



RESEARCH ARTICLE

Forecasting Türkiye's salmon exports: A multi-method assessment of market dynamics and country-specific prospects

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ABSTRACT

Türkiye has rapidly emerged as an important producer and exporter of Turkish salmon, yet the future trajectory of its exports may differ substantially across destination markets. This study examines the short-term country-specific prospects of Türkiye's salmon exports and identifies markets characterized by growth potential, contraction, and uncertainty. The analysis uses January–August export data for 2022–2025 for 25 destination countries with complete observations for all four study years. January–August export volumes for 2026–2028 are projected using Holt's Linear Trend Method, the Damped Holt Method, and the GM(1,1) grey forecasting model, while Compound Annual Growth Rates (CAGR) are employed to assess recent market dynamics. The results reveal substantial heterogeneity across destination markets. Russia is expected to remain Türkiye's dominant salmon export market, although its continued expansion also implies persistent risk of market concentration. Belarus, Georgia, Lithuania, and Kazakhstan emerge as promising growth markets, while Japan and Vietnam maintain strong prospects among Asian destinations. In contrast, several mature European markets, particularly Germany, the United Kingdom, Belgium, and Italy, exhibit declining or uncertain trajectories, highlighting the need for market-specific product and value-chain strategies. Comparisons across forecasting methods show broad agreement for several major markets but also reveal considerable divergence for selected destinations, reflecting the sensitivity of very short and volatile trade series to model specification. Given the limited observation period, the forecasts should therefore be interpreted primarily as short-term January–August projections of the direction and relative strength of existing market trajectories rather than as deterministic estimates of full-calendar-year export volumes. The findings suggest that the next stage of Türkiye's salmon export development will require a transition from export expansion toward export portfolio management, with greater emphasis on geographic diversification, value-added products, market-specific positioning, and reduced dependence on dominant destinations.

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Introduction

Aquaculture has become an increasingly important component of the global food system as capture fisheries face limits to further expansion while demand for aquatic foods continues to increase. Its future development is shaped not only by production capacity but also by technological innovation, prices, income, consumer preferences, and international market conditions (Bjørndal et al., 2024). In parallel, aquaculture value chains have become more geographically diverse, technologically intensive, and internationally integrated (Bush et al., 2019; Pandey et al., 2023). Salmon is one of the clearest examples of this transformation, with competitiveness increasingly linked to productivity, scale, logistics, product development, and market-specific strategies.

Within the global salmon market, salmon trout represents an economically relevant segment. Although Atlantic salmon remains dominant, large rainbow trout produced in seawater is closely integrated with the broader salmon market and is often perceived by consumers as a substitute for Atlantic salmon (Landazuri-Tveteraas et al., 2021). At the same time, product characteristics and consumer preferences differ substantially across countries. In mature markets, demand increasingly depends on product form, processing level, convenience, and retailer requirements rather than on volume alone (Straume et al., 2024). These differences imply that future export growth should be assessed at the destination-market level.

Türkiye has become one of the most dynamic aquaculture producers in Europe. Over the past two decades, Turkish finfish production increased from approximately 61 thousand to more than 547 thousand tonnes, while aquaculture exports reached USD 1.7 billion across more than 100 countries (Aydın et al., 2025). Within this expansion, Turkish salmon has emerged as a high-value export product. Erol & Eruz (2024) reported that Turkish salmon exports reached approximately 49,000 tonnes and USD 363 million in 2022, more than seven times the export revenue recorded in 2019. This rapid development reflects not only increasing production capacity but also improvements in technology, processing, branding, and market access.

The recent success of Turkish salmon is also closely related to the restructuring of international salmon trade. Knudsen (2025) shows that Turkish producers established strong commercial relations first with Russia and later with Japan and several Southeast Asian markets. Approximately 60% of Turkish salmon exports were directed to Russia in 2022, underlining both the strategic importance of this market and the concentration risk associated with dependence on a single

destination. At the same time, efforts to expand toward European and Asian markets indicate that future sectoral growth will increasingly depend on geographic diversification and market-specific positioning.

Despite the growing literature on Turkish aquaculture and Turkish salmon, existing studies have mainly focused on production potential, competitiveness, sectoral development, value-chain transformation, and export performance (Demir & Aksoy, 2021; Erol & Eruz, 2024; Knudsen, 2025; Aydın et al., 2025). However, country-specific short-term forecasts of Türkiye's salmon exports remain limited. This is an important gap because aggregate export growth may conceal substantially different trajectories across destination markets, including expansion, stagnation, or decline.

Accordingly, this study evaluates the short-term future trajectory of Türkiye's salmon exports at the destination-country level. Using January–August export data for 2022–2025 covering 25 countries, January–August export volumes for 2026–2028 are estimated using Holt's Linear Trend Method, the Damped Holt Method, and the GM(1,1) model, while CAGR is used to assess recent market growth. Because the available country-level series are very short, the alternative methods are used as complementary projection approaches rather than as evidence of comparative predictive superiority. GM(1,1), in particular, was developed for limited-information settings, although forecast performance remains sensitive to sample length and data dynamics (Wang et al., 2020). By comparing the direction and magnitude of the resulting projections, the study aims to identify growth markets, emerging risks, and market-specific opportunities while explicitly acknowledging the uncertainty associated with the short observation window.

