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AQUACULTURE IN TRANSITION: PREDICTIVE INSIGHTS INTO ROMANIAN AQUACULTURE PRODUCTION

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Abstract

The significance of aquaculture in contributing to global food security is well-established, especially as traditional fishery yields plateau. Recognizing the essential role of hatcheries and nurseries in sustainable development, this paper examines Romanian aquaculture, predicting production trends until 2034. Employing time-series analysis via Microsoft Excel, it forecasts production at various life cycle stages, from eggs to juveniles, excluding mature aquaculture outputs. The study highlights expected outputs alongside their associated confidence intervals, pinpointing potential fluctuations. The forecasted trends in Romanian aquaculture highlight the potential for growth in the sector, reflecting an industry poised to meet future demands. However, the variability encapsulated within the confidence intervals suggests that stakeholders should remain adaptable to changes. Strategic planning should therefore incorporate these forecasts while also considering environmental, economic, and technological developments that could influence production. The findings underscore the need for ongoing research and adaptive management to maintain and enhance the contribution of aquaculture to food security and economic development in Romania and beyond.

Key-words: *aquaculture forecasting, fish production, hatcheries and nurseries, food security*

INTRODUCTION

Aquaculture holds a pivotal position in bolstering global food security, particularly as the demand for high-quality animal protein escalates in parallel with the world's population growth [13, 7, 9, 1]. This surge in aquaculture has been crucial in offering a sustainable seafood source, notably in low and middle-income countries, where it plays a significant role in enhancing food and nutrition security [15, 18]. Recognized as one of the most efficient methods of animal protein production, aquaculture is instrumental in mitigating food shortages and augmenting human nutrition [24, 12]. Hatcheries, nurseries, and fish egg production emerge as essential components within the aquaculture development framework, facilitating the consistent supply of high-quality fish for human consumption. These infrastructures are vital for advancing biotechnology research and applications in aquaculture, thereby ensuring sustainable practices and efficient fish production management. Leveraging best practices and innovative techniques, such as genome editing, the aquaculture sector can enhance breeding and production processes to cater to the escalating global seafood demand [13].

Beyond merely supplying food, aquaculture significantly contributes to income generation, social development, and poverty reduction across various regions. Its expansion and intensification are imperative for satisfying the growing food demand and securing a stable supply of aquatic products [6, 2, 5, 8]. Integrating aquaculture into food systems and policy frameworks enables countries to bolster food and nutrition security, particularly for vulnerable populations.

The EU financially sustains the development of fishery aquaculture and fishery. In Romania the Operational Program for

Fisheries and Maritime Affairs (AM-POPAM) is destined to put in practice the absorption of European funds for the period 2014-2020 [11].

However, global fisheries confront numerous challenges that threaten their sustainability and marine ecosystems' health. Characterized by overexploitation, dwindling fish stocks, and inadequate management practices, the current state of global fisheries demands urgent attention [22, 14].

The underreporting and neglect of small-scale fisheries exacerbate these issues, leading to misinformed management and conservation strategies [20].

Moreover, illegal, unreported, and unregulated (IUU) fishing further complicates sustainable fisheries governance, necessitating enhanced management practices to ensure fish stocks' longevity [4, 21].

Acknowledging aquaculture's role in economic and social development, it is evident that the sector harbors significant growth potential and societal impact. Aquaculture's contribution extends beyond economic benefits, fostering social capital and networks that underpin community resilience and sustainable development [19, 3].

Despite these contributions and potential, there exists a notable research gap in forecasting and understanding the full scope of aquaculture's impact, particularly in specific regions like Romania.

This study aims to bridge that gap by providing detailed forecasts of Romanian aquaculture production, encompassing various life cycle stages and examining the implications for food security, economic growth, and policy development.

By offering these insights, the study contributes significantly to aquaculture research and informs policy-making processes, ensuring that aquaculture continues to play a vital role in global food security and socio-economic advancement.

MATERIALS AND METHODS

Data Collection

Data on Romania's aquaculture production, spanning various stages of the life cycle, was collected from the European Statistical Office (EUROSTAT) database[6]. The dataset includes annual production figures from 2013 to 2022 and encompasses:

(i)Production from aquaculture excluding hatcheries and nurseries.

