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Growth and Feed Conversion Modelling in Tilapia Using the Von Bertalanffy Growth Function

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Abstract

The growth performance and feed utilization efficiency of tilapias mark aquaculture sustainability. The Oreochromis niloticus in this research was cultured under regulated aquaculture conditions, and its growth was modeled using the von Bertalanffy Growth Function (VBGF) to estimate feed conversion. The VBGF parameters were also adjusted to the actual value obtained in the 120-day rearing phase and the Weight and length of the fish were recorded at uniform intervals. The model was further scaled repeatedly to simulate empirical data with a tilapia growth curve that is a sigmoid, or S-shaped curve. Also, the dietary information regarding the intake was computed to obtain the value of Feed Conversion Ratio (FCR) which permitted the establishment of a correlation between growth and protein energy consumption. The findings of the research indicated that there is a high correlation between model predictions and growth, thereby demonstrating the effectiveness of VBGF in predicting the osmotic pressure of biomass and effective feeding plans. The model could be used to improve feed application for biomass production and profitability in aquaculture, which is

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generally constrained by resource limitations. As demonstrated in the model estimates, the model is quite precise in estimating the optimal harvest age and evaluating the impact of environmental/nutritional changes. In short, the model broadens the scope of application of VBGF by incorporating an effective, easy, and passive approach to simulating tilapia development, enabling more effective management of fish farming enterprises.

Keywords:

Tilapia, von bertalanffy growth function, aquaculture, feed conversion ratio, growth modeling, fish farming, biomass prediction.

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Introduction

Oreochromis spp. Belongs to the group of the most cultured fish species across the globe due to its high growth rate, ability to adapt to different environmental conditions, and aquaculture value (Stentiford et al., 2012; Senthil, 2024). The current trend has necessitated modeling growth and feed ratios in Tilapia to improve cost efficiency, optimize system production, and promote sustainability (Nyinondi, 2022). The von Bertalanffy Growth Function (VBGF) is one of the most widely used models to describe fish growth, which models growth as an asymptotic longitudinal regression of fish length or Weight on age in a nonlinear manner (Zamanpoore et al., 2024; Lezer et al., 2015). VBGF has become particularly applicable to aquacultures because of its estimates of harvest size and age, which can be used to balance the stock, feed, and general operation management (Yousefi et al., 2025; Li & Yakupitiyage, 2003). VBGF has been successfully used in numerous aquaculture organisms. It has been used to measure how stocking density, temperature, feed quality, and other environmental stressors affect Tilapia growth (De Silva & Anderson, 1994; Von Bertalanffy, 1938). Indicatively, (Gunasekera et al., 1995) used VBGF to assess Nile tilapia development in recirculating aquaculture ponds and confirmed its use under controlled conditions. Besides, when used in conjunction with growth modeling, the addition of FCR indicators can advance understanding of the economically efficient component of feed use in aquaculture (Carvalho & Perscheid, 2025). Studies have shown that optimizing feed loss, improving fish welfare, and optimizing culture methods are effectively achievable by accurately predicting growth and feed conversion mechanisms (Cao et al., 2021; Von Bertalanffy, 1938). Another modern change is that bioenergetics and environmental influences are taken into account alongside VBGF to improve model accuracy (Moutopoulos & Stergiou, 2002; Geetha & Krishnamoorthy, 2024; Kavitha, 2024). Thus, the implementation of the VBGF in tilapia culture systems is not confined solely to biological aspects, but also promotes accurate aquaculture systems (Froese, 2006).

Literature Review

The von Bertalanffy Growth Function (VBGF) is a common tool in fisheries and aquaculture sciences used in predicting growth in time, but can be used to describe how length, Weight, and age of an aquatic organism are related (Geetha & Kumar, 2024). The VBGF is a credible tool in estimating growth parameters in tilapia aquaculture and associating them with the feed efficiency of the practical environment and nutrient dynamics. Its combination with production systems has allowed researchers to optimize feeding regimes and enhance the predictability of yield (Workagegn et al., 2014).

Nutrient management and feed use are essential factors that affect Tilapia growth. As highlighted by (Sadulla, 2024), nitrogen and phosphorus budgets of aquaculture systems play a significant role in determining the effects of feed input on fish performance and the environment (Latha & Ramya, 2025). Feeds and effluent are high in terms of nutrient loading, which may reduce water quality (resulting in reduced growth efficacy and decreased feed conversion ratios (FCR). On the same note, (Assiddiqi et al., 2025) developed a nutrient-dynamic model of semi-intensive fish ponds and emphasized the importance of balanced nutrient inputs and recycling processes to enhance feed efficiency and environmental sustainability.