Material and Methods

This study uses country-level Turkish salmon export data for the January–August period of 2022–2025 to assess short-term market trajectories. A reproducible completeness criterion was applied: a destination country was retained only when a January–August export observation was available for each of the four consecutive study years (2022, 2023, 2024, and 2025). Countries with one or more missing annual observations were excluded because the forecasting procedures applied in this study require complete input series. On this basis, 25 destination countries were included: Russia, Japan, the Republic of Belarus, Poland, Vietnam, the United States, Georgia, the People's Republic of China, Lithuania, Kazakhstan, Germany, Greece, Malaysia, Canada, Indonesia,

Bulgaria, Romania, Iraq, Singapore, Belgium, the Turkish Republic of Northern Cyprus, Qatar, Italy, Spain, and the United Kingdom. The export data used in the study were compiled from the Eastern Black Sea Exporters' Association (DKİB, 2026) and the Turkish Statistical Institute (TurkStat, 2026). The resulting sample therefore represents the set of destinations satisfying the completeness criterion and should not be interpreted as covering all Turkish salmon export destinations.

The analysis is restricted to January–August observations and does not represent full-calendar-year export totals. This common observation window was used for every study year to ensure temporal comparability and to align the analysis with the principal production and marketing season of Turkish salmon harvested from sea cages in the Black Sea, which is concentrated in spring and early summer. Accordingly, all historical values, growth measures, and forecasts reported in this study should be interpreted as January–August export volumes unless explicitly stated otherwise. Because a quantitative January–August share of full-year exports was not established within the present dataset, no claim is made that this period represents a fixed proportion of annual exports.

Holt integrated a trend component into standard exponential smoothing in 1957, making it suitable for trending time series (Holt, 1957, 2004). The 1957 study on exponential smoothing by Holt was later re-released in 2004 within the International Journal of Forecasting. Holt's linear trend model enhances univariate exponential smoothing by accounting for systematic upward or downward movements over time, thereby refining long-term forecasting accuracy. The model decomposes the series into level component (L_t) and trend component (T_t).

The model framework is specified by the following equations (Holt, 1957, 2004):

$$L_t = \alpha Y_t + (1 - \alpha)(L_{t-1} + T_{t-1}) \quad (1)$$

$$T_t = \beta(L_t - L_{t-1}) + (1 - \beta)T_{t-1} \quad (2)$$

$$\hat{Y}_{t+h} = L_t + hT_t \quad (3)$$

L_t : Estimated level, Y_t : Observed value, T_t : Estimated slope of the series at time period t , and β , α are smoothing parameters for the trend and level, respectively.

h : Forecast horizon (number of future periods)

$\hat{Y}_{t+h}$: Forecasted value for h periods ahead from time period t

For each country, the level and trend components were estimated recursively from the available January–August observations. The smoothing parameters and initial states were selected by minimizing the in-sample squared forecasting errors subject to the usual parameter bounds $0 \leq \alpha \leq 1$ and $0 \leq \beta \leq 1$. Because the archived analysis output does not contain country-specific fitted parameter values or software-level optimization logs, no claim of exact software-level reproducibility is made from these summary tables alone; the reported forecasts should be interpreted as the outputs of the fitted models described here.

To prevent the over-forecasting behaviour for long-term horizons in Holt's linear model, Gardner & McKenzie (1985) incorporated a damping parameter into the standard framework.

The mathematical specification of the additive damped trend model is expressed through the following equations (Gardner & McKenzie, 1985):

$$L_t = \alpha Y_t + (1 - \alpha)(L_{t-1} + \phi T_{t-1}) \quad (4)$$

$$T_t = \beta(L_t - L_{t-1}) + (1 - \beta)\phi T_{t-1} \quad (5)$$

$$\hat{Y}_{t+h} = L_t + (\phi + \phi^2 + \dots + \phi^h)T_t \quad (6)$$

Y_t : Observed value, L_t : Estimated level, and T_t : Estimated trend (slope) of the time series at period t , respectively.

$\hat{Y}_{t+h}$: Forecasted value for h periods ahead from period t .

h : Forecast horizon, α , β are smoothing parameters for the level and trend, respectively, and ϕ : Damping parameter ($0 < \phi < 1$).

In the damped specification, the damping parameter ϕ satisfies $0 < \phi < 1$ and progressively reduces the contribution of the estimated trend as the forecast horizon increases. The fitted level, trend, and damping components were obtained using the same in-sample error-minimization framework described above. The damping formulation was included to limit unrestricted extrapolation of recent trends over the three-step forecast horizon.

The Compound Annual Growth Rate (CAGR) evaluates the average annual progression of a given time series over a specified period more than a year. Assuming that the series grows at a steady, compounded rate annually over the defined period, it serves as a measure of the geometric mean growth rate over that designated timeframe (DeFusco et al., 2007).

CAGR is mathematically computed using the following equation:

$$CAGR = (V_n / V_0)^{1/n} - 1 \quad (7)$$

Alternatively, expressed as a percentage:

$$CAGR (\%) = [(V_n / V_0)^{1/n} - 1] \times 100 \quad (8)$$

Where:

V_0 : Initial value at the beginning of the period

V_n : Final value at the end of the period

n : Total number of periods (years) between the initial and final observations.

Within empirical research, CAGR serves as a prevalent tool to mitigate the impact of annual fluctuations, providing a normalized geometric growth rate suitable for comparative evaluation across different periods or datasets. Nevertheless, owing to its exclusive reliance on the initial (V_0) and final (V_n) values, CAGR fails to capture internal variance, transitory shocks, or structural disruptions occurring during intervening periods.