(ii)Production of fish eggs for human consumption from aquaculture.

(iii)Production of hatcheries and nurseries at the egg stage.

(iv)Production of hatcheries and nurseries at the juveniles stage.

Data for the latter two categories is limited, with some years presenting no recorded production, reflecting either a lack of production or unreported data.

Forecasting Methodology

The forecasting model was constructed using Microsoft Excel's suite of data analysis tools. The data was subjected to time series analysis, with the following statistical forecasting models applied:

-Exponential Smoothing: Used for forecasting aquaculture production while accounting for trends and seasonal variations where data was sufficient.

-Linear Regression Analysis: Applied to identify trends in the data over time and to project future values.

Confidence intervals were computed to gauge the potential range of the forecast values,providing upper and lower bounds for the predictions.

Statistical Measures

The forecast's accuracy was assessed using several statistical measures:

-Alpha (α): The smoothing constant for the level in the Exponential Smoothing model.

-Beta (β): The smoothing constant for the trend in the Exponential Smoothing model.

-Gamma (γ): The smoothing constant for the seasonality in the Exponential Smoothing model.

-Mean Absolute Scaled Error (MASE): A measure of the accuracy of forecasts in a time series.

-Symmetric Mean Absolute Percentage Error (SMAPE): A measure of percentage errors between forecasted and actual values.

-Mean Absolute Error (MAE): The average of the absolute errors between forecasted and observed values.
-Root Mean Square Error (RMSE): The square root of the average of squared differences between forecasted and observed values.
These metrics were utilized to evaluate the performance of the forecasting models and the reliability of the predictions.

Software

The entire analysis was conducted using Microsoft Excel (version 2024), which provided the necessary computational tools for the statistical forecasting and regression analysis.

RESULTS AND DISCUSSIONS

The forecast of fishery production in Romania, specifically considering aquaculture excluding hatcheries and nurseries, indicates a steady increase in production over the forecast period extending to 2034 (Figure 1). According to the collected data, the actual recorded production from 2013 to 2022 shows fluctuations with a slight downward trend until 2020, after which an uptrend is noticeable. The forecasted values suggest a gradual increase in production starting from 11,212 thousand units in 2022 to an estimated 12,758 thousand units by 2034.

The forecasts also include lower and upper confidence bounds, which represent the range within which the actual values are expected to lie with a certain probability. These bounds suggest a degree of uncertainty in the forecast, with the lower bound indicating a minimum expected production and the upper bound suggesting a maximum expected production. For 2022, the lower and upper confidence bounds are approximately 10,123 and 12,678 thousand units, respectively, illustrating the potential variability in the production levels.

The linear trend line displayed in the graph, characterized by the equation $y = 123.4x + 11{,}008$, with an R-squared value of 0.1702, indicates that only a small portion of the variability in the fishery production data can be explained by this linear trend.

The wide range between the lower and upper confidence bounds indicates substantial uncertainty, which could stem from various factors such as environmental changes, economic conditions, and policy changes affecting the aquaculture industry.

The statistical metrics provided include a high Alpha value of 0.90, suggesting a strong level of confidence in the current trend continuing into the future. However, the Beta and Gamma values are zero, indicating no trend or seasonal adjustments are considered in this forecast. This could be a limitation if there are indeed underlying trends or seasonal patterns in the fishery production data.

The Mean Absolute Scaled Error (MASE) of 0.92 and the Symmetric Mean Absolute Percentage Error (SMAPE) of 0.04 suggest a good fit of the forecast model relative to the mean model and the magnitude of the errors in percentage terms, respectively. The Mean Absolute Error (MAE) of 501.37 and the Root Mean Square Error (RMSE) of 651.68 provide measures of the average error magnitude and the standard deviation of the forecast errors, respectively. These values are relatively low, which generally indicates a reasonable accuracy of the forecast model, although these errors should still be considered when making decisions based on these forecasts.

Our analysis of production from aquaculture excluding hatcheries and nurseries aligns with global expectations of significant growth in the aquaculture sector over the coming decade. Our data support the notion that freshwater aquaculture will continue to be a pivotal contributor, as it already constitutes a substantial share of worldwide edible aquaculture output, corroborating the observations made by [23].

