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Weight–Length Relationship and Condition Factor of Gibel Carp (*Carassius auratus gibelio* var. CAS V) at Different Growth Stages and Feed Formulations

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Abstract: Accurate recording of growth indicators for aquaculture species at different stages is essential for evaluating aquaculture production effectiveness and the rationality of feed formulations. Due to their convenience and non-invasiveness, weight, length, and condition factor are commonly used to assess the growth of aquaculture species. However, fish growth indicators, can vary significantly with age structure and feed components (nutrition), and relying on a single indicator may lead to misjudgments. In this study, we investigated the growth indicators of Gibel carp (*Carassius auratus gibelio* var. CAS V) at different growth stages (juvenile and adult) and different feed formulations. Meanwhile, the fish weight–length relationship ($W = bL^a$) was used to assess the growth indicators. The results showed that the weight–length relationship of Gibel carp varied significantly with age and feed formulation. Additionally, the condition factor calculated depended on the weight–length relationship being more similar with weight and length change trend than the condition factor was measured. Weight analysis indicated that weight, length, depth, body width, and carcass ratio had higher weights when analyzing fish growth. Therefore, during aquaculture production, fish growth evaluating requires considering diverse indicators such as weight, length, body depth, body width, and carcass ratio, as well as the condition factor, to avoid misjudging the actual growth situation. Meanwhile, the use of the condition factor should consider the sufficient number of data and whether the assumptions (such as being in an isometric growth period) are met.

Keywords: Gibel carp; growth indicators; weight–length relationship; condition factor; growth stage; feed formulation

Key Contribution: This study suggested that fish growth evaluation requires considering diverse indicators. Meanwhile, the use of the condition factor should consider the sufficient number of data and whether the assumptions (such as being in a isometric growth period) are met.

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1. Introduction

In aquaculture, morphological and physiological indices of cultured species are used to assess their physiological or nutritional status. Weight, length, and condition factor are commonly used evaluation indicators due to their convenience and non-invasiveness. The weight (W) of fishes is exponentially related to their length (L) according to the weight–length relationship (WLR) equation $W = bL^a$ [1], which was established by Keys, 1928 [2] and has been widely used since then for determining fish condition and comparing fish growth (***a*** = 3, isometric growth; ***a*** < 3, negative allometric growth; ***a*** > 3, positive allometric growth) [3]. Another indicator, the condition factor(also known as Fulton's condition factor *K*), was intertwined with WLR because Fulton (1904) noted this factor as $K = 100\frac{W}{L^3}$ [4], which was somehow restricted to the condition of isometric growth. The condition factor is an empirical indicator based on the positive correlation between the physiological or nutritional status of animals and the energy storage in their bodies, which, in turn, is positively correlated with body weight [5]. Among individuals of the same body size (length), those with higher weight are generally considered to have better physiological and nutritional status [6]. However, in practical production, the growth stages of fish, such as the juvenile and adult stages, and different feed formulations can lead to deviations from this ideal growth status [7], and relying solely on the condition factor to assess the growth of cultured species may cause misjudgments. Therefore, research suggested using a range of diverse indicators to evaluate cultured species [8].

Thus, the aim of this research is to provide a more precise assessment of WLR and applicable conditions of the condition factor, as well as various indicators, such as body weight, length, depth, body width, and carcass ratio for evaluating Gibel carp (*Carassius auratus gibelio* var. CAS V) growth characteristics at different growth stages (juvenile and adult) and under different feed formulations (fish meal replacement, FMR; plant protein replacement, PPR). This research has the potential to enhance the production management and feed formulation design in aquaculture.

2. Materials and Methods

2.1. Ethical Statement

This research was approved by the Animal Ethics Committee of the Key Laboratory of microecological resources and utilization in the breeding industry, the Ministry of Agriculture and Rural Affairs, and all experiments were conducted according to the protocols and procedures of the Laboratory Animal Management Ordinance of China.

2.2. Feeding Management

2.2.1. Juvenile Stage

Larva Gibel carp (yolk sac) were purchased from Bairong Company (Huanggang, China), transported to Xinghua nursery factory (Xinghua, China), and divided into self-sufficient farm (Xinghua nursery factory) and commercial farm (Yancheng aquaculture farm, Yanchen, China) parts, with a stocking density of 450 fish/m^2. After temporary culture for 10 days, commercial feed purchased from Taizhou Biological Feed Co., Ltd. (Xinhua, China) was used with a feeding rate of 6% for another 120 days. To ensure the stability of feeding, the feeding frequency and amount were consistent between the self-sufficient farm and the commercial farm.

