to support the conservation and recovery of *Tor* spp. in the wild.

The study addresses the lack of biometric data for *Tor* spp. by aiming to: (i) establish baseline data on the length-weight relationship (LWR) and condition factor (K-values) of *Tor* spp.; and (ii) compare the growth pattern and condition factors between wild and cultured populations. The findings from this LWR analyses will provide valuable insights into the growth characteristics of *Tor* spp. in Peninsular Malaysia, supporting conservation initiatives and the development of sustainable mahseer aquaculture practices, both locally and in other tropical regions.

MATERIALS AND METHODS

STUDY FISH, SAMPLING LOCATION, AND FISH HUSBANDRY

Malaysian mahseer from different water tributaries (natural or artificial estuaries) and fish breeding facilities were employed in this study (Figure 1). Several sampling efforts were achieved between February 2019 and March 2020. Fish samples from tributaries were obtained with the assistance of fishermen, caught using a net or fishing rod, and later categorized as 'Wild, W'. Sampling locations include tributaries within state parks (Royal Belum, RB, and Taman Negara Pahang, PHG) and national forests (Sungai Galas Kelantan, KLTN, and Sungai Terengganu Mati, TGNU).

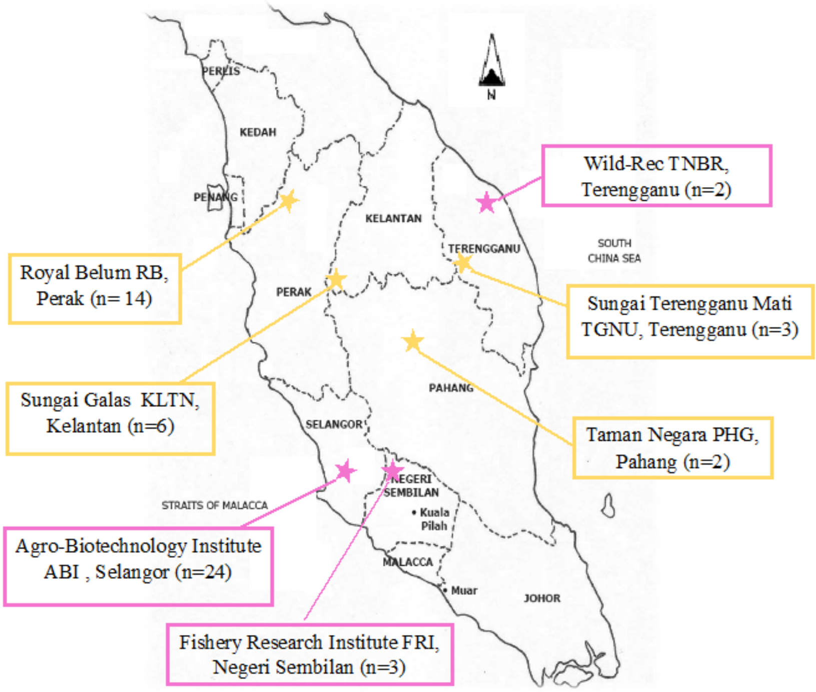

FIGURE 1. Sampling locations of *Tor* spp. across Peninsular Malaysia. Each location is grouped as cultured (pink box) or wild (yellow box) origins, followed by abbreviation and total fish count. Cultured origins, C: ABI, FRI, TNBR (n=29); Wild origins, W: KLTN, PHG, RB, TGNU (n=25)

In contrast, 'Cultured fish, C', have been collected by personnel from fishing agencies and the fish were provided to our research team. Fish were maintained in an artificial environment (cement or polycarbonate tank) suitable for fish growth, and these criteria vary according to the hatcheries. Fish from the Agro-Biotechnology Institute (ABI) are progeny of broodstock initially captured from the wild, acclimatized to groundwater, and bred in a hatchery. They were fed twice daily with self-formulated pellets containing 42% protein and 6% lipid. Fish from the Fisheries Research Institute Malaysia (FRI) and Wild REC TNB Research (TNBR) were reared in tanks using local stream water to mimic natural freshwater conditions, including temperature, pH, and oxygen content. Their diet consisted of commercial carp fish pellets. Animal care and all experimental procedures for this study were approved by the Universiti Kebangsaan Malaysia Animal Ethics Committee (FST/2019/SHAIRAH/20-MAR./992-MAR.-2019-AUG.-2022).