Consistent with the broader trends identified by [24], the aquaculture sector is poised for expansion to satisfy the escalating demand for seafood. This growth trajectory is not isolated but parallels the development seen in terrestrial crop and livestock production sectors, highlighting aquaculture's critical role in the global food system as emphasized by [16].

Despite these optimistic trends, the sector faces hurdles, notably the pressure to supply high-quality fish products sustainably. Addressing these challenges necessitates a concerted focus on sustainable production practices. This approach not only aligns with the recommendations of [17] but is also essential for the sector's ability to meet the growing seafood demand responsibly.

In the context of Romanian aquaculture, our findings suggest that while the sector is on a growth path, mirroring global trends, it mustnavigate the complexities of sustainable expansion. The emphasis on sustainable practices will be critical for the industry to not only increase production but also ensure that such growth is environmentally sustainable and economically viable, contributing to long-term food security and societal well-being.

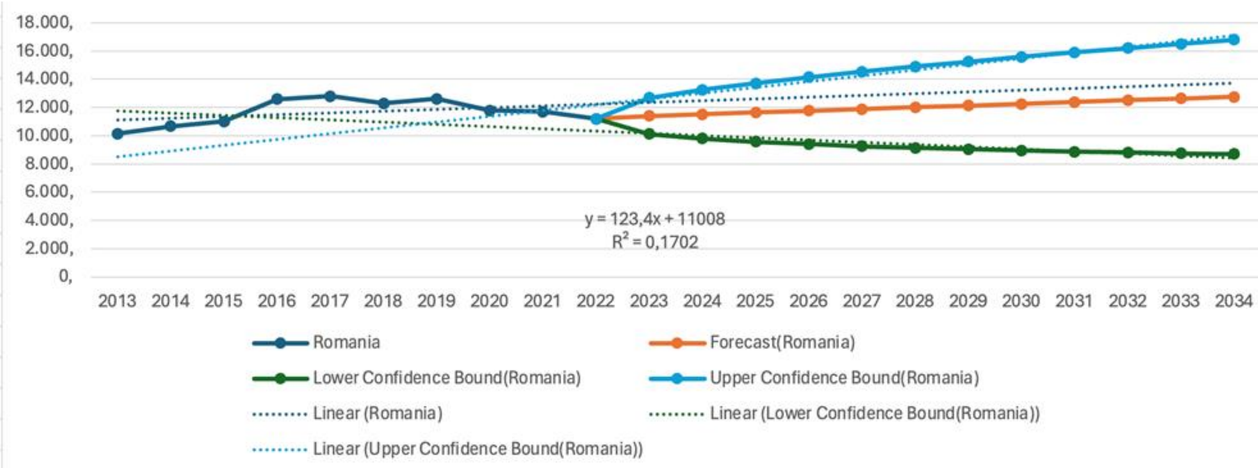

Fig. 1. Production from aquaculture excluding hatcheries and nurseries
Source: EuroSTAT [6].

The data regarding the production of fish eggs for human consumption from aquaculture in Romania displays an exponential growth based on a limited dataset that includes only the years 2021 and 2022 (Figure 2). According to the information provided by EUROSTAT, the actual production in 2021 was 0.421 thousand units, which then forecasted an exponential increase to 1,287 thousand units in 2022. The forecast projects a continuation of this rapid growth, reaching an estimated 16,725.948 thousand units by 2034.

The forecast model is defined by a linear equation y = 1,286.6x - 1,286.2 with an R-squared value of 1, indicating a perfect fit of the model to the data points. However, given the limited data points available, this high R-squared value may not be indicative of actual future trends but rather a result of overfitting to the very limited historical data.

The lower and upper confidence bounds are identical to the forecast values, suggesting no variation in the forecasted model. This is an artifact of the limited data and the statistical model applied, which does not account for any potential variability in future outcomes.

The exponential increase reflected in the forecast suggests a very optimistic outlook for the industry; however, the dataset is highly limited, with only two years of actual data, which severely constrains the robustness and reliability of the forecast.

The statistical parameters provided in the model (Alpha = 1.00, Beta = 0.75, Gamma = 0.00) indicate that the model is highly sensitive to the level and trend but does not account for any seasonal variability, which may not be relevant in this particular context. Moreover, the MASE, SMAPE, MAE, and RMSE values are all zero, which in a real-world context is highly unlikely and again is indicative of overfitting due to the limited dataset.