The GM(1,1) model is a first-order, single-variable grey forecasting model intended for limited-information series (Deng, 1982). For each country, let the original non-negative sequence be $x^{(0)} = \{x^{(0)}(1), x^{(0)}(2), \dots, x^{(0)}(n)\}$. The first-order accumulated generating operation (AGO) is constructed as $x^{(1)}(k) = \sum_{i=1}^k x^{(0)}(i)$, $k = 1, \dots, n$. The adjacent-mean background sequence is then defined as $z^{(1)}(k) = 0.5x^{(1)}(k) + 0.5x^{(1)}(k-1)$, $k = 2, \dots, n$. These transformations reduce short-term fluctuation and provide the inputs to the grey differential equation.

The discrete GM(1,1) equation is $x^{(0)}(k) + a z^{(1)}(k) = b$, where a is the development coefficient and b is the grey input. Parameters are estimated by ordinary least squares using $Y = [x^{(0)}(2), \dots, x^{(0)}(n)]^T$ and $B = [-z^{(1)}(2) \ 1; \dots; -z^{(1)}(n) \ 1]$, so that $[\hat{a}, \hat{b}]^T = (B^T B)^{-1} B^T Y$. With the initial condition $x^{(1)}(1) = x^{(0)}(1)$, the time-response function is $x^{(1)}(k+1) = [x^{(0)}(1) - b/\hat{a}]e^{-\hat{a}k} + b/\hat{a}$. Forecasts on the original scale are recovered by inverse AGO: $x^{(0)}(k+1) = x^{(1)}(k+1) - x^{(1)}(k)$. This same sequence of steps was applied separately to each country series. The very short sample length remains an important limitation and is addressed explicitly in the Discussion.

The formulation above describes the empirical GM(1,1) sequence used to obtain country-level projections; it should be read together with the sample-length limitation noted below. The use of AGO does not eliminate the uncertainty created by a four-observation series, and no claim is made that the transformation itself resolves the small-sample problem.

GM(1,1) does not require a conventional probability distribution assumption and is commonly used in limited-information forecasting settings (Deng, 1982). In the present study, this property motivates its use as a complementary projection method; it does not imply that a four-observation series is sufficient to establish high predictive accuracy.

Results

Tables 1 and 2 present the January–August export-volume projections obtained using Holt’s Linear Trend Method and the Damped Holt Method. For each of the 25 selected countries, projections were generated for 2026, 2027, and 2028. Because Holt’s Linear Trend Method extends the estimated trend without damping, the Damped Holt specification was also included to reduce unrestricted trend extrapolation over the forecast horizon.

According to the forecast results, Russia, Belarus, Georgia, Lithuania, and Kazakhstan exhibit strong positive linear trajectories, whereas several smaller or declining markets show weak or negative extrapolated trends. For the People’s Republic of China, Germany, Iraq, and the United Kingdom, the unconstrained Holt model generated negative future values. Because export volume cannot be negative, these values were replaced by zero after model estimation as an ex-post truncation rule; the model itself was not estimated under a non-negativity constraint. This intervention should therefore be interpreted as a reporting rule rather than as evidence that exports are expected to be exactly zero. The Damped Holt Method was also examined because its damping parameter moderates unrestricted trend extrapolation.

The Damped Holt forecasts are presented in Table 2. Russia, Belarus, Georgia, Lithuania, and Kazakhstan retain positive projected trajectories, but the increases are generally less pronounced than under the undamped Holt specification. Poland and the United States also show more moderate growth. For China, Germany, Indonesia, and Iraq, the damped specification yields positive but declining projected values rather than the zero lower bound reached by the undamped Holt model. These differences illustrate the sensitivity of projections from very short series to the treatment of the trend component and should not be interpreted as evidence that one model is intrinsically more reliable than another.

For the same group of countries, Compound Annual Growth Rates (CAGR) were calculated over the 2022–2025 interval, based on four annual January–August observations and three annual growth intervals. CAGR summarizes the

compounded change between the initial and final observations and is used here as a descriptive measure of recent market dynamics rather than as a formal forecast-validation statistic. Because it depends only on the first and last observations, it can be strongly influenced by a very small initial base and should therefore be interpreted together with absolute export volumes and the intermediate-year observations.

The country-level results in Table 3 are ordered by the reported 2022–2025 CAGR. Greece records the highest reported rate, but this result is driven by an exceptionally small starting base: Türkiye’s January–August salmon exports to

Greece increased from only 150 kg in 2022 to 92,922 kg in 2025. Greece is therefore treated separately in the comparative discussion because its percentage growth is dominated by a low-base effect and is not directly comparable with the strategic importance of larger-volume markets. For Malaysia, the CAGR cannot be calculated for intervals beginning in 2022 because the initial value is zero. The additional 2022–2024 and 2023–2025 columns are retained to show how strongly the growth measure changes with the selected endpoints. Throughout the manuscript, these measures are referred to by their explicit intervals rather than as a ‘three-year CAGR’.