WEIGHT AND LENGTH MEASUREMENT

Upon collecting each fish, their weight and length were measured individually before their bodies were frozen for future analysis. All fish were measured for their fork length to the closest 0.01 cm with a measuring board and weighed to the nearest 0.01 g accuracy using a digital weighing machine (Precision Balance XY-2C). When measuring the fish on-site was not possible, images of the fish were taken, and ImageJ was used to estimate their length (Schneider, Rasband & Eliceiri 2012).

ANALYSES OF COVARIANCE (ANCOVA) AND LENGTH-WEIGHT RELATIONSHIP (LWR)

Ideally, LWRs should be established according to the population from which the fish was obtained. To evaluate any heterogeneity in the model due to influence of different population origins (covariate) and the measurement, Analysis of covariance (ANCOVA) was first employed. We hypothesize that the population origins, W vs. C, might influence the fish's weight and length increment rate affecting the homogeneity of regression slopes (b) and regression intercept (a) between the two origins (Das, De & Mazlan 2014; Froese 2006).

Two ANCOVA models were used in this analysis (Das, De & Mazlan 2014; Froese 2006). In Model I, the dependent variable y, which is the fish's log weight (log W), is determined by the interaction between the fish's log length (log L (x)) and a covariate, i.e., population origins (Pop). This model tested for homogeneity of regression slopes. On the contrary, Model II does not involve the interaction between the covariate and the main factor; instead, it measures the summation of both factors in the second model. In Model II, log weight is modelled only by adding log length with population covariate without interaction (Lewis 2010), testing for homogeneity of regression intercept. The equations for both models are displayed in Table 1. The statistical differences were considered significant if the p-value was less than 0.05 ($p < 0.05$). The significant p-value was deemed to influence further linear regression analysis on LWR, and the analysis regression was conducted separately based on population origins (Froese, Tsikliras & Stergiou 2011). The statistical analysis was performed using the *ggpredict* package in the R programming computer software (Langel 1982; Pope & Kruse 2007).

LWR regression analyses based on linear equations was performed to identify the relationship between two variables, i.e., weight and length. The relationship between body weight (g) and body length (cm) was initially expressed in $W=aL^b$ (Jisr et al. 2018; Le Cren 1951). This formula is log-transformed as $\log W = \log a + b \log L$ to achieve a linear relationship ($y = mx + c$). L refers to the length, while W relates to the weight in the equation. As parameter ‘a’ represents the intercept, and parameter ‘b’ represents the slope in the equation, it is possible to estimate both parameters (Stergiou & Politou 1995; Zar 1984). The significance of the regression was assessed by ANOVA, using ordinary least square regression (95% confidence). The null hypothesis, H_o, in regression analysis states that there is no corresponding relationship between both variables ($b = 0$), i.e., the length of the fish does not significantly affect the weight of the fish. LWR analyses were conducted in R studio using ‘lm()’ function.

DETERMINATION OF GROWTH PATTERN BASED ON THE ‘b’ PARAMETER

The b coefficient in a linear LWR equation, $\log W = \log a + b$, helps infer certain fish species’ growth patterns and general body shape (Karachle & Stergiou 2012; Kuriakose 2017). The threshold value of the b parameter is 3, representing an isometric growth. This value indicates an ideal growth relationship where fish body parts grow at a similar rate. When the b value deviates from 3, it represents an allometric growth that might have been caused by certain environmental circumstances or growth conditions (Jisr et al. 2018). If b is less than 3, the fish is concluded to experience a negative allometry (hypoallometry) growth, where the body shape of the fish is elongated and thinner. In contrast, the fish exhibit hyperallometry growth if the b value exceeds 3, i.e., the fish becomes heavier, indicating much more optimum conditions for growth. The deviation of regression parameter b from the threshold value of 3 (H_o: $b = 3$) was quantified by calculating Pauly’s *t*-test statistics (Equation 1). The b value is different from 3 if *t* values are greater than the table *t* values for n-2 degree of freedom at α level = 0.05 (Kuriakose 2017; Pauly 1984; Satilmis et al. 2014).

$$t_{n-2} = \frac{(|b-3|)\sqrt{(n-2)\sum_{i=1}^{n}(x_i-\bar{x})^2}}{\sqrt{\sum_{i=1}^{n}(y_i-\bar{y})^2 - b^2\sum_{i=1}^{n}(x_i-\bar{x})^2}} \qquad (1)$$

While slope b helps determine the growth pattern of fish in a population, intercept a is also useful for predicting the average body shape of the fish population. Intercept a has the following values: (i) 0.001, the fish has an eel-like shape; (ii) 0.008, the fish has an elongated shape; (iii) 0.013, the fish has a fusiform shape; and (iv) 0.018, the fish is shorter and has a deep shape (Mohamad Radhi et al. 2017).