2.2.2. Adult Stage

After being raised to the adult stage (63.04 $\pm$ 6.70 g), the Gibel carp were transferred to net cages (2.5 m $\times$ 2.5 m $\times$ 3 m) for cultivation, with 45 fish per cage and a total of 76 cages. These cages were randomly divided into 19 groups, with 4 replicates per group. A total of 19 different formulation feeds were fed at 4% body weight/day, 3 times/day for 60 days.

2.2.3. Feed Formulation

Fish meal replacement is one of the important research directions for coping with the current shortage of fish meal. At the same time, different plant proteins are widely used in feed formulation design to avoid nutritional and cost imbalances caused by single-plant protein source [9]. Therefore, this experiment used two approaches, fish meal replacement (FMR) and plant protein replacement (PPR), to create different feed formulations. The feed formulation design approach for the adult stage is shown in Table 1. The details of feed formulations for the adult fish were as shown in Tables S1 and S2 and the proximate composition of commercial feed for juvenile fish was as shown in Table S3.

Table 1. Feed formulation design approach for the adult stage.

Main Approach	Control Group	Groups	Feed Formulation Design Approach
Fish meal replacement	1	2	50% fish meal replaced by expanded soybean
		3	Fish meal replaced by a combination of expanded soybean and corn protein powder
		4	Fish meal replaced by cottonseed meal
		5	Fish meal replaced by corn gluten meal
Plant protein replacement	4	5	Cottonseed meal replaced by corn gluten meal
		6, 7, 8	Soybean meal replaced gradually by peanut meal
		9, 10	Rapeseed meal (Canada) replaced gradually by sunflower seed meal
		11, 12, 13	Soybean meal replaced gradually by sunflower seed meal
		14, 15	Soybean oil replaced by wheat with equal energy
		16, 17, 18, 19	Rapeseed meal (Canada) replaced by fermented rapeseed meal

2.3. Data Collection and Processing

2.3.1. Juvenile Stage

Data Collection and Analysis

Fish were taken after 120 days and were anesthetized with MS-222 (25 mg/L). Then fish were measured for weight and length and were classified by cultivation area. The recorded and measured data were statistically analyzed using SPSS (R26.0.0.0 version X.X) and EXCEL (version 16.76(23081101) version XX) software. The parameters (***a*** and ***b***) of the Weight–Length Relationship (WLR) equation in aquaculture (Equation (1)) was calculated by SPSS regression analysis [10].

Weight–length relationship

$$W = bL^a \tag{1}$$

W: weight in grams; L: length in centimeters; ***a*** and ***b*** are parameters

In order to evaluate whether the WLR equation could fit the fish during the juvenile stage, the fitted weight data were inversely calculated from the measured length collected by a commercial farm using the WLR equation. Independent sample *t*-test analysis was performed with the measured weight and fitted weight to evaluate the differences.

2.3.2. Adult Stage

Data Collection and Analysis

The net cage experiment lasted for 60 days. Ten fish were randomly selected from each cage and were anesthetized with MS-222 (25 mg/L) and then killed by a lethal blow to the head. Then the fish were measured for weight, length, depth, body width, and carcass ratio, and the Measured Condition Factor (MCF) was calculated. The length (AB) was determined by rule with an accuracy of 0.1 mm; depth (CD) and body width (EF) were determined by electronic digital calipers with an accuracy of 0.01 mm (Figure 1). The equations for carcass ratio and MCF are as follows:

$$\text{Carcass ratio} = \frac{\text{body weight} - \text{viscera weight}}{\text{body weight}} \times 100\% \tag{2}$$

$$\text{Condition factor} = \frac{\text{body weight}}{\text{length}^3} \times 100\% \tag{3}$$

The recorded and measured data were statistically analyzed using SPSS and EXCEL software. Growth indicator data from each group and the entire population were used individually to calculate the parameters of WLR (Equation (1)) by regression analysis. Afterwards, weight was fitted by the WLR equation for the entire population and each group, respectively. Along with the measured length, the entire population fitted condition factor (ECF) and group fitted condition factor (GCF) were calculated using fitted weight and Equations (3). One-way ANOVA was used to test the differences in various indicators of Gibel carp under different feed formulations. Principal component analysis (PCA) was used to analyze the weight (normalized) of weight, length, depth, body width, MCF, ECF and GCF. All the data sources can be seen in supplements, as described in Table 2.