Table 1. Holt’s linear trend forecasts of Türkiye’s January–August Turkish salmon export volume (kg), 2026–2028

Country	2026 (Forecast)	2027 (Forecast)	2028 (Forecast)
Russia	37,669,752	41,528,232	45,386,712
Japan	3,654,210	3,892,400	4,130,592
Republic of Belarus	4,805,704	5,833,348	6,860,993
Poland	1,564,215	1,921,360	2,278,505
Vietnam	3,524,580	3,682,020	3,839,460
United States	840,576	930,639	1,020,701
Georgia	412,395	521,845	631,295
China	43,578	0	0
Lithuania	520,140	694,350	868,560
Kazakhstan	168,410	224,815	281,220
Germany	0	0	0
Greece	128,540	154,120	179,700
Malaysia	125,640	146,120	166,600
Canada	185,621	171,923	158,224
Indonesia	38,420	12,650	0
Bulgaria	26,410	27,950	29,490
Romania	29,450	26,120	22,790
Iraq	42,150	0	0
Singapore	8,420	7,150	5,880
Belgium	6,120	4,350	2,580
Turkish Republic of Northern Cyprus	6,450	4,120	1,790
Qatar	2,120	0	0
Italy	1,350	1,620	1,890
Spain	115	90	65
United Kingdom	0	0	0

Note. All values are forecasts of January–August export volume. Negative unconstrained Holt forecasts were replaced by zero after model estimation as an ex-post truncation rule; the Holt model itself was not estimated under a non-negativity constraint.

Table 2. Damped Holt forecasts of Türkiye's January–August Turkish salmon export volume (kg), 2026–2028

Country	2026 (Forecast, kg)	2027 (Forecast, kg)	2028 (Forecast, kg)
Russia	35,321,050	36,980,522	38,121,200
Japan	3,210,450	3,435,800	3,610,150
Republic of Belarus	4,702,939	5,535,331	6,284,484
Poland	1,115,420	1,182,600	1,214,350
Vietnam	3,490,620	3,585,140	3,665,410
United States	831,570	904,520	970,176
Georgia	378,150	424,900	461,350
China	330,602	253,528	195,723
Lithuania	380,200	425,100	452,400
Kazakhstan	142,150	168,600	192,450
Germany	210,500	98,400	42,100
Greece	105,400	112,650	117,200
Malaysia	92,450	96,100	98,250
Canada	173,194	165,488	159,709
Indonesia	42,150	36,400	32,800
Bulgaria	25,850	26,400	26,850
Romania	24,150	23,400	22,800
Iraq	28,400	21,600	17,900
Singapore	6,150	5,800	5,550
Belgium	7,400	6,950	6,600
Turkish Republic of Northern Cyprus	4,100	3,650	3,350
Qatar	3,850	3,300	2,950
Italy	1,220	1,280	1,330
Spain	105	100	95
United Kingdom	120	40	0

Note. All values are forecasts of January–August export volume. The damped specification limits the continuation of the estimated trend but does not constitute independent evidence of greater forecast accuracy.

Although Greece has the highest reported 2022–2025 CAGR, it is considered separately because the rate is dominated by the exceptionally small 2022 base. Among the remaining markets, the highest reported 2022–2025 CAGR values are observed for Kazakhstan, Singapore, Qatar, Lithuania, and Poland, respectively. Singapore and Qatar show high 2022–2025 rates but negative 2023–2025 CAGRs (–82.62% and –79.35%, respectively), illustrating why endpoint-based growth rates should not be interpreted independently of recent sub-period dynamics and absolute trade volumes.

During the 2022–2025 period, the countries recording the largest declines in salmon imports from Türkiye were Germany, Italy, the United Kingdom, the Turkish Republic of Northern Cyprus (TRNC), and Belgium, respectively. Among these countries, Italy exhibited a different pattern. Türkiye's salmon exports to Italy showed substantial declines across all three CAGR periods. However, the Damped Holt Method indicates a relatively stable future trend with a slight increase. Accordingly, exports are projected to increase from 1,220 kg in 2026 to 1,330 kg in 2028. Although these findings may initially

appear contradictory, an examination of Türkiye's salmon export data to Italy suggests that they are consistent. Italy imported 37,675 kg of salmon from Türkiye in 2022 and 40,271 kg in 2023. However, imports declined sharply to 524 kg in 2024. Despite this decline, a considerable recovery occurred in 2025, when imports increased to 1,163 kg. Thus, although the 2025 level remained substantially below that recorded in 2022, the recent recovery suggests an improvement in the Türkiye-Italy salmon trade, which is reflected in the slightly positive future projections.

Türkiye's January–August salmon export data for 2022–2025 were also analyzed for the 25 countries using the GM(1,1) forecasting method based on Grey System Theory. Country-specific projections were generated for 2026, 2027, and 2028. These projections are compared descriptively with the Damped Holt results and the CAGR patterns to identify directional agreement and disagreement across methods; such agreement is not treated as formal forecast validation.

Table 3. Compound annual growth rates (CAGR) of Türkiye's January–August Turkish salmon export volume

Country	2022-2025 CAGR (%)	2022 - 2024 CAGR (%)	2023 - 2025 CAGR (%)
Greece	752.46	146.80	-40.79
Kazakhstan	289.20	241.12	168.14
Singapore	138.51	152.43	-82.62
Qatar	133.31	70.41	-79.35
Lithuania	132.28	195.19	43.30
Poland	118.37	160.34	58.74
Georgia	97.25	42.16	311.94
Republic of Belarus	66.50	80.82	25.97
Iraq	50.70	133.96	-61.53
Russia	28.62	51.10	13.85
Spain	27.24	250.57	-87.27
United States	10.06	26.92	-17.29
Bulgaria	7.69	20.03	-36.75
Vietnam	7.15	-2.94	11.90
Japan	-0.31	-38.36	41.65
Canada	-11.46	-0.92	11.88
Romania	-16.84	-0.16	-21.29
China	-18.49	-84.23	48.93
Indonesia	-20.65	51.91	-30.13
Belgium	-44.29	-80.59	-53.54
Turkish Republic of Northern Cyprus	-45.79	-45.79	-45.79
United Kingdom	-68.60	-37.59	-81.87
Italy	-68.63	-88.23	-82.75
Germany	-88.70	-68.54	-98.90
Malaysia	Cannot be calculated (initial value = 0)	Cannot be calculated (initial value = 0)	-11.54

Formal comparative forecast accuracy is not inferred from in-sample GM(1,1) diagnostics. Aggregate MAPE and posterior error-ratio statistics are not used as validation evidence because country-level aggregation, weighting, and zero-handling procedures are not documented in sufficient detail. The GM(1,1) results are therefore interpreted as an alternative projection path and are evaluated descriptively through their directional agreement or disagreement with the other methods.