The forecast should be used as a tentative projection of the industry's potential under the assumption that current growth trends continue unabated, which is unlikely in a real-world biological and economic context. The absence of variability in the confidence intervals and the perfect R-squared value highlight the need for caution in interpretation.

Given the exponential nature of the forecast, it is vital to consider the capacity of the environment, the aquaculture industry's infrastructure, market conditions, and potential biological constraints that could limit such growth. Future forecasts would benefit significantly from more comprehensive data over several years to provide a more reliable and nuanced projection that accounts for the complexities of aquaculture production.

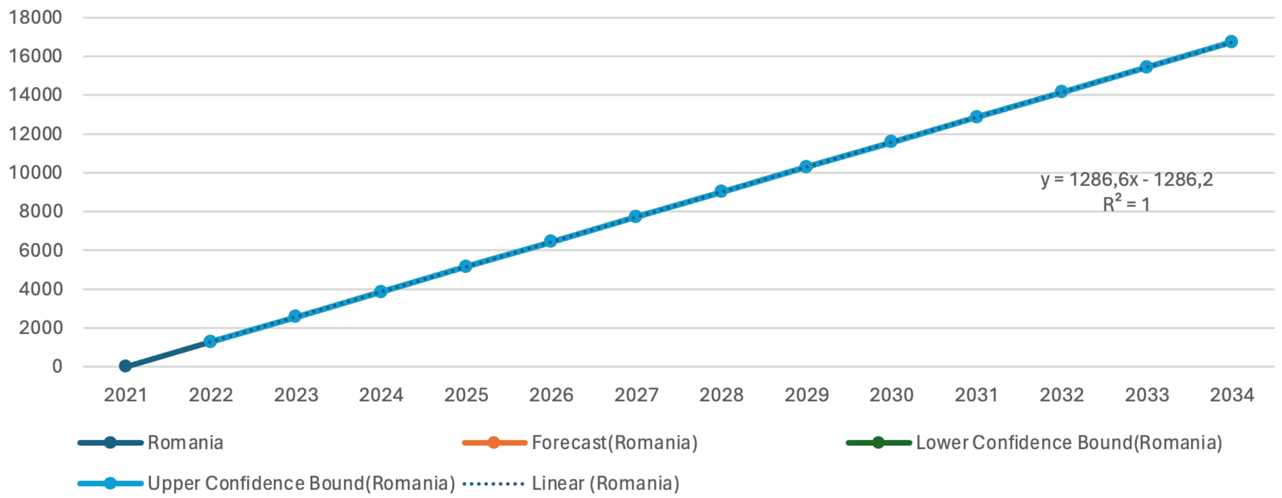

Fig. 2. Production of fish eggs for human consumption from aquaculture
Source: EuroSTAT [6].

The analysis of the production of hatcheries and nurseries at the egg stage in life cycle in Romania demonstrates notable variability from 2014 to 2021, with an overall increasing trend (Figure 3). The historical data shows fluctuations with values ranging from a low of 0.58 in 2016 to a high of 115.03 in 2014. Notably, there has been a substantial increase to 10.706 in 2021.

The forecasted data predicts a continuing upward trend with production expected to increase from 91.26 in 2022 to 69.81 in 2034. It is essential to observe that the lower confidence bounds are negative from 2023 onwards, whichis not feasible for actual production values and indicates a high degree of uncertainty in the forecast. Conversely, the upper confidence bounds suggest a potential for higher production, increasing from 173.708 in 2023 to 360.593 in 2034.

The linear regression model applied to the forecast has an equation of $y = -1.0727x + 30.917$ with an R-squared value of 0.0044, indicating that the linear model does not effectively explain the variance in the production data, and thus may not be suitable for making accurate predictions.

Statistically, the Alpha value of 0.90 suggests strong weighting on recent observations, while a Beta of 0.00 indicates that the model does not account for the trend component of the time series. A Gamma value of 0.00 means the seasonal component is also not considered. Given the MASE of 0.95, the model performs slightly better than a naïve benchmark model.