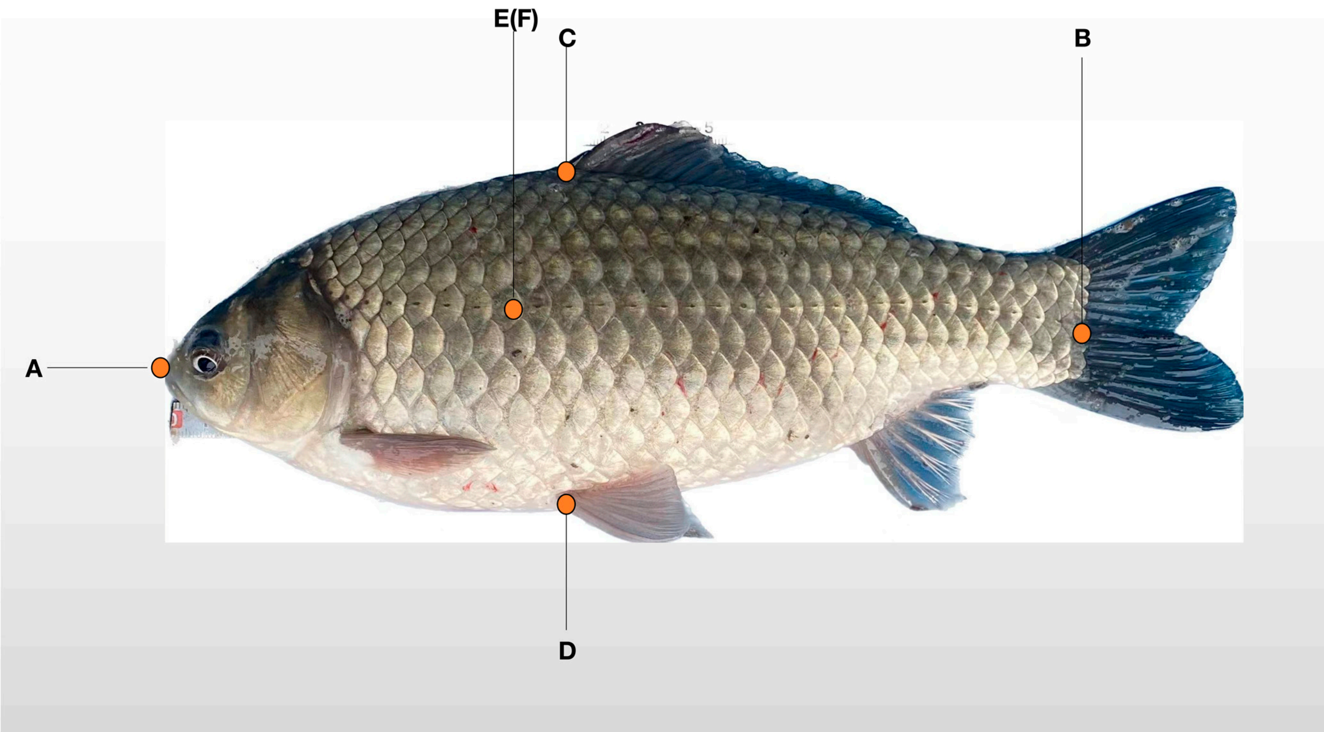

Figure 1. Measurement of morphological indicators (Gibel Carp is shown as an example). AB, body length; CD, body depth; EF, body width (F is the point E on the other side of the fish).

Table 2. Data source of Figure/Table/Equations.

Figure/Table/Equation	Data Source	Sheet
Equation (4)/Figure S1	Data source for Juvenile fish.xlsx	sheet 1: Data from self-sufficient farm
Table 3–Juvenile fish	Data source for Juvenile fish.xlsx	sheet 2: Data from commercial farm
Table 3–Adult fish	Data source for Adult fish.xlsx	Sheet 1: Weight analysis
Tables 4–9	Data source for Adult fish.xlsx	sheet 2: All data
Table 6	Data source for Adult fish.xlsx	sheet 2: All data/sheet3: WLR

3. Results

3.1. Juvenile Stage

Weight–Length Relationship in Juvenile Stage

A regression analysis was performed on the data sampled from the self-sufficient farm, and the values of ***a*** and ***b*** were calculated by regression analysis, resulting in an exponential relationship (r = 0.978) (Equation (4)). This exponential equation fits well with Equation (1) (Figure S1). When the data collected by commercial farm were used, the fitted weight based on the WLR was not significantly different from the measured weight (p = 0.87, Table 3), indicating that Equation (4) is consistent with the actual situation.

$$W = 3.023 \times 10^{-5} L^{3.023} (r = 0.978) \quad (4)$$

Table 3. Statistical significance between measured and fitted weight of juvenile and adult fish.

