Economic Evaluation of Bivalves in Egypt: A Potential for Aquaculture Production

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Abstract

This study investigates how landing sites (Mediterranean Sea, Red Sea, and Bitter Lakes) and temporal trends affect bivalve production quantity (tons) in Egypt over an eleven-year period (2009–2019). Also, to forecast bivalves' production to investigate investment opportunities in this sector. Data were obtained from official national records, including the General Authority for Fish Resources Development (GAFRD) and the Central Agency for Public Mobilization and Statistics (CAPMAS). A mixed effect model (MEM) was used to evaluate regional differences and time effects on production. Results revealed that region was a significant determinant of bivalve production, with the Mediterranean Sea demonstrating notable growth, while Bitter Lakes and the Red Sea remained stable. To forecast future production, autoregressive integrated moving average (ARIMA) models were fitted separately for each region. ARIMA projections indicated a potential production decline in the Mediterranean region despite its past growth, whereas Bitter Lakes maintained steady output, and the Red Sea exhibited persistently low production levels. It is concluded that integrating MEM and ARIMA methodologies provides a comprehensive framework for understanding and forecasting bivalve production, informing resource management and policy decisions. The findings underscore the importance of site-specific fisheries management and suggest that adaptive strategies may be required to sustain growth in the Mediterranean region, maintain stability in Bitter Lakes, restore bivalves' population, and explore alternative economic activities for the Red Sea. Many bivalves are adapted to the Egyptian fisheries which suggests the high potential for aquaculture production.

Key words: ARIMA, Aquaculture, Bivalves, Mixed effects model

Introduction

With a population of more than 100 million ***(CAPMAS, 2025)***, the Egyptian government needs to exert continuous efforts to ensure sustainable production of high-quality food. This goal is challenged by factors such as climatic changes, rising production costs, and geopolitical circumstances. Aquatic animal production can play a significant role in addressing these challenges. In Egypt, natural fisheries provide 20.82% of total production of aquatic animals while aquaculture supplies the remainder ***(GAFRD, 2020)***. Egypt leads the aquaculture production in Africa, and although global production includes fish, crustaceans, bivalves, other aquatic animals, and algae ***(FAO, 2022)***, aquaculture production in Egypt is limited to fishes and shrimp ***(GAFRD, 2020)***. A noticeable political pressure facing the Egyptian government was observed to explore alternatives that diversify fishing activities and uphold the social stability of fishers. Bivalves present one such opportunity. Some of them are rich in high quality proteins ***(Song et al., 2024)***, Egyptian consumers are familiar with several bivalve species, and most of the bivalves produced globally are farmed ***(Pinello et al., 2020)***. Bivalves provide food, pearls, shells and ecosystem services ***(Olivier et al., 2020)***. Their shells serve as a source of calcium carbonate and calcium oxide which have various industrial applications. In addition, they are used as calcium supplements in animal feed and can also be used in cosmetics ***(FAO, 2022)***. Some bivalves are bio-indicators for any habitat degradation as they can tolerate high pollution ***(Belal et al., 2016)***. Furthermore, farming bivalves offers advantages over other aquatic species due to less costly infrastructure and feed requirements ***(Pinello et al., 2020)***. Despite these economic benefits, private and public investments in bivalve aquaculture are lagging. Proper investigation of bivalves can indicate the potential for aquaculture production ***(Argente et al., 2014)***. The Mediterranean and Red Seas each have large fishing areas, covering roughly 10 million feddan in Egypt ***(CAPMAS, 2012)***, and serve as habitats for bivalves ***(Beltagi, 2015)***.

This study adds to the body of knowledge on bivalves in the Egyptian market ***(FAO EastMed, 2014; Pinello et al., 2020)*** and is the first, to the best of authors' knowledge, that study bivalves on the macro level by analyzing the production trends of bivalves in their main landing sites, aiming to highlight the potential for domestic aquaculture production and policy measures needed to sustain their production.

Materials and methods

1. Data Collection and Sources

The study investigates the effect of landing sites (the Mediterranean Sea, the Red Sea, and the Bitter lakes) and temporal trends on production quantity (tons) of bivalves over an 11-year period. Data were obtained from official records of the General Authority for Fish Resources Development (GAFRD) and Central Agency for Public Mobilization and Statistics (CAPMAS). The production quantity (tons) of bivalves in Egypt is illustrated in (Figure 1).

2. Statistical and Forecasting Methods

To analyze production dynamics and forecast future trends, a mixed effects model (MEM) to evaluate regional effects and an autoregressive integrated moving average (ARIMA) model to predict future production levels were applied using R software ***(R Core Team, 2020)***.