FULTON’S CONDITION FACTOR (K)

Once the b parameter has been estimated, the K-value can be calculated to evaluate the condition of an average individual fish in different populations (Ighwela, Ahmed & Abol-Munafi 2011). It is also used as a parameter to identify the suitability of habitat concerning the environment, food availability, and other factors towards the growth of fish (Jisr et al. 2018). Value depends on the fish length, i.e., varying length of a fish with almost similar weight produces variable K-values. The K-value will decrease as the length of a fish increases. In this study, K is defined as $W/L^3 \times 100$, while W represents the observed weight (g), and L represents the observed length (cm) of the fish (Guino-o 2012).

RESULTS AND DISCUSSION

FISH BODY LENGTH AND WEIGHT MEASUREMENT

Due to technical logistics and permit restrictions, we obtained limited sample sizes at nearly all locations. This necessitated the pooling of fish samples based on their origin. Consequently, this limitation impacts the overall representativeness and statistical power of the study. The mean length and weight for fish in each sampling are shown in Table 2. These locations are classified into two groupings, C (cultured) or W (wild) origins. Differences in mean with standard error of fish according to the location are shown in Figure 2. The mean weight values for wild fish are generally higher than cultured fish except for those found in KLTN. It is also true for the mean of length, although the differences in mean value are less prominent. The body sizes of cultured samples gathered from all three locations were chosen randomly; however, efforts were made to match their body lengths and weights with samples collected from the wild.

Phenotypic differences between wild and cultured fish are observed in aquaculturally important species like coho salmon, *Oncorhynchus kisutch* (Swain, Riddell & Murray 1991) and North African catfish,

TABLE 1. Summary of the equation used in both models for testing statistical analysis of covariance

Model tested via ANCOVA	Mathematical equation
Model I	logW ~ logL * Population Origin
Model II	logW ~ logL + Population Origin

TABLE 2. Total count of fish specimens according to population origin, sampling location, and range of length and weight

Fish population origins	Location (Abbrev.)	Total count (n)	Length (cm)		Weight (g)	
			Range	Mean ± Std. Error	Range	Mean ± Std. Error
Cultured, C	FRI	3	26.37 – 41.30	32.64 ± 7.75	191.37 – 273.91	233.39 ± 41.29
	ABI	24	15.30 – 27.00	23.58 ± 2.96	63.71 – 435.50	290.01 ± 98.59
	TNBR	2	25.00 – 38.00	31.50 ± 9.19	138.00 – 559.00	348.50 ± 297.69
Wild, W	TGNU	3	44.00 – 46.00	45.33 ± 1.15	620.00 – 1060.00	813.33 ± 224.80
	KLTN	6	12.00 – 34.00	25.17 ± 8.70	22.00 – 478.00	308.83 ± 219.55
	RB	14	23.00 – 46.00	34.73 ± 7.20	125.00 – 1025.00	519.29 ± 269.42
	PHG	2	36.65 – 37.33	36.99 ± 0.48	543.97 – 570.96	557.47 ± 19.08