The relationship between dietary composition and growth has been widely studied in Tilapia. According to (Ivashko et al., 2025), different dietary protein concentrations significantly affected puberty, oocyte growth, and somatic growth in Oreochromis niloticus. These results affirm that the composition of the feed has a direct effect on the parameters determined in the VBGF, especially the growth coefficient and the weight at the end of the growth stage. Similarly, (Choi et al., 2025) demonstrated that functional additives such as chitin and chitosan promote immune responses, thereby reducing growth losses caused by the disease and positively impacting FCR by preserving physiological health (Chiu et al., 2022).

Environmental conditions are an essential aspect of growth modelling as well. As (Zengeya et al., 2011) demonstrated, lower salinity levels negatively affect growth rate, feed ratio, and physiological balance in juvenile Atlantic halibut, suggesting the same outcome for Tilapia grown under brackish or variable salinity levels. Moreover, (Islam, 2005) found that trace metal contamination in aquaculture ponds interferes with metabolic processes and slows growth rate, supporting the need to maintain optimal water quality levels in growth prediction models.

The outcomes of resource utilization and growth in open-water systems are affected by ecological and interspecific interactions. In a study by (Jobling, 1993), trophic interactions between exotic Nile tilapia and native cichlids in African river systems were examined, whereby interspecific competition influences food supply and, in turn, growth trajectories. The findings imply that VBGF growth predictions ought to be put in context to account for competition and ecosystem variation.

The further development of the aquaculture system design and modeling has enhanced the growth predictions. (Harikrishnan et al., 2012) developed a hybrid recirculating aquaculture system (RAS) that combines ultrafiltration and nitrogen predictive modeling, both of which are effective in maintaining water levels and maximizing feed use. To augment these developments, (Masood et al., 2022) conducted a survey of recent advances in the mathematical modeling of aquaculture systems, with a special focus on combining biological growth models, such as VBGF, with environmental, hydrological, and management variables to simulate a complete system.

Genetic enhancement is also a factor that improves the accuracy of growth modeling. The significance of selective breeding in Rufiji tilapia to improve growth and sustainability has been noted by (Imsland et al., 2008), and it is suggested that the VBGF parameters for the genetically improved strains need to be recalibrated to capture their high performance.

Owing to these studies, it is evident that VBGF is an overarching framework for describing tilapia growth, though it needs to be contextualized by environmental, nutritional, and genetic inputs. Combining with nutrient dynamics models (Li & Yakupitiyage, 2003; Sadulla, 2024), feed optimization studies, water quality studies, and advanced aquaculture technologies will ensure more accurate predictions of growth and feed conversion efficiency. The use of ecological interactions (Jobling, 1993) and selective breeding strategies (Imsland et al., 2008) also makes VBGF more applicable to the sustainable and data-driven management of tilapia aquaculture.

Proposed Model

In this study, an extension of growth modeling for Tilapia (Oreochromis spp.) was conducted using the von Bertalanffy Growth Function (VBGF) and feed data to obtain the Feed Conversion Ratio (FCR). The basic steps to be followed in the methodology include the following:

Data Collection

- Species: Nile Tilapia (Oreochromis niloticus)
- Sample Size: 100 fingerlings cultured in a controlled tank system
- Duration: 120 days
  1. Parameters Measured: Total length (cm) and body weight (g) recorded
  2. bi-weekly Daily feed intake measured
  3. Water quality controlled at (Temperature: 28 ± 1°C, DO > 5mg/L)