Table 4 is important because it presents market projections for 2026, 2027, and 2028. While the Damped Holt projection

for the United Kingdom reaches the zero lower bound by 2028, the GM(1,1) model produces a small but positive export projection for the same year. The GM(1,1) projections are broadly consistent with those obtained using the Damped Holt Method, although they present slightly more positive expectations. These differences primarily reflect the distinct model structures: the Damped Holt method explicitly attenuates the continuation of the estimated trend through the damping parameter (φ), whereas GM(1,1) derives its projections from the accumulated generating operation and the estimated grey differential equation.

Table 4. GM(1,1) Forecasts of Türkiye's January–August Turkish salmon export volume (kg), 2026–2028

Country	2026 (Forecast, kg)	2027 (Forecast, kg)	2028 (Forecast, kg)
Russia	38,718,984	43,344,020	48,521,650
Japan	4,218,406	4,513,700	4,829,600
Republic of Belarus	4,364,903	5,412,500	6,711,500
Poland	1,716,488	2,325,800	3,151,400
Vietnam	3,938,735	4,214,450	4,509,460
United States	612,492	598,600	585,000
Georgia	426,310	586,200	806,000
China	498,150	518,000	538,700
Lithuania	447,165	509,700	581,100
Kazakhstan	164,715	242,100	355,800
Germany	239,679	145,200	87,950
Greece	141,055	162,200	186,500
Malaysia	126,840	145,800	167,670
Canada	211,834	214,600	217,400
Indonesia	68,210	54,500	43,500
Bulgaria	26,418	24,300	22,350
Romania	31,420	24,800	19,600
Iraq	48,910	34,200	23,900
Singapore	5,980	3,880	2,520
Belgium	4,650	2,880	1,780
Turkish Republic of Northern Cyprus	8,150	5,300	3,450
Qatar	6,115	4,580	3,430
Italy	890	680	520
Spain	245	140	80
United Kingdom	210	70	25

Note. All values are forecasts of January–August export volume. GM(1,1) projections are interpreted as an alternative small-sample projection path and not as independently validated evidence of superior predictive performance.

However, some differences between the two methods are observed. While the Damped Holt Method produces positive trends for the United States, Italy, and Bulgaria, the GM(1,1) projections indicate negative trends for these countries. Conversely, the Damped Holt Method indicates negative trends for China and Canada, whereas the GM(1,1) model produces positive projections. These differences can be explained by the distinct ways in which the two methods process historical observations. Because the Damped Holt Method applies exponential smoothing to previous observations, the influence of earlier observations, such as those from the initial year of 2022, gradually diminishes. Consequently, a sharp fluctuation in the most recent year, 2025, may have a relatively strong influence on subsequent forecasts. In contrast, the GM(1,1) model first applies an accumulated generating operation to the observations over the study period, producing an accumulated series. As a result, a substantial change in the final year may exert less influence on future projections than under the Damped Holt approach.

In this respect, the GM(1,1) method provides an alternative projection by capturing the cumulative trend in the data. Furthermore, when the CAGR results for the 2023–2025 period are considered, the direction of the GM(1,1) projections for the United States, Italy, Bulgaria, China, and Canada is consistent with the corresponding CAGR trends. Thus, the results obtained from these two approaches provide a descriptive indication of directional consistency in recent export trends.

Formal comparative forecast-accuracy claims are not made. The dataset contains only four annual January–August observations per country, and a pseudo-out-of-sample exercise would require re-estimating each country-specific model using only the 2022–2024 observations and then evaluating a separate 2025 holdout forecast. Such re-estimated holdout outputs are not reported here. Accordingly, the previously presented overall sMAPE-based superiority statements and the Diebold–Mariano discussion have been removed. Differences among Holt, Damped Holt, CAGR, and GM(1,1) are interpreted as model-dependent projection uncertainty rather than as statistically validated differences in forecast performance. The AGO transformation in GM(1,1) can smooth a short sequence, but it does not remove the information limitation associated with $T = 4$.

The multi-method framework is therefore used to identify areas of directional agreement and disagreement across alternative projection structures. Agreement across methods is treated as supportive descriptive evidence, whereas divergence

is treated as an indication of model sensitivity and market uncertainty.

Discussion

The present study provides a country-specific assessment of the short-term trajectory of Türkiye's salmon exports by integrating Holt linear trend, Damped Holt, CAGR, and GM(1,1) approaches. Taken together, the results indicate that the future expansion of Turkish salmon exports is unlikely to be geographically uniform. Instead, the projections point to an increasingly differentiated market structure characterized by continued growth in Russia and several Eurasian markets, relatively strong prospects in selected Asian destinations, and pronounced contraction or uncertainty in several mature European markets. This pattern is consistent with the broader transformation of Turkish aquaculture from a production-oriented sector into an increasingly export-driven and internationally integrated industry. Erol & Eruz (2024) reported that Turkish salmon exports reached approximately 49,000 t and USD 363 million across 37 countries in 2022, representing more than a sevenfold increase in export revenue relative to 2019. More recently, Aydın et al. (2025) described Turkish aquaculture as a high-value export sector operating in more than 100 countries and emphasized the increasing importance of Turkish salmon within Türkiye's export portfolio. Thus, the growth identified by the present forecasts should not be interpreted as an isolated statistical tendency, but rather as the continuation, albeit with substantial destination-specific heterogeneity, of a broader structural expansion already documented in Turkish aquaculture.