The SMAPE of 1.19, along with MAE of 24.80 and RMSE of 46.85, reflect the average percentage errors and absolute errors in the model, indicating that there is room for improvement in the forecast accuracy.

Given these insights, stakeholders and policymakers should treat the forecast as indicative rather than definitive. It would be prudent to consider additional factors and perhaps utilize more sophisticated time series analysis techniques that can account for the non-linear nature of the data.

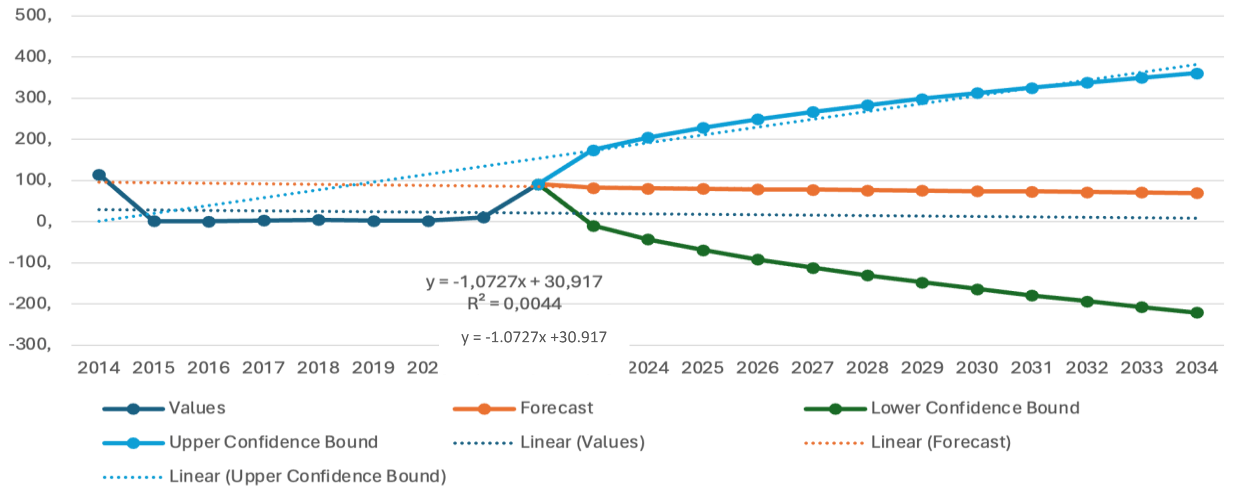

Fig. 3. Production of hatcheries and nurseries at eggs stage in life cycle
Source: EuroSTAT [6].

This approach would likely result in more reliable and actionable insights for planning and decision-making processes in the Romanian hatcheries and nurseries sector.

The projection of significant growth in the production of fish eggs for human consumption from aquaculture over the next decade aligns with our scientific findings. In this regard, [10] emphasize the sector's burgeoning role in supplying sustainable seafood sources, a trend that our analysis confirms for Romania. This growth is indicative of the broader expansion within aquaculture, underscoring its critical position in addressing the increasing global demand for fish products.

The data regarding the production of hatcheries and nurseries at the juvenile stage in the life cycle in Romania indicates a dramatic fluctuation in historical values, with a sharp peak in 2017 at 286.877, a significant drop in the subsequent years, and a low point of 0.9743 in 2022 (Figure 4).

The forecast suggests a decreasing trend over the period up to 2034, where production is expected to diminish to 15.1683999092.

Interestingly, the lower confidence bounds for the forecast are negative from 2023 onwards, which is not practical or possible for production values and indicates substantial uncertainty in the projection.

The upper confidence bounds, however, consistently remain in the positive range, suggesting that while there may be a decline, the potential for maintaining some level of production exists.