2.1. MEM

MEM was used given the fact that production data were collected repeatedly over time from multiple regions. This creates a hierarchical (or panel) data structure with time nested within regions. The linear MEM accommodates these repeated measures by modeling each region's baseline while allowing fixed effects for overall trends and region-specific differences. MEM allows including an interaction term (Year × Region), the MEM tests whether each region follows a distinct trajectory over time, yielding nuanced insights that simple ANOVA or single-level regressions might miss ***(Wang and Goonewardene, 2004)***. A linear MEM was employed to assess the impact of region and time on bivalve production. The model structure was defined as:

$$Quantity_T = \beta_0 + \beta_1 Year + \beta_2 Region + \beta_3 (Year * Reggion) + u \qquad (1)$$

where:

- β_1 captures the overall trend in production over time.
- β_2 accounts for baseline differences in production across regions.
- β_3 represents the interaction effect, allowing each region to have its own production trajectory.
- $u \sim N(0, \sigma^2)$ denotes the random effect on regions to account for unobserved heterogeneity.

The model was implemented with the year treated as a fixed effect and regions as a random effect.

2.2. Time-Series Forecasting with ARIMA

To provide robust forecasts for bivalve production, ARIMA model for each region was employed separately ***(Chatfield, 2001; Stock and Watson, 2001)***. ARIMA is a proper choice because bivalve production often exhibits serial correlation, where the current year's production depends on previous years. ARIMA explicitly models these dependencies through autoregressive (AR) and moving average (MA) terms. Additionally, natural resource data can trend or fluctuate so, differencing in ARIMA (the "I" part) transforms non-stationary series into stationary ones, which is crucial for valid forecasting. The model selection was performed using automated ARIMA, ensuring optimal selection of parameters (p, d, q) based on the Akaike Information Criterion (AIC) and the Schwarz's Bayesian Information Criteria (BIC).

The general ARIMA model used is:

$$Y_t = \emptyset_1 Y_{t-1} + \emptyset_2 Y_{t-2} + \cdots + \emptyset_p Y_{t-p} + \theta_1 \epsilon_{t-1} + \theta_2 \epsilon_{t-2} + \cdots + \theta_q \epsilon_{t-q} + \epsilon_t$$

where:

Y_t: The value of the time series at the current time t.

Y_{t-i}: The value of the time series at a lag of i periods before t.

$\emptyset_i$: The autoregressive (AR) parameters that multiply past values of the series.

ϵ_t: The error term (or white noise) at time t.

θ_i: The moving average (MA) parameters that multiply past error terms.

3. Model Evaluation and Validation

MEM was assessed using variance components, likelihood ratio tests, and AIC/BIC scores to ensure robustness ***(Wang and Goonewardene, 2004)***. ARIMA models were evaluated based on Root Mean Squared Error (RMSE), Mean Absolute Error (MAE), and residual diagnostics ***(Cruz et al., 2022)***. Forecast accuracy was further tested by comparing historical observed values with predicted values to assess model reliability.

Results and discussion

1. Regional Differences in Bivalve Production

MEM was used to analyze production differences across regions and over time. The results, presented in Table 1, showed that the region played a significant role in production levels, while time had a limited impact except for the Mediterranean region. Results of MEM showed that the Mediterranean region had a significantly different baseline production compared to Bitter Lakes ($p<0.05$). The Mediterranean region also showed a significant positive trend over time ($p=0.022$), confirming growth. Bitter Lakes had the highest production but remained stable over time ($p>0.05$). On the other hand, Red Sea production remained minimal, with no significant trend ($p>0.05$).

The values of R squared (Table 2) indicated that the model explains 52.1% of variation within regions and 63.7% of overall variation. Additionally, AIC/BIC scores confirm that this model provides a good fit for the data.

2. Production Forecasting Using ARIMA

ARIMA models were applied separately to each region to predict future production trends. Results (Table 3 and Figures 2-4) indicate that Mediterranean production shows a declining trend in ARIMA predictions, despite showing growth in the MEM, while Bitter Lakes production remains stable, with no trend detected. On the other hand, Red Sea production remains low, with no forecasted growth.

The model validation results illustrated that all models showed no strong autocorrelation, confirming model reliability. This can be seen from the last column values of residuals. From the values of ME, MAE, and RMSE, the predictions of ARIMA are considered robust, but external factors may need to be considered for Mediterranean trends. The environmental and disease conditions might affect the abundance of bivalves. Reductions in the bivalves' numbers will impact the trophic webs and the economy ***(Cabiddu et al., 2025)***. Bivalves differ in their abundance and distribution along the Red Sea coast of Egypt ***(Abdelmeneam et al., 2025)***. The distribution of bivalves varies among different locations according to their environmental preferences ***(Cerdeira-Arias et al., 2024)***. Bitter Lakes suffer from high exploitation rates of some bivalves ***(Ghobashy et al., 2017; Farghaly et al., 2022)***. Chemical pollutants, including discharges from ships, may contribute to the damaging of the marine ecosystem ***(Yu et al., 2011)***. The accumulation of some heavy metals can lead to infertility problems which impact the aquatic populations ***(Oliveira Ribeiro et al., 2002)***. Although environmental traits influence growth rate, but their effect on the abundance and distribution of wild populations is less clear ***(Baptista and Leitão, 2014; Baptista et al., 2014)***. Population structure can vary among years ***(Gama et al., 2020)***. Annual variations of population might be due to climate change, human activities and predation ***(Wijsman et al., 2019; de Fouw et al., 2024)***.

