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Predictive modeling of body weight from body length in koi fish (*Cyprinus carpio* var. *koi*) cultivated in Indonesia

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Abstract. Koi fish (*Cyprinus carpio* var. *koi*) is a highly valued ornamental species, renowned for its diverse coloration and distinctive body patterns. Although koi aquaculture in Indonesia continues to expand, scientific studies on their morphological characteristics remain limited, considering their economic and aesthetic importance. Body weight is a critical parameter for evaluating growth performance and production value. However, there is no quick or non-destructive method to measure it accurately. Breeders traditionally rely on body length as the primary indicator of growth, yet the ability to estimate body weight from length would provide a practical alternative. This study aimed to develop a predictive model of body weight based on body length in koi cultivated in Indonesia. A total of 112 koi individuals aged 4–10 months, representing six varieties (Kohaku, Showa, Sanke, Shiro, Platinum, and Matsuba), were measured. Body length ranged from 11.27 to 20.12 cm, corresponding to the typical size of koi commonly found in the market for early selection. Length was measured using a caliper from the head to the caudal peduncle, while body weight was determined with a digital scale. Linear regression analysis revealed a strong, significant relationship between body length and body weight, with a correlation coefficient (R) of 0.880 and a coefficient of determination (R^2) of 0.774, indicating that 77.4% of the variation in body weight is explained by body length. The regression equation obtained was $Y = -142.663 + 13.874 \times \text{Length}$, with a standard error of 17.090. This model is reliable for koi with body lengths of 11.27–20.12 cm, demonstrating that body length is a practical and accurate predictor of body weight. These findings provide a valuable tool for selection, feeding management, and growth evaluation in koi aquaculture.

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1 Introduction

Koi fish (*Cyprinus carpio var. koi*) is one of the most widely cultivated ornamental fish species worldwide, valued for its distinctive body coloration and patterns, as well as its cultural significance. Its high economic value is supported by strong demand from both domestic and international markets, particularly in Asia, Europe, and North America. In Indonesia, koi aquaculture has experienced significant expansion in recent years, driven by favorable breeding conditions and growing market demand[1]. Several varieties, including Kohaku, Showa, Sanke, Shiro, Platinum, and Matsuba, have become dominant strains in both the local and export markets, contributing to the growth of the ornamental fish industry [2,3].

Assessment of koi quality and market value traditionally relies on body length as the primary determinant [1,4]. Body length is widely used due to its practicality and ease of measurement in field settings. Body weight provides additional information on growth performance, nutritional status, and body conformation[5–7]. Koi of identical length may vary substantially in weight, depending on factors such as muscle development, fat deposition, and body proportions. Fish with more balanced weight-to-length ratios are often perceived as having superior aesthetic quality and, therefore, a higher market value [1].

In other fish species, this method is often used to assess growth quality [8,9]. Despite the importance of these parameters, no published study has yet quantitatively examined the length–weight relationship of koi fish in Indonesia. The absence of such data limits the development of objective evaluation methods, resulting in a heavy reliance on subjective visual assessments for quality grading and pricing. This subjectivity contributes to inconsistent valuation, reduced transparency in trading, and inefficiencies in both production and marketing [1].

Establishing a predictive model for estimating body weight based on body length offers practical and economic benefits. It enables more accurate monitoring of growth performance, improves feed management, and facilitates standardized, non-invasive quality assessments. Linear regression analysis has been widely applied in fisheries research to describe length–weight relationships in various commercial species [10]. This study aims to develop a predictive model to estimate koi body weight from body length measurements at sizes commonly traded in Indonesian markets. The results are expected to support objective quality evaluation and contribute to more consistent pricing systems within the ornamental fish industry.

2 Materials and Methods

The koi used in this study were obtained from breeders with credible maintenance records in Daerah Istimewa Yogyakarta (DIY) and Blitar, East Java. These two regions were selected using a purposive sampling strategy, as they are widely recognized as major koi aquaculture centers in Indonesia with established breeding practices. Farms were chosen based on accessibility, documented husbandry standards, and breeder willingness to participate. This approach was intended to capture practical variability in koi quality and management conditions commonly encountered in commercial and hobbyist settings. While the sampling was not random and therefore does not represent all Indonesian koi farms, it was designed to reflect realistic production environments and a broad range of fish quality, from high-grade to lower-grade specimens.

