Article

Arima-Based Forecast of Gross Fish Production in Sustainable Aquaculture

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Abstract: Forecasting gross fish production in sustainable aquaculture using the ARIMA (Autoregressive Integrated Moving Average) model has become an important analytical tool for production planning, risk management, and policy formulation in the fisheries sector. The ARIMA model is particularly effective for analyzing time series data, as it enables the identification of long-term trends and dynamic patterns in fish production volumes. Recent empirical studies demonstrate that ARIMA-based approaches provide reliable forecasts of aquaculture output across different time horizons. In particular, model-based projections indicate a steady growth trend in gross fish production over the medium and long term, reflecting the increasing role of innovative technologies and improved management practices in aquaculture. The strength of the ARIMA model lies in its ability to utilize historical production data to generate accurate forecasts of future output, which is especially relevant in regions where fish farming performance is affected by environmental conditions, feed efficiency, technological intensity, and market factors. The application of ARIMA forecasting allows fish producers and policymakers to anticipate production fluctuations, improve resource allocation, and support sustainable development objectives in aquaculture. Overall, the use of the ARIMA model in forecasting gross fish production contributes to a deeper understanding of production dynamics and provides a scientific basis for designing effective strategies to enhance the economic efficiency and sustainability of fish farming.

Keywords: aquaculture, fish farming, gross fish production, ARIMA model, time series analysis, dynamic series, forecasting, efficiency, sustainability.

1. Introduction

It is widely recognized that the standard of living of the population in any country largely depends on the level of availability and accessibility of essential food products. In this context, fish and fishery products play a significant role in ensuring food security, improving nutritional quality, and diversifying protein sources for the population. In recent years, aquaculture has become one of the fastest-growing sectors of the global food system, contributing substantially to meeting the increasing demand for animal protein [1]. In many regions, including developing economies, fish consumption has steadily increased due to population growth, changing dietary preferences, and the promotion of healthy nutrition. Therefore, taking into account demographic expansion and rising demand for fish products, the development of reliable forecast indicators for fish production has become one of the most pressing issues in the sustainable development of the fisheries sector.

Accurate forecasting of gross fish production is essential for effective production planning, investment decision-making, and the formulation of evidence-based public policies. In this regard, econometric and statistical forecasting methods provide valuable analytical tools for assessing future production dynamics [2]. Among these methods, correlation and regression analysis, as well as time series models, make it possible to identify the strength and nature of relationships between production volumes and influencing factors, as well as to project future trends. The scientific literature on production forecasting highlights a wide range of approaches used to estimate output volumes and market conditions in agriculture and aquaculture. According to Djumanova R.F., more than 130 forecasting methods are applied in practice, and socio-economic processes can be conditionally classified into several major groups. These include extrapolation methods, expert-based forecasting approaches, and econometric modeling techniques [3]. Within this framework, the ARIMA model has gained particular importance due to its ability to capture dynamic patterns in time series data and generate reliable forecasts of production volumes in the fisheries sector.

Literature Review

The development of fisheries as one of the important branches of agriculture, the introduction of innovative and intensive technologies, and the improvement of economic efficiency have been widely studied by foreign scholars, researchers from CIS countries, and domestic scientists. In particular, the scientific works of foreign scholars such as F. Berkes, R. Hilborn, M. Solomon, R. Maxon, and P. Daniel focus on issues related to the management of fisheries and aquaculture, efficient use of natural and economic resources, and increasing economic efficiency based on intensive and innovative technologies [4]. These studies emphasize the importance of sustainable fisheries, the integration of ecological and economic factors, and the role of modern management approaches in ensuring long-term sectoral development.

In addition, researchers from CIS countries have conducted extensive studies on the organization of the fisheries sector, the improvement of its organizational and economic mechanisms, and its development based on innovative approaches. In this regard, the scientific contributions of S. I. Kurdyukov, A. K. Bogeryuk, O. V. Kuznesova, N. V. Alesina, V. K. Kiselyov, and A. A. Tarasenko are noteworthy. Their works analyze the economic mechanisms of fish farming, optimization of production costs, enhancement of investment activity, and the introduction of intensive technologies as key factors for improving sectoral efficiency [5].