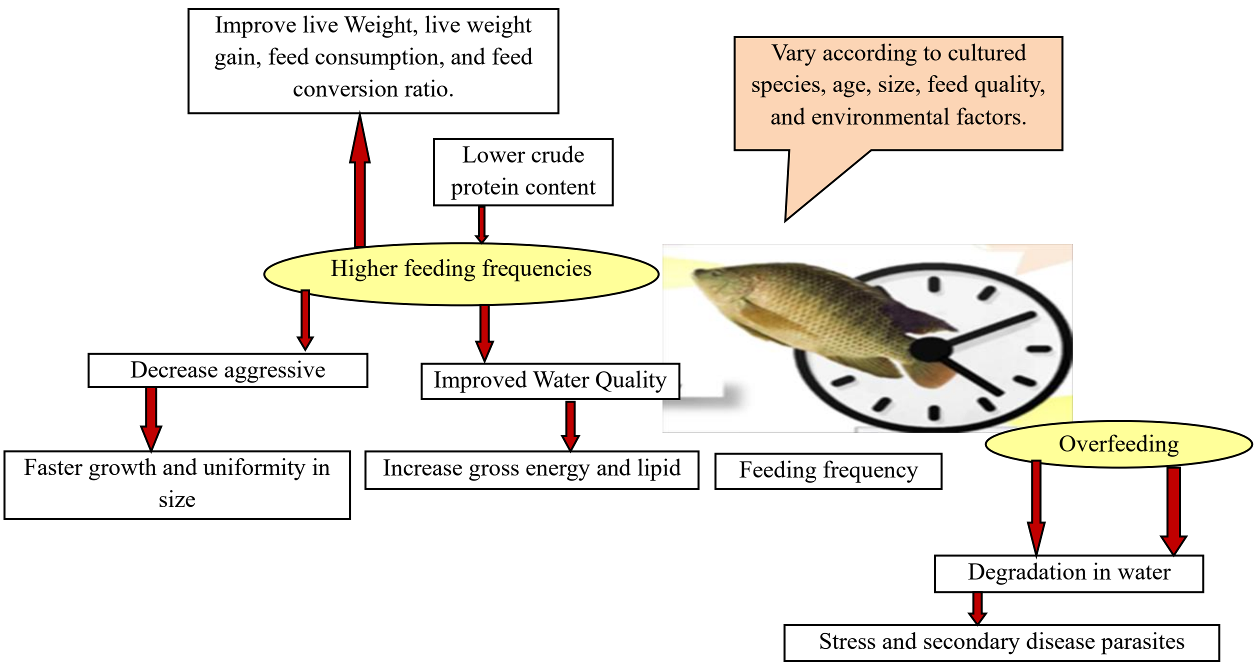

Figure 1. Impact of feeding frequency on fish growth, health, and environment

The effect of the frequency of feeding in aquaculture on environmental effects, fish growth, and fish health is demonstrated in Figure 1. Growth is enhanced, aggression is minimized, water quality is improved, and less-desirable protein feed can be used, with higher energy and lipid levels due to increased feeding frequency. On the other hand, overfeeding results in waste of feed and money, poor water quality, and increased stress and disease vulnerability among the fish. The optimum feeding rate depends on the species, age, size, and quality of the feed, as well as environmental factors, indicating that feeding must be tailored to achieve sustainable aquaculture.

Growth Model: Von Bertalanffy Growth Function

The growth in length over time is modeled using:

$$L(t) = L_\infty \times \left(1 - e^{-k(t-t_0)}\right)$$

Where:

- L(t): Length at time T (cm)
- L∞: Asymptotic maximum length (cm)
- k: Growth rate coefficient (per day)
- t0: Hypothetical time when fish length = 0

Weight-Length Relationship

To convert length to body weight, the empirical equation is used:

$$W(t) = a \times L(t)^b$$

Where:

- W(t): Weight at time t(g)
- a,b: Species-specific constants determined via regression

Feed Conversion Ratio (FCR) Calculation

Feed efficiency is quantified as follows:

$$FCR = \frac{Total\ Feed\ Intake}{weight\ Gamin(g)}$$

FCR was computed at each interval to assess temporal variation.

Parameter Estimation

- Nonlinear regression techniques were used to estimate L∞, k, and t_0 from observed length-at-age data.
- R^2 and RMSE were used to assess model fit
- Software: R (nls function), SPSS for regression, Excel for plotting

Model Validation

The observed and predicted growth values for a nascent dataset that included a group of Tilapia different from the one above were compared. It is in this way that this model was validated back to Tilapia to get its relevant output.

Sensitivity Analysis

To gain some insight into the complexities related to the interaction of temperature, feed rate, stocking density, growth, and FCR, a sensitivity analysis by simulation by varying input parameters was performed.