3. Fisheries Management Implications

The findings have important implications for fisheries management and policy planning. The Mediterranean Region might have some potential constraints on growth. Despite showing past growth, ARIMA forecasts predict a decline. This can be explained by environmental constraints (climate variability, changes in water temperature and quality), regulatory limitations, quota systems affecting long-term production, or market saturation reducing profitability and discouraging expansion. Bitter Lakes is considered a stable production hub. The region showed no significant increase or decrease in production. This might be due to the absence of external factors significantly impacting production, and hence an increasing opportunity for aquaculture production. Lastly, the Red Sea showed limited potential for expansion. It has a persistently low production that reached zero tons for the last two years of the studied period, with no trend indicating future growth. This could be due to unfavorable environmental conditions, limited demand or inadequate fishing infrastructure.

Table 1. *Mixed Effects Model Results*

Effect	Estimate	Std. Error	t-value	p-value
Intercept (Bitter Lakes Baseline)	41,649.00	48,654.11	0.86	0.40
Year (Overall Trend)	-20.00	24.12	-0.83	0.42
Mediterranean (Difference from Bitter Lakes)	-161,458.40	68,807.31	-2.35	0.03
Red Sea (Difference from Bitter Lakes)	-34,607.71	68,807.31	-0.50	0.62
Year × Mediterranean (Trend Over Time)	81.42	34.11	2.39	0.02
Year × Red Sea (Trend Over Time)	16.52	34.11	0.49	0.63

Table 2. *MEM Fit and Validation*

Model	AIC	BIC	Log-Likelihood	R^2 (Within)	R^2 (Overall)
Mixed Effects Model	396.7	402.9	-192.35	0.521	0.637

Table 3. *ARIMA Model Results*

Region	ARIMA Model	AIC	BIC	RMSE	Trend
Mediterranean	ARIMA (0,2,0)	126.38	126.58	219.35	Declining
Bitter Lakes	ARIMA (0,0,0)	158.37	159.16	269.83	Stable
Red Sea	ARIMA (0,0,0)	103.45	104.25	22.23	Stable (low production)

Table 4. *ARIMA Model Validation*

Region	Mean Error (ME)	Mean Absolute Error (MAE)	RMSE	ACF1 (Autocorrelation of Residuals)
Mediterranean	-59.42	169.86	219.35	-0.290
Bitter Lakes	0.00	199.64	269.83	-0.175
Red Sea	-4.52	20.10	22.23	0.218

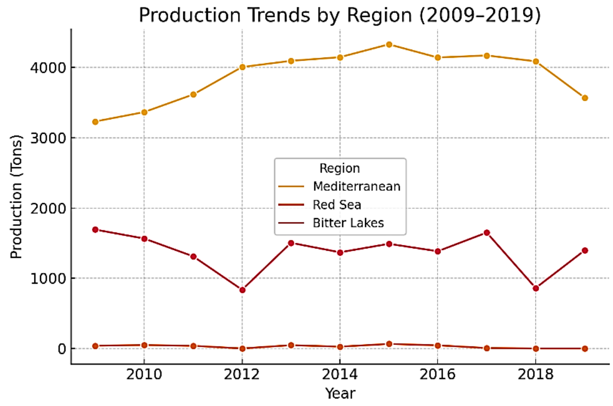

Figure 1. Bivalves' production quantities in Egypt, 2009-2019.

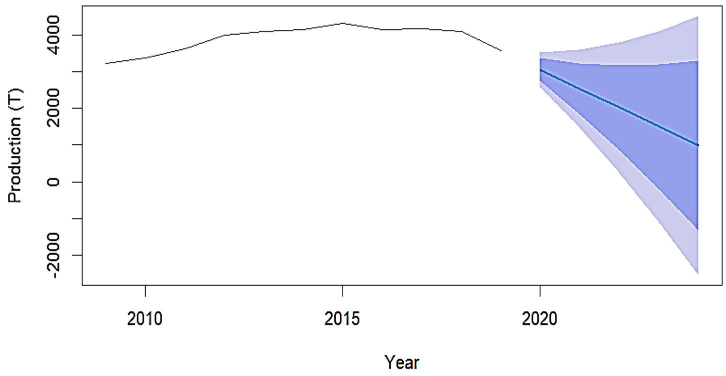

Figure 2. ARIMA forecast for the Mediterranean region.