The studies conducted by domestic scholars mainly focus on the development of the fisheries sector, the improvement of its organizational and economic foundations, and the implementation of certain innovative elements in practice. In particular, the works of Q.A. Chariev, J.K. Sauxanov, D.R. Shoximardonov, S.S. G'ulomov, R.X. Ergashev, and I.O. Yunusov, as well as other researchers, examine specific economic aspects of the sector, including production efficiency, financial performance, and state support mechanisms [6].

However, an analysis of the existing literature reveals that at the regional level, particularly using the Syrdarya region as a case study, issues related to the comprehensive assessment of the economic efficiency of innovative fish farming, analysis based on integral indicators, and forecasting using econometric and time-series models have not been sufficiently and systematically explored. This research gap determines the relevance and scientific significance of conducting further in-depth studies in this area.

2. Materials and Methods

Linear regression analysis and ARIMA (Autoregressive Integrated Moving Average) models were applied using the Stata software to forecast gross fish production in aquaculture [7]. These methods make it possible to identify key factors influencing fish farming development and to assess their impact on production dynamics. Time-series data for the period 2019–2024 were used to estimate the models and to determine future trends in fish production.

3. Results and Discussion

An analysis of gross fish production in the Republic over the period 2000–2022 shows a steady upward trend in aquaculture development. In 2000, total fish production amounted to 3,929.4 thousand tons, while by 2022 this figure had increased to 7,913.1 thousand tons, representing a growth of 201.3 percent compared to the base year. This dynamic indicates a significant expansion of the fisheries sector, driven by increased production capacity, technological modernization, and rising demand for fish products.

Globally, a wide range of models has been developed to assess food security and ensure its sustainability, including simulation and forecasting models [8]. At the macroeconomic level, forecasting tools such as EPACIS, ARMA, Aglink, and ARFA are widely used in countries with high levels of food security to evaluate production stability and future supply trends. In this context, time-series forecasting models, including ARIMA, are particularly effective for analyzing production dynamics in aquaculture [9].

To identify the determinants of changes in gross fish production, the following econometric specification was applied:

y – gross fish production, thousand tons (or kg per hectare of water surface);

x_1 – total area of water bodies used for fish farming, thousand hectares;

x_2 – water quality index (point-based assessment);

x_3 – feed input per unit of production (kg per ton of fish);

x_4 – share of intensive fish farming systems in total production, %;

x_5 – level of provision with modern equipment and technologies in fish farming, %;

x_6 – availability of machinery and aeration capacity per 100 hectares of water surface (thousand horsepower).

Based on the values of these variables, a correlation matrix of pairwise correlation coefficients was generated using the Stata software to examine the relationships among the factors influencing changes in fish production [10]. The dataset for the period 2000–2023 provides sufficient statistical observations for robust econometric analysis. The ARMA model applied in the study consists of autoregressive (AR) and moving average (MA) components, where the value of the production variable in the current period depends on its values in previous periods. For the model to be stable, all autoregressive coefficients were required to lie within the unit circle, which was confirmed by the estimation results.

For forecasting purposes, a multivariate regression analysis was initially conducted to assess the impact of key production factors on gross fish output [11]. The estimated relationships were then used in conjunction with the ARIMA model to generate reliable forecasts of future fish production and to evaluate the sustainability of aquaculture development under current technological and economic conditions.

$$y = \alpha_0 + \sum_{i=1}^{n} a_i x_i \quad [1]$$

Here, y represents the resulting indicator, namely gross fish production, while x_1, x_2, …, x_n denote the factors influencing fish farming performance, and β_0, β_1, …, β_n are unknown parameters. To determine the relationship in the linear model

$$y = f(x_1, x_2, \ldots, x_n), \quad [2]$$

it is necessary to estimate the unknown parameters. For this purpose, the least squares method is applied, which allows the estimation of model coefficients by minimizing the sum of squared residuals. Using this approach, the unknown parameters are determined by constructing and solving a system of normal equations, providing statistically consistent estimates of the impact of key factors on gross fish production [12].

$$\begin{cases} na_0 + a_1 \sum x_1 + a_2 \sum x_2 + \ldots + a_n \sum x_n = \sum y \\ a_0 \sum x_1 + a_1 \sum x_1^2 + a_2 \sum x_1 x_2 + \ldots + a_n \sum x_n x_1 = \sum y x_1 \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ a_0 \sum x_n + a_1 \sum x_1 x_n + a_2 \sum x_2 x_n + \ldots + a_n \sum x_n^2 = \sum y x_n \end{cases} \quad [3]$$

When the number of unknown parameters exceeds two, the estimation of the model becomes computationally complex; therefore, it is advisable to implement the analysis using specialized statistical software [13]. In this study, computer-based econometric tools are employed to estimate the parameters of the fish production model and to ensure the accuracy and reliability of the results.