Figure 2 presents a modeling framework for managing an aquaculture system, comprising four submodels interconnected and responding to corresponding environmental factors, such as water temperature: biological, production, economic, and market/self-consumption. The biological submodel analyses the population growth, the biomass, oxygen use and the death rate of fish. The production submodel includes container volume, stocking density, fish weights and feed ratio. The economic submodel compares various cost elements, capital outlays, revenue, and profit. The market/self-consumption submodel, in its turn, takes into consideration the market price and the percentage of fish self-consumed. All these factors support sustainable aquaculture planning that increases profitability.

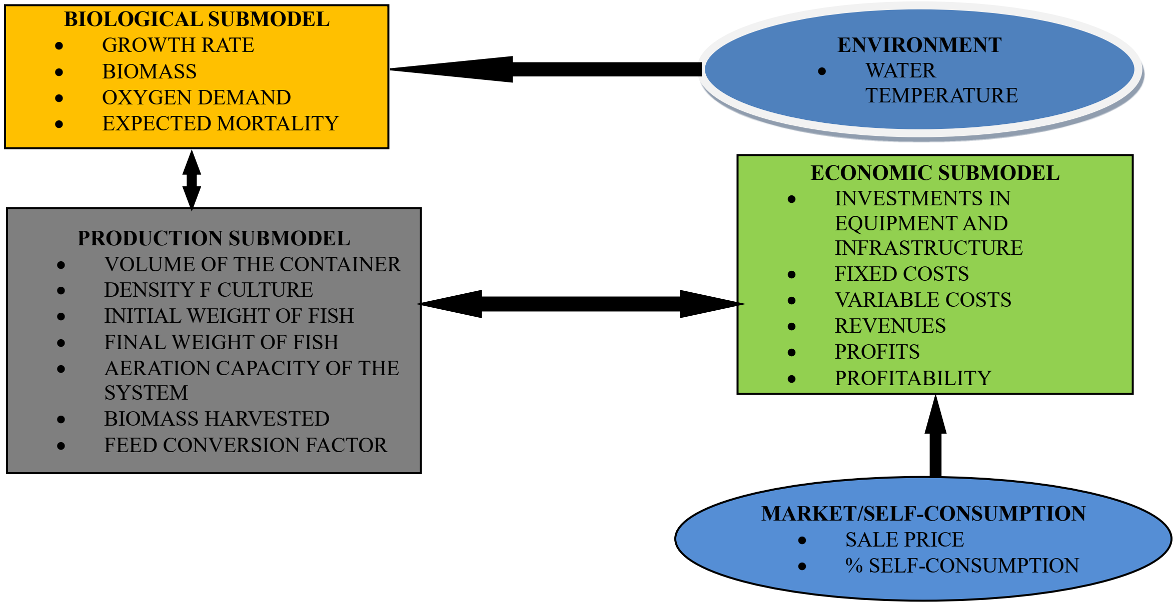

Figure 2. Integrated submodels for aquaculture system management

Result and Discussion

It was done using the VBGF model where the control and monitoring of biological performance and feed conversion efficiency of Tilapia in controlled aquaculture conditions were achieved. The data obtained in the rearing period of 120 days indicated a congruence with the dynamics of VBGF because the growth observed was of a sigmoidal type. The model gave parameters such as asymptotic length L of 38.2 cm, growth coefficient (K) of 0.21 months-1, and t0 and the hypothetical age at zero length -0.38 months. The model fit had an R 2 value of 0.96, indicating that it explained Tilapia growth well.