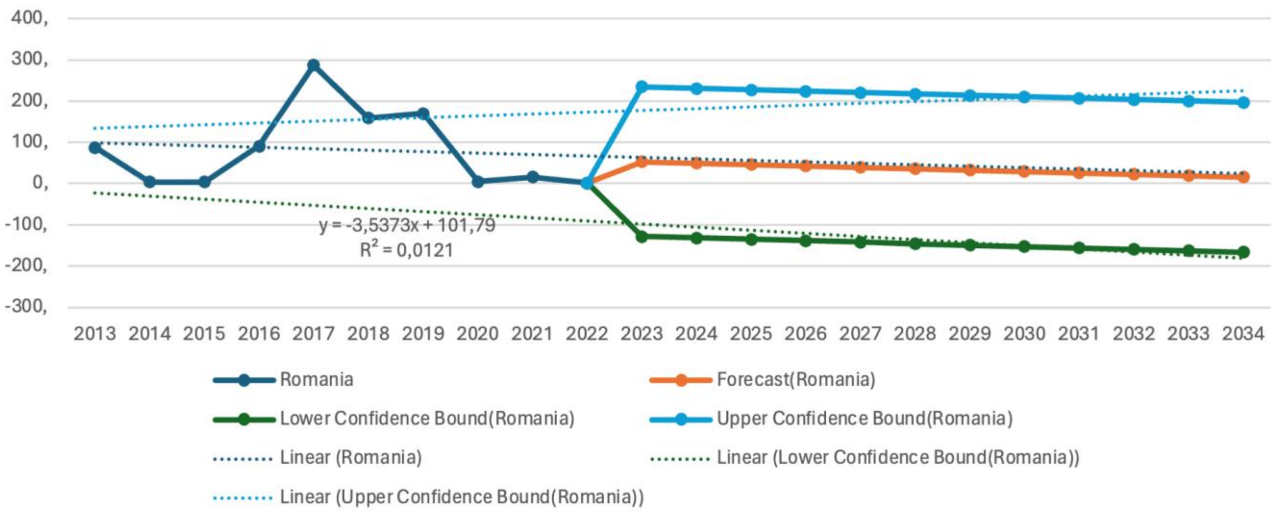

Fig 4. Production of hatcheries and nurseries at juvenile stage in life cycle
Source: EuroSTAT [6].

The linear regression model shows a decreasing trend line with the equation y = -3.5373x + 101.79 and an R-squared value of 0.0121, suggesting a very weak correlation between the time and the production values, indicating that the model does not adequately capture the factors influencing production levels.

The accuracy measures including MASE at 0.95, SMAPE at 1.15, MAE at 73.69, and RMSE at 92.51 indicate that the model's predictions are not very close to the actual data points. These metrics suggest that while the model's performance is slightly better than a naive model (as indicated by the MASE), there is a significant average percentage error (SMAPE) and substantial average and root mean square errors (MAE and RMSE, respectively).

Given the decreasing trend and the high level of uncertainty indicated by the negative lower confidence bounds, stakeholders in Romania'shatcheries and nurseries sector should be cautious.

CONCLUSIONS

This study offers a comprehensive forecast and analysis of the Romanian aquaculture sector, highlighting areas such as production from aquaculture excluding hatcheries and nurseries, and the production of fish eggs for human consumption, alongside hatcheries and nurseries outputs at different life stages. The findings underscore a sector poised for substantial growth, reflecting broader global shifts towards increased reliance on aquaculture to satisfy escalating seafood demand.

The projected expansion within Romanian aquaculture underscores the sector's burgeoning role in bolstering food security, both nationally and globally. This anticipated growth further emphasizes the imperative for sustainable production practices. As the sector evolves, prioritizing environmental stewardship and sustainable methodologies will be crucial for ensuring its longevity and mitigating impacts on ecosystems.

Notably, the expected increase in the production of fish eggs for human consumption represents a significant opportunity for Romania's aquaculture industry. This segment presents a pathway to high-value products within the global seafood market, necessitating a focus on innovation, quality, and sustainability in production processes.

The sector's journey forward is marked by both challenges and opportunities. Environmental concerns and sustainable resource management remain critical issues. However, these challenges also pave the way for technological advancements, research breakthroughs, and the implementation of best practices that can drive the industry forward.

Continuous research is vital for keeping pace with market dynamics and environmental changes, ensuring the Romanian aquaculture sector's resilience and success in the global arena.

In summary, the Romanian aquaculture sector is at a pivotal point, with sustainable growth and innovation key to its future success. By leveraging opportunities for high-value production, such as fish eggs, and committing to environmental and sustainable practices, Romania can enhance its contribution to global food security and assume a leading role in the international aquaculture landscape. Further research and adaptive strategies will be essential in navigating the challenges and seizing the opportunities that lie ahead.

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