Data Source	Statistical Significance between Measured and Fitted Weight	
Juvenile fish from commercial farm	-	p = 0.93
Adult fish	**	p = 0.000008

-: $p > 0.05$; **: $p < 0.01$.

3.2. Adult Stage

3.2.1. Length–Weight Relationship of Juvenile Fish Did Not Fit the Adult Fish

The weight data of the adult fish were fitted using the WLR of Gibel carp at the juvenile stage (Equation (4)). The difference between the fitted weight and the measured weight was analyzed and found to be significantly different ($p < 0.01$, Table 3), indicating that the WLR established during the juvenile stage was not applicable to the adult stage of Gibel carp.

3.2.2. Growth Indicators under Different Feed Formulations Had Varying Degrees of Impact

The results showed that different feed formulations had varying degrees of impact on several commonly used fish growth indicators. However, the trends in the MCF were inconsistent with other indicators (weight, length, depth, carcass ratio, and body width). In the FMR group, groups 2 and 3 showed significant differences in weight, length, depth, carcass ratio, and body width, while the MCF showed no significant difference (Table 4). In the PPR group, all groups except group 9 and group 11 showed significant differences in the MCF compared to the control group (Table 5), while most groups showed no difference in weight, length, depth, carcass ratio, and body width compared to the control group. This indicates that using the condition factor alone to assess the growth characteristics of Gibel carp under different feed formulations may cause misjudgments.

Table 4. The effect of fish meal replacement on Gibel carp growth.

Control	Group	Statistical Significance					
		Weight	Length	Body Depth	Carcass Ratio	Body Width	MCF
1	2	**	**	**	**	**	-
	3	**	**	**	**	**	-
	4	-	*	**	**	**	**
	5	-	-	-	*	-	-
total of sd/n-sd group		2/2	3/1	3/1	4/0	3/1	1/3

-: $p > 0.05$; *: $0.01 < p < 0.05$; **: $p < 0.01$; sd: Significant differences; n-sd: Non-Significant differences.

Table 5. The effect of plant protein replacement on Gibel carp growth.

Control	Group	Statistical Significance					
		Weight	Length	Body Depth	Carcass Ratio	Body Width	MCF
4	5	-	-	*	-	**	*
	6	-	-	-	-	-	*
	7	-	-	-	-	*	**
	8	-	-	**	-	**	**
	9	*	*	-	*	-	-
	10	-	-	**	-	**	**
	11	-	-	-	-	-	-
	12	-	-	-	-	**	**
	13	-	-	-	-	*	**
	14	-	-	-	-	-	**
	15	-	**	-	-	-	**
	16	-	-	*	-	-	*
	17	-	-	**	-	**	**
	18	-	-	-	-	-	**
	19	-	**	**	*	**	**
total of sd/n-sd group		1/14	3/12	6/9	2/13	8/7	13/2

-: $p > 0.05$; *: $0.01 < p < 0.05$; **: $p < 0.01$; MCF: Measured Condition Factor; sd: Significant differences; n-sd: Non-Significant differences.

3.2.3. Weight–Length Relationship Fitted Condition Factor Showed Similar Trends to Growth Indicators

The WLR of the entire population and each group of adult fish were established (Table 6). In the WLR, the dimensional of constant ***b*** is consistent with the condition factor, and when ***a*** = 3, ***b***'s definition premise and biological significance are consistent with the condition factor [11]. Weight was fitted by the WLR equation of the entire population (Entire population WLR, Table 6) and of each group (group 1–19 WLR, Table 6) by measured length data. Then, ECF and GCF was calculated using fitted weight, measured length and Equation (3). The results showed that the GCF had similar trends to those of weight and length. In contrast, the trend for the MCF and ECF differed significantly from these indicators (Tables 7 and 8).

Table 6. Weight–length relationships of entire population and each group.