A consistent finding across the projection approaches is the continuing predominance of Russia. Under the Damped Holt model, exports to Russia are projected to increase from approximately 35.3 million kg in 2026 to 38.1 million kg in 2028, whereas GM(1,1) generates a higher trajectory, reaching approximately 48.5 million kg by 2028. Although the magnitude differs between models, both methods agree on the direction of change, while the 2022–2025 CAGR remains positive at 28.62%. This directional agreement is consistent with the historical evolution of Turkish salmon trade. Erol & Eruz (2024) identified Russia as Türkiye's largest Turkish salmon market in 2022, accounting for approximately 28.5 thousand tonnes and USD 211 million in export revenue. Their data also showed that exports to Russia increased by 64% in volume between January–August 2022 and the corresponding period of 2023. More importantly, Knudsen (2025) provides a

structural explanation for this market position: following Russia's restrictions on Norwegian salmon after 2014, Turkish producers developed commercial relationships first with Russia and subsequently with Japan and Southeast Asian markets. Knudsen estimated that approximately 60% of Turkish salmon exports were destined for Russia in 2022.

The agreement between our projections and these independent historical observations strengthens the interpretation that Russia is likely to remain the principal destination for Turkish salmon in the short term. Nevertheless, the same evidence also reveals a strategic vulnerability. Knudsen (2025) noted that Türkiye's strong dependence on Russia became particularly visible during the disruption in Russian demand in 2023, when producers experienced difficulties marketing their output. Consequently, the high Russian forecasts in the present study should not be interpreted solely as evidence of market strength. They simultaneously indicate export concentration risk. The projected expansion therefore increases the economic importance of Russia while also strengthening the case for geographic diversification. This distinction is important because rapid growth in one dominant destination can improve short-term export earnings while increasing exposure to geopolitical, exchange-rate, regulatory, and demand shocks in that market.

The positive forecasts for Belarus, Georgia, Lithuania, and Kazakhstan reinforce the broader Eurasian orientation observed for Russia. Both Holt-based models identify these countries as expanding markets, and the GM(1,1) projections likewise indicate sustained growth, although the absolute scale remains substantially below that of Russia. Kazakhstan is particularly noteworthy because its 2022–2025 CAGR reaches 289.20%, while the 2023–2025 CAGR remains strongly positive at 168.14%; Georgia similarly exhibits a particularly high recent CAGR of 311.94% for 2023–2025. These results suggest that the significance of Eurasia extends beyond the Russian market itself. Such a pattern is compatible with the broader concept of increasing multipolarity in aquaculture value chains described by Bush et al. (2019), according to whom international aquaculture trade is becoming less adequately characterized by simple unidirectional producer–consumer structures and increasingly involves diverse and geographically dispersed production and consumption nodes. In the Turkish case, therefore, emerging Eurasian destinations could provide an important partial counterweight to excessive dependence on a single major buyer, although their current absolute volumes remain too small to substitute for Russia.

The Asian market results are more heterogeneous but strategically important. Japan remains one of the largest projected destinations, reaching approximately 3.61 million kg in 2028 under Damped Holt and 4.83 million kg under GM(1,1), while Vietnam is projected at approximately 3.67 and 4.51 million kg, respectively. This is consistent with earlier trade evidence. Erol & Erüz (2024) identified Vietnam and Japan among the leading Turkish salmon markets in 2022 and interpreted the expansion of these destinations as evidence of increasing market diversification toward Russia and the Far East. Knudsen (2025) similarly documented the development of commercial links from Russia toward Japan and Southeast Asian markets.

Japan deserves particular attention because the commercial suitability of salmon trout for this market has a well-established product-specific basis. Landazuri-Tveteraas et al. (2021) showed that salmon trout is strongly integrated into the broader Atlantic salmon market, but also documented historically important differences in consumer preferences. In particular, Japanese consumers have shown a stronger preference for redder-fleshed salmonids, and salmon trout historically benefited from this characteristic in the Japanese market. Their market integration analysis further showed that fresh and frozen salmon trout prices are closely integrated with Atlantic salmon prices, with Atlantic salmon acting as the price leader. Therefore, the positive Japanese projections observed here are economically plausible, but they should not be interpreted as implying that Turkish salmon is insulated from the global salmon market. On the contrary, the strong integration reported by Landazuri-Tveteraas et al. (2021) implies that Turkish salmon exporters operating in Japan are likely to remain exposed to broader Atlantic salmon price dynamics.

This interpretation also provides an important qualification to the concept of Turkish salmon as a completely differentiated product. Although branding and flesh colour may facilitate market access, Landazuri-Tveteraas et al. (2021) found no general evidence that salmon trout constitutes an economically separate market from Atlantic salmon; instead, the products behave largely as substitutes. Accordingly, future export growth will probably depend not only on expanding Turkish production but also on the ability of Turkish suppliers to compete within the wider global salmon market in terms of price, quality, logistics, product form, reliability of supply, and branding. This is consistent with Demir & Aksoy (2021), who found that Türkiye possesses a comparative advantage in

international trade in fresh and chilled fish but has historically been less competitive in several more processed fish categories.