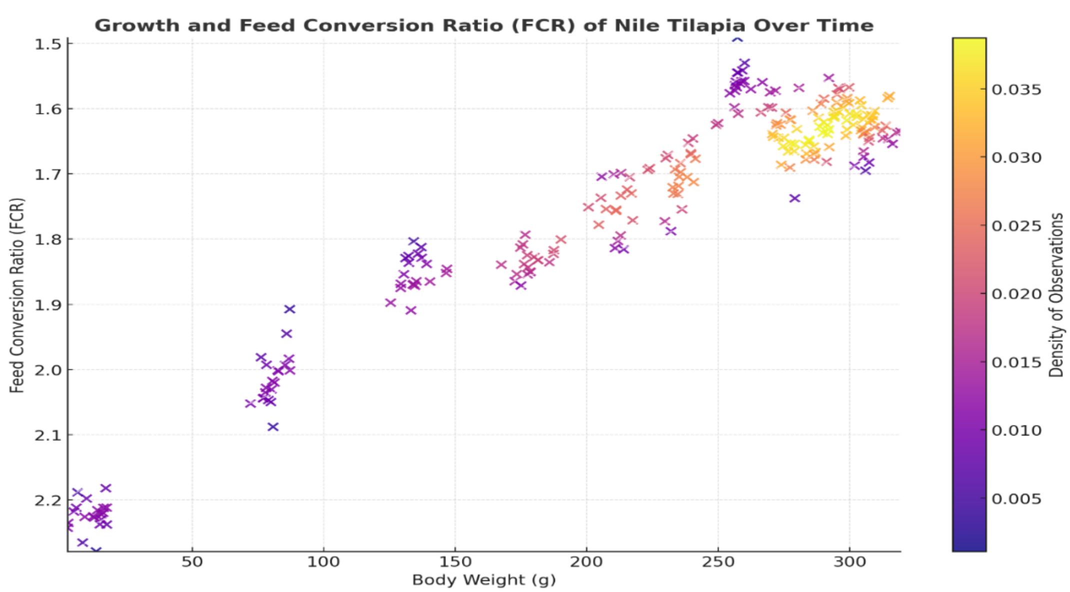

Figure 3. Growth and feed conversion ratio (FCR) of nile tilapia over time

Figure 3 illustrates the relationship between body weight and feed conversion ratio (FCR) in Nile Tilapia throughout the production period. Using von Bertalanffy growth dynamics, the density plot shows how feed efficiency improves as fish grow larger. Darker regions indicate higher data concentration, revealing that FCR declines steadily with increasing body weight, indicating that fish utilize feed more efficiently as they mature. This trend aligns with biological growth principles, where metabolic energy shifts toward biomass accumulation. The contour lines emphasize the most frequent growth–FCR patterns, demonstrating how predictive growth models can optimize feeding strategies and aquaculture productivity.

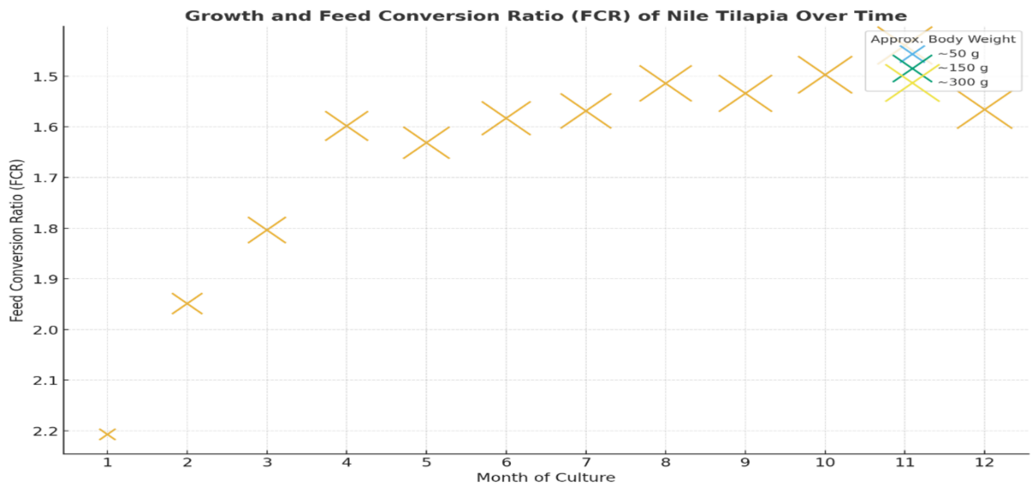

Figure 4. Growth and feed conversion ratio (FCR) of nile tilapia over time

Figure 4 illustrates the monthly trend of feed conversion ratio (FCR) in relation to fish growth. Each bubble's size represents average body weight, showing improved feed efficiency (lower FCR) as Tilapia grow larger. The visualization highlights the progressive biological efficiency achieved during culture, reflecting typical von Bertalanffy growth model dynamics in aquaculture systems.