Figure 3. ARIMA forecast for the Red Sea region.

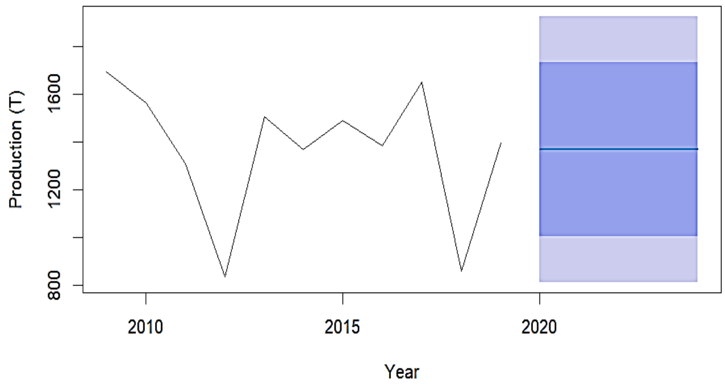

Figure 4. ARIMA forecast for the Biter Lakes region.

4. Conclusion and recommendations

The integration of MEM and ARIMA methodologies provided comprehensive insights into historical dynamics and future projections of national bivalve production. The Mediterranean region faces potential constraints, highlighting the necessity of further investigation into factors affecting the abundance of bivalves such as climate conditions, resource availability, and market demands. It is recommended to implement adaptive management strategies, focusing on monitoring external constraints and adjusting production targets accordingly. The government can build on the processing infrastructure at Ghalion, where a major seafood processing facility exist, through investing in depuration processes to add value and increase consumer's acceptability for bivalves.

Bitter Lakes, identified as a region with stable and reliable production, should continue current management practices with periodic evaluations to ensure sustainability. Investing in infrastructure improvements and environmental monitoring are advisable to maintain production stability.

The Red Sea region, with persistently low production levels, appears economically non-viable without significant intervention. It is concluded that the bivalves' population in the Red Sea are heavily exploited which indicates the urgency of starting restoration programs.

It is recommended that policymakers explore alternative economic activities or aquaculture innovations that better suited to the region's conditions, rather than relying on traditional bivalve fisheries.

Investments in aquaculture production need to be directed toward the Mediterranean Sea, and the government needs to implement and update the existing monitoring programs and to enforce environmental protection laws to observe bivalves' populations. These recommendations aim to guide targeted, sustainable, and economically viable resource management across Egypt's diverse marine ecosystems.

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التقييم الاقتصادي للمحاريات في مصر: إمكانية الاستزراع

الملخص العربي

بحثت الدراسة تأثير مواقع الصيد في البحر الأبيض المتوسط والبحر الأحمر والبحيرات المرة و كذلك الاتجاهات الزمنية على إنتاج المحاريات في مصر. تم الحصول على البيانات من الهيئة العامة لتنمية الثروة السمكية والجهاز المركزي للتعبئة العامة والإحصاء، وتم استخدام نموذج التأثيرات المختلطة (MEM) لتقييم اختلافات مواقع الصيد والتأثيرات الزمنية. كشفت النتائج أن المنطقة تعد محددًا مهمًا للإنتاج، وأظهر البحر المتوسط نموًا ملحوظًا، بينما ظلت البحيرات المرة والبحر الأحمر مستقرين. للتنبؤ بالإنتاج ، تم تصميم نماذج المتوسط المتحرك المتكامل الانحداري الذاتي (ARIMA) لكل منطقة. وقد أشارت التوقعات إلى انخفاض محتمل في الإنتاج من البحر المتوسط ، بينما حافظت البحيرات المرة على إنتاج ثابت، وأظهر البحر الأحمر مستويات إنتاج منخفضة باستمرار.وخلصت الدراسة إلى تكيف العديد من ذوات الصدفتين في المصايد البحرية، مما يشير إلى إمكانات الاستزراع. كما أن دمج منهجيتي MEM وARIMA يوفر إطارًا شاملاً لفهم الإنتاج والتنبؤ به لإدارة الموارد واتخاذ القرارات المناسبة. وتؤكد النتائج أهمية إدارة المصايد، و تشير إلى أن استراتيجيات التكيف ضرورية لدعم النمو في منطقة البحر المتوسط، والحفاظ على الاستقرار في البحيرات المرة، واستعادة أعداد ذوات الصدفتين واستكشاف أنشطة اقتصادية بديلة في البحر الأحمر.