Accordingly, based on the above data, a multivariate linear regression model combined with an ARIMA specification was estimated using the Stata software to analyze and forecast gross fish production. The ARIMA model is one of the most widely applied approaches for short-term forecasting, as it effectively captures the dynamic behavior of time-series data through autoregressive and moving average components [14]. In the econometric analysis, the correlation coefficient was used to evaluate the strength and direction of relationships between variables. A correlation coefficient of 1 indicates a perfect positive linear relationship, whereas a coefficient of –1 reflects a perfect negative linear relationship. A value close to 0 suggests the absence of a linear relationship. A positive correlation implies that an increase in one variable is associated with an increase in another, while a negative correlation indicates an inverse relationship. As shown in the correlation matrix, there is a strong positive relationship between gross fish production (Y) and several explanatory variables (X).

The estimated regression coefficients represent the marginal effect of each independent variable (x_1, x_2, …, x_6) on the dependent variable (Y – gross fish production) within the linear model. For instance, holding all other factors constant, the coefficient of x_3 (feed input intensity) is estimated at 0.883, indicating that a one-unit increase in feed input is associated with an average increase of 0.883 units in gross fish production. Pairwise correlation analysis provides a statistical assessment of the relationships between individual pairs of variables [15]. The correlation matrix indicates that the correlation coefficient between Y and x_1 is –0.321, suggesting a weak negative relationship, whereas Y exhibits a strong positive correlation with variables x_3, x_5, and x_6, with correlation coefficients exceeding 0.7. In addition, variable x_1 shows a strong negative correlation with variables x_3 and x_4, as reflected by correlation coefficients below –0.7.

Overall, the presented results confirm the suitability of the ARIMA-based regression model for analyzing time-series data on fish production and for identifying the key factors influencing the dynamics and sustainability of aquaculture development.

Table 1. Regression analysis of factors affecting gross fish production

Variables	Coefficient	Standard error	t-statistic	P-value	95% CI (Lower)	95% CI (Upper)
X1 – Water area used for fish farming (thousand ha)	2.602	3.743	0.70	0.497	-5.333	10.537
X2 – Water quality index (points)	892.946	388.613	2.30	0.035	69.123	1716.769
X3 – Feed input per unit of production (kg)	8.649	5.006	1.73	0.031	-1.962	19.260
X4 – Share of intensive fish farming technologies (%)	6.671	38.175	0.17	0.063	-74.258	87.599
X5 – Provision with modern equipment and technologies (%)	52.256	71.923	0.73	0.078	-100.214	204.727
X6 – Availability of machinery and aeration capacity (thousand HP per 100 ha)	13.200	23.669	0.56	0.085	-36.976	63.375
Constant	-55,406.4	21,305.199	-2.60	0.019	-100,571.45	–

The correlation coefficient of the multifactor model is R = 0.89, indicating a very strong relationship between the resulting indicator, namely gross fish production, and the influencing factors (Table 1). Accordingly, the coefficient of determination is also high (D = R^2 = 0.89), which implies that approximately 89% of the variation in fish production is explained by the factors included in the model. The remaining 11% can be attributed to other external influences, including natural, environmental, and unobserved factors that were not explicitly considered in the analysis.

Based on the values of the selected explanatory variables, the model reflects the relationship between the factors affecting changes in fish production productivity and is closely related to stability analysis in aquaculture [16]. This relationship can be effectively expressed using the ARMA model, which combines autoregressive and moving average components. The ARMA model is a widely used statistical tool for forecasting time-series data and analyzing dynamic production processes.