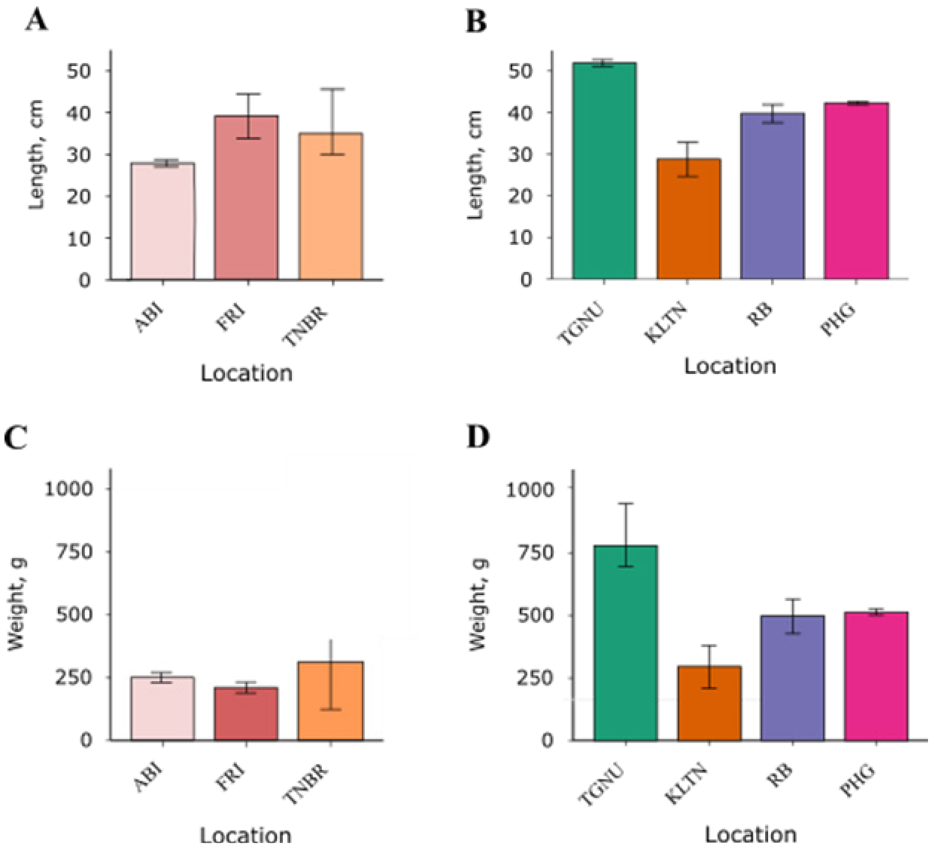

FIGURE 2. Bar chart showing mean values of (A) length for cultured population origin, C, and (B) wild fish population, W; (C) weight for C origins, and (D) for W origins. Abbreviations for each location are used following Figure 1

Clarias gariepinus (Solomon, Okomoda & Ogbenyikwu 2015). Similar differences are reported in an endangered *Tor putitora* (Patiyal et al. 2014). This could be attributed to environmental differences: hatchery fish rely on uniform pellets in controlled settings, while wild fish select from diverse, abundant natural food sources, with natural selection favoring larger individuals.

EFFECT OF POPULATION ORIGINS ON WEIGHT INCREMENT

ANCOVA tested for any influence of covariate (i.e., population origins) on the weight data using two models. Model I include the interaction between length and origins, while Model II measures the summation of both factors without interaction (Lewis 2010). The ANCOVA results for both Model I and Model II indicate that the covariate, population origins (wild vs cultured), significantly influences weight gain. In Model I, a significant interaction was detected between predictor variable of fish length and population origins ($R^2 = 0.85$, F = 107.7, df = 56, $p < 0.05$), indicating different regression slopes for the two populations. For Model II, ANCOVA showed a significant p-value for the intercept ($R^2 = 0.83$, F = 143.9, df = 57, $p < 0.001$), therefore, rejecting the null hypothesis of similar regression intercepts between populations. These findings demonstrate that fish origin significantly affects morphology, particularly weight gain. Differences in weight gain at similar lengths likely result from environmental factors, such as diverse food availability and competition in wild populations compared to controlled feeding in cultured environments (Pope & Kruse 2000). Consequently, these results suggest that linear regression analyses should be conducted separately for each population origins to accurately represent the LWR of wild and cultured fish.

LENGTH-WEIGHT RELATIONSHIP (LWR) AND HYPOALLOMETRIC GROWTH OF *Tor* spp.

The LWR was estimated from the allometric model $W = aL^b$ (Jisr et al. 2018; Le Cren 1951). By transforming this formula into a linear LWR equation, both a and b constants can be calculated, and the relationship between the length and the weight of the fish can be determined based on regression analyses.

In our study, we have quantified LWR equations separately for the wild ($W_W = 0.0483 * L^{2.5939}$) and cultured ($W_C = 0.8692 * L^{1.7789}$) Malaysian mahseer populations. Linear regression analysis plot represents each set of regression analyses shown in Figure 3. ANOVA analysis of the linear regression LWR for wild and cultured fish populations showed a significant relationship between fish length and weight, rejecting the null hypothesis (W origins: $R^2 = 0.96$ F = 465, df = 23, $p < 0.001$; C origins: $R^2 = 0.52$, F = 29.64, df = 27, $p < 0.001$). The high R^2 value for wild fish indicates that 95% of the variability in weight is explained by length, suggesting a strong model fit. In contrast, the moderate R^2 value of 52% for cultured fish reflects lower explanatory power and greater variability in the relationship. Overall, the LWR model for wild fish is considered more robust and reliable compared to the cultured population model (Figure 3(a)).