One of the most striking findings of the present study is the sharp deterioration observed in several European markets, particularly Germany, the United Kingdom, Belgium, and Italy. Germany represents the clearest structural break. While Germany was among Türkiye's largest Turkish salmon destinations at the beginning of the study period, its 2022–2025 CAGR declined to –88.70%, and both Damped Holt and GM(1,1) project comparatively low export volumes by 2028. The United Kingdom likewise records a strongly negative 2022–2025 CAGR (–68.60%), while Belgium and Italy show declines of –44.29% and –68.63%, respectively. These trends contrast markedly with the continued growth projected for Russia and several Eurasian markets and therefore suggest that Turkish salmon is undergoing not simply an aggregate expansion, but a reallocation of export destinations. Poland, however, constitutes an important exception to the generally weaker outlook observed in several European destinations. All three forecasting models indicate a positive trajectory, while the positive CAGR values for both 2022–2025 and 2023–2025 suggest that this expansion is not solely driven by an early-period base effect.

The decline in European destinations should, however, not be attributed to a single factor such as geographical proximity to Norway without direct empirical testing. The literature instead suggests a more complex market structure. Straume et al. (2024), comparing France, Germany, Spain, and the United Kingdom, demonstrated substantial cross-country heterogeneity in salmon product forms, consumer markets, and price transmission. Highly processed products are particularly important in the United Kingdom, whereas the structure of consumption differs substantially in Germany and Spain. The authors further showed that product development can deepen mature markets and that more processed products may sustain demand by insulating retail prices from producer-level price volatility. These findings offer a plausible interpretation of our European results: access to mature salmon markets may depend increasingly on matching country-specific preferences and product formats rather than simply supplying additional fresh whole fish.

This issue is particularly relevant to Türkiye because Demir & Aksoy (2021) reported that Türkiye's competitive advantage has historically been strongest in fresh and chilled fish, whereas processed and higher-value products constitute a comparatively weaker segment of the export structure. They also emphasized that processing and product diversification

can generate important commercial advantages in international seafood markets. Therefore, the contraction projected for Germany and the United Kingdom does not necessarily imply an absence of demand for salmon in these countries. Rather, when considered alongside Straume et al. (2024), it suggests that Turkish exporters may face a market–product mismatch in some mature European destinations. This hypothesis cannot be demonstrated from the present volume data alone, but it provides a testable explanation and points toward product differentiation, processing, packaging, certification, and retailer-specific supply arrangements as relevant variables for future research.

The European results should also be interpreted in the context of sustainability and value-chain requirements. Bush (2018) showed that eco-certification within salmon value chains is closely associated with producer capability, production risk, and the organization of value-chain coordination. Knudsen (2025) similarly notes that Turkish salmon producers have historically been less engaged in international certification systems than the Turkish seabass and seabream industry, while recent efforts to obtain certification have partly been motivated by improved access to European markets. Thus, European market development may require more than price competitiveness; it may increasingly depend on alignment with buyer requirements, certification, traceability, processing specifications, and retail-chain governance. This interpretation is consistent with the broader transformation of Turkish marine aquaculture described by Ertör & Ortega-Cerdà (2019), who characterized the sector's expansion through simultaneous widening, deepening, and marketing strategies.

The divergent CAGR results further demonstrate why short-term market dynamics should not be evaluated from a single growth metric. Greece, for example, records an exceptionally high reported 2022–2025 CAGR of 752.46%, but this value is driven by the extremely low 2022 export base of 150 kg and is accompanied by a negative CAGR for 2023–2025. For this reason, Greece is discussed separately from the ranking of the other high-growth markets. Singapore and Qatar provide similar warnings about endpoint sensitivity: despite high 2022–2025 CAGRs, their 2023–2025 CAGRs are negative and the Damped Holt projections indicate contraction. These cases show that very large CAGR values can overstate the strategic importance of small or volatile markets when the initial trade volume is low. CAGR should therefore be interpreted together with absolute export quantities, recent sub-period dynamics, and model-based projections.

The comparison between Damped Holt and GM(1,1) adds another important dimension to the results. The two approaches agree on the broad direction of several major markets, most notably the expansion of Russia, Belarus, Georgia, Lithuania, Kazakhstan, Japan, and Vietnam and the contraction of several smaller markets, but they differ substantially in projected magnitudes and in the direction of selected markets such as the United States, Canada, China, Italy, and Bulgaria. This divergence should not be treated as a weakness; rather, it reflects the sensitivity of very short time series to model structure. The Damped Holt model attenuates the continuation of recent trends, whereas GM(1,1) transforms the original observations through an accumulated generating operation and therefore extracts a smoother underlying trajectory.

GM(1,1) was included because grey forecasting methods were developed for limited-information settings, and Wang et al. (2020) discuss applications with short samples. However, the same study emphasizes that prediction error is sensitive to sample length and to the dynamics of the underlying series. This qualification is central here because each country series contains only four annual observations and several markets show abrupt year-to-year changes. The AGO transformation can smooth the observed sequence, but it should not be interpreted as overcoming the information loss inherent in $T = 4$. Accordingly, the GM(1,1) outputs are treated as short-term, scenario-like projections of the continuation of observed trajectories rather than as deterministic forecasts. Agreement across methods strengthens descriptive confidence in the direction of a trend, whereas disagreement identifies markets for which model uncertainty is greatest.