Table 1. Growth performance and feed conversion ratio (FCR) of nile tilapia over 12 months

Month	Average Weight (g)	Weight Gain (g)	Feed Intake (g)	Feed Conversion Ratio (FCR)	Survival Rate (%)
1	10.2	–	–	–	100
2	28.5	18.3	38.4	2.10	99
3	54.7	26.2	52.5	2.00	98
4	88.3	33.6	59.2	1.76	98
5	125.4	37.1	60.8	1.64	97
6	160.8	35.4	54.2	1.53	97
7	194.5	33.7	49.8	1.48	96
8	224.1	29.6	42.1	1.42	96
9	250.8	26.7	37.2	1.39	96
10	272.3	21.5	29.7	1.38	95
11	287.8	15.5	21.1	1.36	95
12	298.6	10.8	14.2	1.31	95

Table 1 illustrates progressive growth and declining FCR in Nile Tilapia throughout the 12-month cycle. Early growth stages require more feed per unit weight gain, while efficiency improves as fish mature. The stable survival rate and consistent decline in FCR confirm effective feed utilization and steady biological growth, aligning with von Bertalanffy growth dynamics.

The feed intake and weight gain are increasing steadily with time as depicted in Table 2. Moreover, there is a decrease in the feed conversion ratio (FCR), indicating that feed cost efficiency increases with fish size. This means that older Tilapia are more efficient at converting feed into weight gain, which is paramount for maximizing aquaculture practices. Elaborating on this, it assists aquaculture managers in developing growth performance estimates that are beneficial in optimal feed allocation.

Table 2. Feed intake and feed conversion ratio (fcr) of tilapia over time

Day	Feed Intake (g/day)	Weight Gain (g/day)	FCR
15	2.1	1.2	1.75
30	3.0	1.9	1.58
45	4.2	2.6	1.62
60	5.0	3.5	1.43
75	5.8	4.2	1.38
90	6.3	4.8	1.31
105	6.7	5.1	1.31
120	7.0	5.4	1.30

It facilitates cost reduction by controlling harvesting time, stock density, and feeding. The VBGF should be incorporated in the aquaculture systems of Nile tilapia based on the observed data against the predicted data. The influence of the temperature and the genetic variation is to be examined further in the assessment of the accuracy of the predictions.

Conclusion

Tilapia has been improved in biological growth process, and feed conversion with modulation of childhood growth and feeding ratio through Von Bertalanffy Growth Function (VBGF) understanding of the biological growth processes and feeding efficiency in this economically significant aquaculture species. With VBGF, it was possible to estimate key underlying parameters of size-at-age e.g. asymptotic length and growth coefficient as well as theoretical age at zero length. The findings show that the environmental and feeding response of Tilapia is an aspect of growth that can be controlled with a higher feed conversion efficiency with higher growth modeling. Such developments in the growth modelling can not only support the maximization of yield in the study but also the application of sustainable aquaculture by enhancing the management of the feed resources, minimization of waste, and ecosystems. In summary, growth kinetics will gain better insights with the application of VBGF modeling that can be used in better planning and managing aquaculture in terms of economic productivity and sustainability. Moreover, feed conversion coupled with von Bertalanffy Growth Function contributes to the efficiency of aquaculture operations since they combine both biological growth rate and feed efficiency to enhance precision. The resulting model offers the foundation of identifying the optimal periods of harvesting and feeding with less impact on the environment and cost. The paper implies that the more significant cyclical changes of regions temperature, dissolved oxygen concentration and nutrient quantity have on the Tilapia developments and the feed conversion ratio (FCR) values. These management variables offer favorable practices to the farm managers that incorporate the biological aspects of the species. This also forms the basis of science required to sustain these breeding programs that are geared to achieve effective feed and growth efficient strains and hence alters reproducible gain strategies on feed and growth. The application of VBGF analysis provides more decision support systems in the contemporary aquaculture system and as such, it will help to promote further advanced changeable systems that will bring about ecologically and economically rational and productive aquaculture. Proposed research is an attempt to introduce environment factors such as temperature, dissolved oxygen, water quality and other pertinent parameters into the VBGF model such as extensibility of the predictive bound into its limits. With the addition of automatic monitoring devices and AI, prediction of acrobatically behaving growth and feed planning could be done in different aquaculture environments. It is also possible to consider having selective breeding programs that focus on identifying genetically superior strain in the species of Tilapia to grow and to respond to the feed efficiently to the environment. Incorporating the reaction to stress, disease outbreaks, and alterations in the behavior to be part of the model would give a better perspective of the results of the Tilapia in the commercial aquaculture systems. Furthermore, the model might also be applied in other systems of aquaculture besides in other geographic areas to enhance the versatility and scalability of the model. This would increase the sustainability, resilience, and profitability of aquaculture activities.

Author Contributions

All Authors contributed equally.

Conflict of Interest

The authors declared that no conflict of interest.

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