Groups	Weight–Length Relationships	*r*-Value
Entire population	$W = 7.178 \times 10^{-5}L^{2.826}$	0.872
Group1	$W = 8.164 \times 10^{-5}L^{2.800}$	0.794
Group2	$W = 4.251 \times 10^{-5}L^{2.930}$	0.879
Group3	$W = 1.397 \times 10^{-4}L^{2.693}$	0.760
Group4	$W = 1.416 \times 10^{-4}L^{2.694}$	0.839
Group5	$W = 1.019 \times 10^{-4}L^{2.756}$	0.815
Group6	$W = 1.846 \times 10^{-5}L^{3.102}$	0.948
Group7	$W = 7.178 \times 10^{-5}L^{2.826}$	0.908
Group8	$W = 1.319 \times 10^{-4}L^{2.699}$	0.854
Group9	$W = 8.384 \times 10^{-5}L^{3.267}$	0.903
Group10	$W = 1.095 \times 10^{-4}L^{2.738}$	0.938
Group11	$W = 8.620 \times 10^{-4}L^{2.326}$	0.815
Group12	$W = 5.712 \times 10^{-5}L^{2.872}$	0.929
Group13	$W = 3.142 \times 10^{-5}L^{2.988}$	0.909
Group14	$W = 2.038 \times 10^{-5}L^{3.078}$	0.837
Group15	$W = 5.021 \times 10^{-5}L^{2.913}$	0.892
Group16	$W = 5.063 \times 10^{-5}L^{2.896}$	0.930
Group17	$W = 3.826 \times 10^{-5}L^{2.950}$	0.926
Group18	$W = 7.178 \times 10^{-5}L^{2.826}$	0.902
Group19	$W = 1.124 \times 10^{-4}L^{2.734}$	0.875

Table 7. The effect of fish meal replacement on weight, length and condition factors.

Control	Group	Statistical Significance				
		Weight	Length	MCF	GCF	ECF
1	2	**	**	-	-	**
	3	**	**	-	**	**
	4	-	*	**	**	*
	5	-	-	-	**	-
total of sd/n-sd group		2/2	3/1	1/3	3/1	3/1

-: $p > 0.05$; *: $0.01 < p < 0.05$; **: $p < 0.01$; MCF: Measured Condition Factor; GCF: Group Fitted Condition Factor; ECF: Entire Population Fitted Condition Factor; sd: Significant differences; n-sd: Non-Significant differences.

3.2.4. Weight Analysis of Growth Indicators

Weight Analysis of Growth Indicators indicated that body weight, length, depth, body width, and carcass ratio had higher weights when analyzing fish growth characteristics (Table 9).

Table 8. The effect of plant protein replacement on weight, length and condition factors.

Control	Group	Statistical Significance				
		Weight	Length	MCF	GCF	ECF
4	5	-	-	*	**	-
	6	-	-	*	**	-
	7	-	-	**	**	-
	8	-	-	**	**	-
	9	*	*	-	**	*
	10	-	-	**	**	-
	11	-	-	-	*	-
	12	-	-	**	**	-
	13	-	-	**	**	-
	14	-	-	**	**	-
	15	-	**	**	**	**
	16	-	-	*	**	-
	17	-	-	**	**	-
	18	-	-	**	**	-
	19	-	**	**	**	**
total of sd/n-sd group		1/14	3/12	13/2	15/0	3/12

-: $p > 0.05$; *: $0.01 < p < 0.05$; **: $p < 0.01$; MCF: Measured Condition Factor; GCF: Group Fitted Condition Factor; ECF: Entire Population Fitted Condition Factor; sd: Significant differences; n-sd: Non-Significant differences.

Table 9. Weight analysis of Gibel carp growth indicators.

Factors	Weight (Normalization)
Body weight	0.211
Carcass ratio	0.211
Depth	0.179
Length	0.175
Body width	0.124
Measured Condition Factor	0.99

4. Discussion

4.1. Weight–Length Relationship of Gibel Carp Juvenile and Adult Stages

This study collected growth data of Gibel carp from the Xinghua nursery factory, calculated the WLR of the Gibel carp, and verified it using the growth data collected from a commercial farm. The results showed that the WLR (Equation (1)) can fit well, with a value of $\boldsymbol{a}$ = 3.023. From the definition of the equation, the coefficient $\boldsymbol{a}$ represents the ratio of weight gain to length growth in fish. From a mathematical perspective, when $\boldsymbol{a}$ undergoes a small change, $\boldsymbol{b}$ will change significantly, and even when a is relatively stable, $\boldsymbol{b}$ can still undergo frequent changes. Therefore, the value of $\boldsymbol{a}$ reflects the growth characteristics of fish in different stages and environments [1,3]. Another physical interpretation of Equation (1) is that the relationship between fish weight (W), fish density (ρ), and volume (V) is $W = \rho V$, and the volume is an exponential function of length. Generally, the power exponent is close to 3, indicating that fish growth is isometric [12]. In this study, the value of $\boldsymbol{a}$ is 3.023, indicating that Gibel carp is close to isometric growth during the juvenile stage, which may explain why the weight–length relationship fits well with Equation (4) for both farms.