The dataset for length–weight relationship analysis consisted of 90 koi fish from six commonly cultivated varieties: Kohaku, Showa, Sanke, Shiro, Platinum, and Matsuba, each measured once. Additionally, 22 individuals from the Kohaku, Platinum, and Matsuba varieties were measured twice to evaluate measurement consistency, bringing the total number of observations to 122. All fish were between 4 and 10 months old with total lengths ranging from 11.27 to 20.12 cm. Variety identity and farm origin (DIY or Blitar) were recorded for each fish. Preliminary exploratory analyses were conducted to assess whether variety or farm location influenced the length–weight relationship. As no substantial systematic differences were detected within the scope of this study, data were pooled across varieties and locations to develop a general predictive model representative of mixed koi populations commonly encountered in practice.

Before data collection, all fish underwent a one-week acclimatization period in the experimental aquarium under controlled conditions. All koi were acclimatized in an indoor aquaculture laboratory before measurement to standardize physiological condition and minimize handling stress. Fish were divided into three 140-L aquariums, with 30 fish per tank, supplied with continuously aerated freshwater. Water temperature was maintained at 26–28 °C. To maintain water quality, a 20–30% partial water exchange was performed every three days. Fish were housed in groups under identical environmental and feeding conditions, and no variety-specific treatments were applied. This standardized acclimatization ensured that measurements reflected biological variation rather than short-term ecological effects. Before length and weight measurement, fish were anesthetized with a koi-specific anesthetic containing the active compound β-hydroxyethyl phenyl ether to minimize handling stress during measurement. Body weight was measured using a digital balance with a precision of 0.01 g, while body length was measured from the tip of the snout to the base of the caudal fin using a digital caliper.

The collected data were used to examine the relationship between body length and body weight, and a predictive model was developed to estimate body weight from length. A simple linear regression analysis was performed using IBM SPSS Statistics, with body length as the independent variable and body weight as the dependent variable. This analysis was conducted to evaluate the strength of the linear relationship between these two morphometric parameters and to model the contribution of length to weight as an indicator of growth in koi fish.

3 Results and Discussion

3.1 Body Length and Weight of Koi Fish

Descriptive statistics of koi fish body length and weight measurements are presented in Table 1. A total of 90 individual koi were included in the study. Among these, 22 fish (15 Kohaku, 3 Sanke, and 4 Matsuba) were measured twice, before and after a 6-month rearing period, to evaluate growth performance. The remaining fish were measured once during morphometric characterization. Consequently, the regression dataset consisted of 112 measurement records, while the number of unique individuals remained 90.

Table 1. Descriptive statistics of koi fish body length and weight measurements.

Measurement	n	Mean	Min	Max	Standard Deviation
Body length (cm)	112	15.49	11.27	20.12	2.270
Body weight (g)	112	72.22	24.73	165.57	35.799

The average body length of koi fish was 15.49 ± 2.27 cm, ranging from 11.27 to 20.12 cm. The average body weight was 72.22 ± 35.80 g, ranging from 24.73 g to 165.57 g. This variability reflects the diversity of the sampled population, which included multiple varieties and quality grades, as well as repeated measurements from a subset of fish to capture growth-related changes.

3.2 Linear Regression Analysis

The results of the simple linear regression analysis between body length and body weight of koi fish are presented in Table 2.

Table 2. Linear regression analysis between body length and body weight of koi fish.

Category	Value
Model Summary	
R	0.880
R Square (R^2)	0.774
Adjusted R^2	0.772
Standard Error	17.090
ANOVA	
F	377.102
p-value	0.000
Regression Coefficients	
Intercept (a)	−142.663 ± 11.183
Length coefficient (b)	13.874 ± 0.714
t (Length)	19.419
p-value (Length)	0.000
95% CI Intercept	−164.825 – −120.501
95% CI Length coefficient	12.458 – 15.290
Regression Equation	**Y** = −142.663 + 13.874 × Length

The strong positive correlation between body length and body weight in *Cyprinus carpio* var. *koi* reflects a well-established allometric growth pattern commonly observed in teleosts. The correlation coefficient (R = 0.880) and determination coefficient (R^2 = 0.774) indicate that approximately 77.4% of the weight variation can be explained by body length, confirming that length is a robust predictor of body mass in this species. This finding aligns with the theoretical framework of allometric growth, where body weight increases disproportionately with length due to somatic growth and tissue accretion [4,11]. Such a pattern is particularly relevant for ornamental fish, in which body conformation and weight distribution are integral to perceived quality and market value.