Italy provides a useful example of this point. Despite a strongly negative 2022–2025 CAGR, the Damped Holt model projects a small increase from 1,220 kg in 2026 to 1,330 kg in 2028, whereas GM(1,1) projects continued decline. The underlying series shows a collapse from 40,271 kg in 2023 to 524 kg in 2024 followed by a partial recovery to 1,163 kg in 2025. Therefore, neither model should be interpreted as establishing the future direction with high confidence. Rather, their disagreement correctly signals a market in transition, where a single additional annual observation could materially alter the forecast. Similar caution applies to China and Canada, where Damped Holt and GM(1,1) imply opposite trend directions. For these cases, the directional correspondence between GM(1,1) and the most recent 2023–2025 CAGR provides useful supporting evidence, but not independent validation, because both are derived from the same underlying observations.

At the sectoral level, the projected ability of Türkiye to expand in multiple markets is consistent with the increasing production capacity and institutional maturation of Turkish aquaculture. Aydın et al. (2025) reported that Turkish finfish production expanded from approximately 61 thousand to more than 547 thousand tonnes over two decades, accompanied by USD 1.7 billion in exports, and attributed this development to technological progress, government support, and growing international demand. Similarly, Knudsen (2025) describes the contemporary Turkish salmon industry as increasingly vertically integrated and largely based on domestic capital, processing capacity, logistics, hatcheries, freshwater and marine production systems, and marketing activities. These structural developments provide a supply-side foundation for the positive projections generated in the present analysis.

However, production growth alone should not be equated with sustainable export growth. Demir & Aksoy (2021) explicitly concluded that high production volume is not sufficient to establish a strong position in international aquaculture trade. At the global level, Pandey et al. (2023) similarly showed that competitiveness in salmon aquaculture is increasingly linked to firm scale, technology adoption, logistics, and the capacity to manage customer-specific relationships rather than merely increasing biological output. Therefore, the strategic implication of our forecasts is not simply that Türkiye should produce more salmon. Rather, future export performance will depend on whether expanding production is accompanied by market diversification, processing and product development, stable logistics, certification, branding, buyer-specific supply-chain integration, and risk management.

The results point toward a transition from export expansion to export portfolio management in the Turkish salmon industry. The first phase of sectoral development was characterized by rapid production growth and successful penetration of a limited number of high-volume markets, particularly Russia. The next phase appears likely to require a more differentiated strategy. Russia remains indispensable but creates concentration risk; Belarus, Kazakhstan, Georgia, and Lithuania represent emerging diversification opportunities; Japan and Vietnam provide large Asian outlets with established or growing market compatibility; whereas Germany, the United Kingdom, Belgium, and other European markets may require a fundamentally different product and value-chain strategy. This interpretation is consistent with the wider literature showing that successful aquaculture value chains increasingly depend on multi-market integration, technological and institutional innovation, product differentiation, and the ability to respond

to heterogeneous consumer and buyer requirements (Bush et al., 2019; Straume et al., 2024; Aydın et al., 2025).

Finally, these findings should be interpreted within the limitations imposed by the short observation window. All forecasts are based on four annual January–August observations and therefore do not represent full-calendar-year export forecasts. The models cannot identify longer-term business cycles, structural breaks, trade-policy shocks, exchange-rate changes, supply constraints, or international salmon-price movements unless such effects are already embedded in the observed series. The exceptionally large CAGR values in initially small markets and the disagreement between Damped Holt and GM(1,1) for some destinations illustrate this sensitivity. Wang et al. (2020) supports the use of grey forecasting in small-sample settings while also showing that sample length and data dynamics materially affect forecast performance. Therefore, the strongest conclusions of this study concern the direction and relative strength of emerging country-specific January–August export trajectories rather than the exact kilogram values projected for 2026–2028. Future work should update the models as additional observations become available and conduct explicit out-of-sample validation.

Conclusion

This study provides a country-specific assessment of the short-term prospects of Türkiye's January–August Turkish salmon exports by combining Holt's Linear Trend, Damped Holt, CAGR, and GM(1,1) approaches. The findings indicate that projected export trajectories are geographically heterogeneous rather than uniform across destination markets. Russia remains the dominant projected destination, while Belarus, Georgia, Lithuania, and Kazakhstan emerge as important growth-oriented markets. Japan and Vietnam also remain significant, whereas declining or uncertain trajectories in several European markets indicate the need for market-specific strategies.

The comparison of alternative projection approaches also demonstrates the uncertainty created by very short and volatile trade series. The methods frequently agree on the direction of major market trajectories but differ in magnitude and, for some countries, direction. These differences are interpreted as model

sensitivity rather than as evidence of statistically validated superiority of one method over another. The findings suggest that the next stage of Türkiye's salmon export development should focus not only on increasing export volumes but also on market diversification, reduced dependence on dominant destinations, value-added product strategies, and competitiveness in mature markets. As additional annual observations become available, the models should be updated and evaluated using explicit out-of-sample forecast validation.

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Compliance With Ethical Standards

Authors' Contributions

GG: Conceptualization, Data analysis, Data curation

MYÇ: Investigation, Data curation, Writing – Original draft, Writing – Review & editing

AYS: Investigation, Methodology, Formal analysis, Writing – Review & editing

All authors read and approved the final manuscript.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethical Approval

For this type of study, formal consent is not required.

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Data Availability

The datasets analysed during the current study are available from the corresponding author on reasonable request.

AI Disclosure

AI-assisted technology was not used in the preparation of this work, except for grammar and spelling checks.

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