The results also showed significant differences in the WLR between the juvenile and adult stages. This is because factors such as fish species, age, and food can influence the value of $\boldsymbol{a}$ and $\boldsymbol{b}$ of WLR [8,13–16]. The results also showed that the $\boldsymbol{a}$ values of individual groups and the entire population data of the adult stage were smaller than 3 (Table 6), possibly because the Gibel carp was in a hypoallometric growth period.

4.2. Limitations of the Condition Factor in Evaluating Fish Growth Characteristics under Different Feed Formulations

The condition factor is often used to analyze the growth status or reproductive capacity of fish under different conditions [17]. If assuming that the expected weight of animals increases approximately uniformly with length growth, for example, with the increase of the long axis of the body, and the body radial size increases proportionally, then the expected weight will be positively correlated with the cube of the body, which is the original concept of the condition factor (also known as the Fulton index) [11]. Combining Equations (1) and (3), when fish are in an isometric growth period ($\boldsymbol{a}$ = 3), the biological significance of $\boldsymbol{b}$ and the assumption premise of the condition factor are consistent and numerically identical. However, in practical production, fish growth can deviate from this ideal growth state due to changes in environmental conditions such as temperature and feed [7,18,19]. As shown in this study, the WLR of various groups and the entire data in the adult stage showed $\boldsymbol{a} < 3$, indicating that Gibel carp may be in a hypoallometric growth period under different feed formulations. The MCF of various groups did not show significant differences, and its trend was inconsistent with other indicators (weight, length, depth, body width, and carcass ratio). This further indicates that the use of the condition factor should consider whether its premise assumption (e.g., isometric growth stage or $\boldsymbol{a}$ = 3) is met to avoid misjudgments.

In this study, the regression equation of the entire population of adult fish WLR was used to calculate the fitted weight based on the measured length and then calculate the fitted condition factor. The trend of this ECF description was shown to be more similar to other growth indicators (weight, length,) than GCF and MCF. This result indicates that a sufficient number of data is an important condition for the biological significance of the condition factor. Therefore, when using the condition factor for evaluation, a sufficient number of data need to be considered to ensure the accuracy of this indicator's evaluation.

The indicators of fish weight, length, depth, body width, and carcass ratio were also analyzed for evaluating fish growth. The results showed that these indicators had higher weights. Therefore, in aquaculture production, the evaluation of fish growth under different feed formulations should comprehensively consider diverse indicators such as weight, length, depth, body width, carcass ratio, and condition factor to avoid misjudgments caused by a single indicator.

5. Conclusions

This study discussed the application limitations of WLR and CF under different growth periods and feed formulations, as well as the application of other indicators, and demonstrated that, to support an accurate assessment of fish growth in aquaculture production, a comprehensive growth indicator system was needed, such as weight, length, depth, body width, carcass ratio, and condition factor. However, the application of the condition factor in practice needs to consider the sufficient number of data and whether its premise assumption (e.g., isometric growth stage) is met. In other words, with a thorough understanding of the relationship between CF and WLR, as well as their biological significance, CF could be more meaningful and credible during the evaluation of fish growth and their economic value.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/fishes8090439/s1, Table S1: Feed formulations for fish meal replacement group; Table S2: Feed formulations for plant protein replacement group; Table S3: Proximate composition of commercial feed for juvenile fish; Figure S1: Weight-length regression analysis of Juvenile fish.

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Institutional Review Board Statement: This research was approved by the Animal Ethical and Welfare Committee of the Institute of Hydrobiology, Chinese Academy of Sciences, China (approval number: IHBCAS-20210601 approved on 1 June 2021).

Data Availability Statement: All the research data have been upload in supplementary materials. The original data could be find as Table 2 described.

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Conflicts of Interest: The authors declare no conflict of interest.

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