The ANOVA results showed a highly significant model (F = 377.102, $p < 0.001$), indicating that body length is an essential predictor of body weight. The regression equation obtained was (Y = -142.663 + 13.874 × Length) with a standard error of 17.090. The length coefficient (13.874 ± 0.714) was statistically significant (t = 19.419; $p < 0.001$). The 95% confidence interval for the length coefficient ranged from 12.458 to 15.290, while the intercept ranged from −164.825 to −120.501. The regression equation Y = −142.663 + 13.874 × Length provides a statistically significant and biologically meaningful model for estimating weight in koi, especially those with lengths of 11.27–20.12 cm. The relatively low standard error and narrow 95% confidence intervals for both intercept and slope indicate high precision and reliability of the model. This linear form is beneficial for the studied size range (11.27–20.12 cm), where growth follows a nearly linear trend. Although more complex, non-linear models such as power functions are frequently used in fisheries science, the strength of the linear model observed here suggests that, within this growth window, a linear approximation is both sufficient and operationally advantageous. This is consistent with previous studies on ornamental and food fish species, where linear models are favored for ease of implementation in hatchery and farm settings [11].

To illustrate the model's practical application, a koi fish with a body length of 16 cm would have a predicted body weight of: $Y = -142.663 + (13.874 \times 16) = 79.32$ g. Considering the model's standard error of estimate (17.09 g), the expected weight for a fish of this length would typically fall within approximately ±33 g (≈95% prediction range), reflecting natural biological variability. This example demonstrates how the model can be used as a practical, non-invasive tool for estimating biomass within the observed size range.

Beyond its statistical strength, this model has significant practical implications for koi breeding and management. Length-based weight estimation enables farmers and hobbyists to evaluate growth performance without direct weighing, thereby reducing stress and handling time for the fish. This is particularly relevant for ornamental aquaculture, where minimizing physical contact preserves scale integrity, coloration, and overall health [1]. Accurate weight prediction also enables more efficient feed management, as ration calculations can be based on estimated biomass rather than periodic bulk weighing. Such practices reduce feed waste and improve feed conversion efficiency, supporting more sustainable production systems.

From a breeding and selection perspective, length–weight models facilitate early identification of individuals with superior growth potential, which can be integrated into selective breeding programs [12]. By establishing predictive growth benchmarks, farmers can optimize stocking densities, grading schedules, and market timing, improving both productivity and profitability. Furthermore, these models provide valuable baseline data for future studies examining the effects of environmental conditions, genetic lines, and nutritional interventions on koi growth dynamics. Integrating length–weight data with other morphometric and genetic parameters may further enhance the accuracy of selection and contribute to the development of improved strains.

In a broader management context, length–weight modeling provides a practical bridge between simple morphometric measurements and decisions that influence growth performance and production value in koi aquaculture. By allowing farmers to estimate biomass from routine length measurements, the model can support feed ration planning, growth monitoring, and cohort evaluation without repeated weighing, thereby reducing handling stress. Differences between predicted and observed growth may also help identify husbandry or nutritional issues early, enabling timely adjustments. Within the size range examined in this study, such applications illustrate how quantitative growth indicators can serve as decision-support tools in everyday management. Future research should expand validation across wider size classes, seasons, and rearing environments to assess model transferability and refine predictive accuracy. Furthermore, these advancements align with the goals of Sustainable Development Goals, particularly SDG 2 (Zero Hunger), SDG 12 (Responsible Consumption and Production), and SDG 14 (Life Below Water), by promoting sustainable aquaculture practices, resource efficiency, and biodiversity conservation.

4 Conclusion

This study establishes a scientific basis for improving koi breeding and culture through morphometric analysis. A simple linear regression model revealed a strong, significant relationship between body length and body weight in koi, enabling accurate weight estimation from length alone. This predictive model provides a reliable, non-invasive tool for rapid quality assessment, selective breeding, and optimized management in ornamental aquaculture.

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