As pooling could mask the actual relationship between predictor variable length and dependent variable weight, we then performed linear regression analysis on a selected sampling location for each population's origins. RB and ABI represent reference fish population for wild and cultured origins, respectively, since most fishes are obtained from these locations as opposed to others. Both RB and ABI showed high R^2, suggesting a good fit of the LWR model (Figure 3(b)) with data obtained from these two locations (RB: $R^2 = 0.95$, F = 172.3, df = 12, $p < 0.001$;

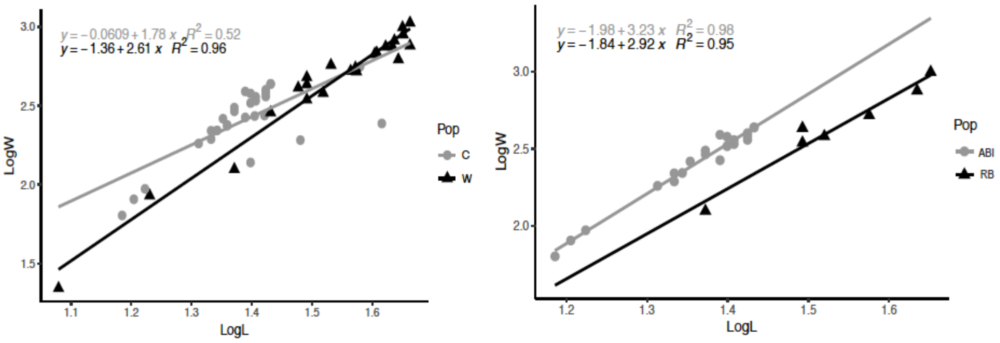

FIGURE 3. Linear regression analysis graph showing log weight against log length and the plot equation for (a) cultured population (grey-colored, denoted as C) and wild population (black-colored, denoted as W), (b) ABI population (grey-colored – representing C) and RB population (black-colored – representing W). LWR equation in the linear form of y = mx+c is $\log_{weight} = b(\log_{length}) + \log a$

ABI: $R^2 = 0.98$, $F = 601.1$, $df = 22$, $p < 0.001$). In the linear relationship $y = mx + c$, the line intercept is represented by log *a*, and the slope is represented by *b.*

Estimates of the coefficients for all parameters obtained from the linear regression analysis modeling the length-weight relationship (LWR) for the fish in both the pooled and representative samples are presented in Table 3. Both W and C pooled (Figure 3(a)) populations have a *b* value of less than 3, indicating that fish likely experienced hypoallometric growth. Pauly's-*t* statistic was calculated and compared to the critical values from Student's *t*-table (n-2 degrees of freedom) to test for deviation from b = 3, which indicates isometric growth. For both wild and cultured fish populations, and the calculated Pauly's t-values exceeded the critical values, leading to the rejection of H_o (Table 3).

The b coefficients for Malaysian mahseer in this study align with reported values from other studied mahseer species. For example, Indus mahseer (*Tor macrolepis*) shows b values ranging from 2.99 to 3.21 (Pervaiz et al. 2012), while *Tor putitora* exhibit allometric growth with a b value of 2.85. This comparison highlights growth variability among mahseer populations and species.

In hypoallometry, the growth of organisms increases faster in body length than in body weight (Jisr et al. 2018; Karachle & Stergiou 2012). Morphologically, fish populations with this growth pattern have a small, thin, and elongated body shape that is particularly noticeable in larger specimens (Froese 2006). Contrarily, the appearance of such a body shape could also be due to less optimal environmental conditions regarding nutrient availability, crowding, and competition (Jisr et al. 2018). These factors inhibit growth, affecting the value of b in the LWR of a species.

Interestingly, when the same test was applied for representative locations, RB from the wild origin was deemed to have a hypoallometry growth (b= 2.918; b < 3). In contrast, ABI of cultured origin have a b value similar to 3 and concluded to have an isometric growth pattern, although the latter is not statistically significant (Table 3). Lack of nutrient availability and less optimal conditions could lead to growth disturbances and adversely affect the overall health of the stocked fish population (Abd Hamid, Mansor & Mohd Nor 2015).

Tor spp. CONDITION FACTOR (K) VALUE ESTIMATION

Estimates of the Condition Factor (K), values for wild and cultured *Tor* spp. populations, and their reference populations, ABI, and RB, are shown in Table 4. K-values for the wild fish population (K = 1.203) are shown to be lower than the farmed fish population (K = 1.891).