The study utilizes sufficient and representative statistical data on gross fish production influenced by the selected factors for the period 2000–2023. Based on this dataset, forecast values of fish production were generated using the ARMA model, allowing for the assessment of future production trends and the sustainability of aquaculture development under existing technological and economic conditions
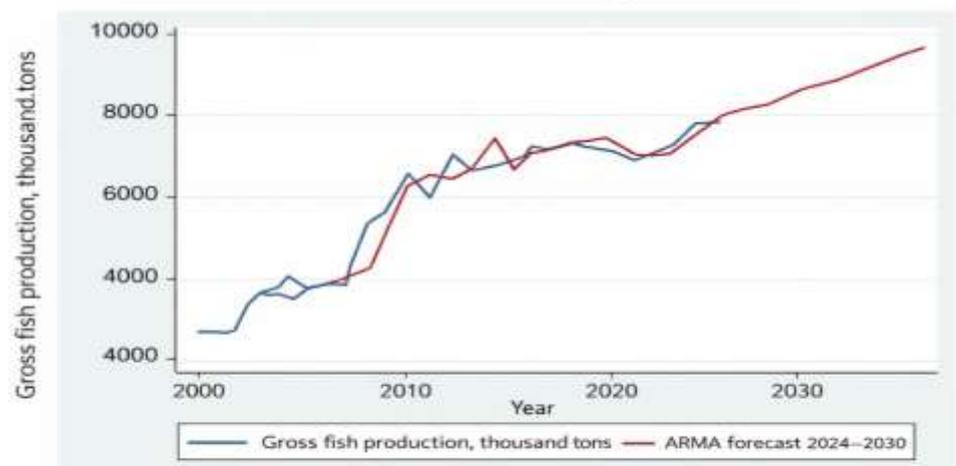
Explanation: The blue line represents the actual dynamics of gross fish production, while the red line shows the forecast trend up to 2030, generated using the ARMA model based on historical production data.

Figure 1. Dynamics of Gross Fish Production Based on the ARMA Model and Actual Values, Thousand Tons

From the figure, it can be observed that during the period 2000–2023, the forecast values and the actual values of gross fish production show a high degree of consistency (Figure 1). This indicates the adequacy and reliability of the applied ARMA model in describing the dynamics of fish production. According to the forecast results, gross fish production is expected to increase steadily up to 2030. Thus, it is projected that the volume of fish production in the aquaculture sector of the Republic will exceed 9,000 thousand tons by 2030, compared to the level observed in 2023.

4. Conclusion

According to research findings, forecasting prospective development can be classified into macroeconomic and microeconomic types depending on the characteristics of the object under study. In this context, correlation and regression analysis within statistical forecasting frameworks can be effectively applied to determine the form and strength of relationships between production indicators and influencing factors. In aquaculture, production efficiency is largely determined by a combination of environmental, technological, and economic conditions, including water quality, feed input, technological intensity, and resource provision.

The results of this study indicate that the multifactor regression approach is appropriate for identifying and analyzing productivity indicators of fish farming based on several interrelated factors. Solving this problem within the research framework made it possible to determine the interdependence of key factors affecting gross fish production and to assess their combined impact on production dynamics. The application of ARIMA/ARMA models further confirmed the reliability of time-series forecasting in evaluating future development trends in aquaculture. Although fish production is projected to increase steadily by 2030, population growth and rising demand for high-quality protein products necessitate the implementation of targeted measures to ensure the sustainable development of fisheries in the Republic. In this regard, the following measures are proposed:

✓ Providing state financial and material support for scientific research, breeding programs, and initiatives aimed at introducing innovative and intensive technologies in fish farming;

✓ Developing and implementing legal and regulatory frameworks to protect the interests of breeders, research institutions, and aquaculture enterprises involved in fish seed (fingerling) production;

✓ Preparing and disseminating training manuals and educational materials aligned with international best practices in aquaculture development;

✓ Focusing on the key factors influencing economic efficiency in sustainable aquaculture, including the introduction of advanced production technologies and enhanced state support mechanisms;

✓ Developing and implementing regulatory measures aimed at liberalizing fish production and marketing systems, promoting market-based mechanisms, and accelerating the digitalization of the aquaculture market.

Overall, the findings of this study provide a scientific basis for improving forecasting accuracy, enhancing economic efficiency, and supporting evidence-based policymaking in the sustainable development of the fisheries sector.

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