The condition factor (K-value) serves as a baseline indicator of the well-being and health of a fish population (Ndiaye et al. 2015). It provides insights into growth, reproduction, and survival, helping assess the requirements for optimal fish growth (Ndiaye et al. 2015). Generally, fish with higher K-values at a given length are in a better growth condition than those with a lower K-value. Abd Hamid, Mansor and Mohd Nor (2015) classified fish condition using K-values: (i) 1.00 indicates suboptimal condition; (ii) 1.20 reflects moderate suitability for sport-

TABLE 3. Estimated parameters a and b values, according to their respective LWR equation, growth pattern, and Pauly's t-test statistic value

Type of population	Parameter estimated value		Length-weight relationship (LWR) equation	Growth pattern	Pauly's t-test statistic value
	a	b			
Wild, W	0.0438	2.614	$W = 0.0438*L^{2.614}$	Hypoallometry	3.3408*
Cultured, C	0.8692	1.779	$W = 0.8692*L^{1.779}$	Hypoallometry	4.1903*
RB	0.0145	2.918	$W = 0.0145*L^{2.918}$	Hypoallometry	2.0850*
ABI	0.0105	3.226	$W = 0.0105*L^{3.226}$	Isometry	1.3946

*indicate that Pauly's t is significantly larger than critical *t*-value table in Student's *t* table for α = 0.05, df = n-2

TABLE 4. Minimum, maximum, mean, and standard deviation value of K for wild and cultured *Tor* spp. population

Type of population	Condition factor, K		
	Minimum	Maximum	mean ∓ std. deviation
Wild, W	0.728	1.730	1.203 ∓ 0.270
- RB	0.943	1.726	1.166 ∓ 0.217
Cultured, C	0.346	2.647	1.891 ∓ 0.530
- ABI	1.660	2.647	2.100 ∓ 0.214

fishing; and (iii) 1.40 represents optimal growth condition. Similarly, Ragheb (2023) utilized the relative condition factor (Kn), which compares a fish's actual weight to its expected weight for a given length. A K-value below 1.00 indicates poor prey availability or high predator density, while values of 1.00 or higher suggest balanced prey-predator dynamics and favorable growth conditions. These variations in K-values offer valuable insights into food availability, predator pressure, and habitat quality.

Based on these, we conclude the wild fish population (K = 1.203) is to experience moderate growth conditions, while the farmed fish population (K = 1.891) is in an optimal growth condition. Alas, both values are higher than 1.00 which imply the sufficient food availability or low predator density supporting population growth (Jisr et al. 2018). Wild fish in our study were collected from gazetted areas such as the National Park. Public access and fishing in these areas are controlled by law and jurisdiction, which likely helps build a sustainable mahseer population (Royal Belum State Park, personal communication). Meanwhile, the higher K-value of mahseer fish nurseries could be attributed to adequate food sources, suitable rearing temperature, and lack of invasive attacks (Jisr et al. 2018). Since cultured fish are reared under controlled conditions, it is possible to regulate the environment and nutrition throughout whole life cycle to achieve fish with higher weight and bigger body confirmation.

We cannot deny that the small sample size may have influenced the estimation ($n < 30$) (Kurtela et al. 2019). The low number of samples tested in this study resulted in the low range of length or weight measured. Quantifying mean values and identifying outliers can be better achieved with larger sample sizes. Sampling fish with narrow size ranges may also bias the estimate (Froese 2006). Compared to the wild fish populations, the length range of the cultured fish population is narrower. This claim is further backed by the fact that cultured fish populations exhibit higher variability (R^2 value = 0.52) compared to populations of wild fish (R^2 value = 0.96) in a linear regression analysis.

CONCLUSION

These findings highlight the contrasting growth and health dynamics of Malaysian mahseer in wild and cultured settings. Wild fish generally exhibit greater length-weight correlation and moderate growth conditions, influenced by diverse food sources and natural competition. Cultured fish, on the other hand, benefit from controlled environments, resulting in higher condition factor (K) values and optimal growth. The observed differences in LWR and growth patterns underscore the environmental influences, with wild fish displaying hypoallometric growth due to resource limitations, while cultured fish experience greater variability under rearing conditions. Future research should address limitations such as small sample size and narrow size ranges to further refine LWR and condition factor estimations for modelling fish growth patterns. Preserving natural Malaysian mahseer habitats and optimizing aquaculture practices are essential for sustaining this species, ensuring both ecological balance and economic viability.

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