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ASSESSING THE INTERPLAY BETWEEN TROPHIC INDEX (TRIX) AND ENVIRONMENTAL HEALTH FROM AN AQUACULTURE PERSPECTIVE

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Abstract
The Trophic Index (TRIX) serves as a comprehensive metric for evaluating eutrophication in aquatic ecosystems by integrating key water quality parameters, including chlorophyll-a, dissolved inorganic nitrogen, total phosphorus, and oxygen saturation deviation. Elevated TRIX values typically signal increased nutrient loading, often linked to anthropogenic activities such as agricultural runoff, wastewater discharge, and aquaculture effluents. This study investigates the interplay between TRIX values, water quality, and the environmental health of aquaculture sites along the Turkish coasts. Through multi-year TRIX monitoring at two designated aquaculture zones in the Aegean and Mediterranean Seas, findings reveal that TRIX values remained below the critical threshold for eutrophication risk, indicating stable environmental conditions. The study underscores the necessity of continuous TRIX-based monitoring to assess trophic dynamics, ensure sustainable aquaculture practices, and mitigate ecological risks. The results contribute to the broader discourse on balancing aquaculture productivity with marine ecosystem health through informed nutrient management strategies.
Key words: TRIX index, eutrophication, cage culture, water quality, nutrient management, fish health

Introduction

Eutrophication, characterized by the excessive enrichment of water bodies with nutrients, poses significant challenges to aquatic ecosystems, leading to algal blooms, hypoxia, and declines in biodiversity (Bricker et al., 2008; Ferreira et al., 2011). Increased nutrient loads, primarily from anthropogenic sources such as agricultural runoff, wastewater discharge, and aquaculture effluents, contribute to this process, disrupting ecological balance and reducing water quality (Pérez-Ruzafa et al., 2019). Changes in water quality parameters can affect physiological and metabolic activities in fish, as well as stress-related behaviors such as swimming, schooling, and feeding, which in turn may influence fish health and welfare, and reflect weak performance and success rate in fish farming activities (Zhang et al., 2025). The Trophic Index (TRIX) serves as a crucial tool for assessing the trophic status of coastal waters by integrating multiple water quality parameters, including chlorophyll-a concentration, dissolved inorganic nitrogen (DIN), total phosphorus (TP), and dissolved oxygen saturation deviation (Vollenweider et al., 1998; Pettine et al., 2007). Originally developed for the Adriatic and Tyrrhenian Seas, TRIX has since been widely applied across various European marine environments, such as the Baltic, North, and Mediterranean Seas to evaluate eutrophication trends and environmental health (Giovanardi and Vollenweider, 2004; Salas et al., 2008; Buyukates et al., 2024).

Turkish aquaculture industry has expanded rapidly over the past few decades, positioning the country among the world's leading producers of farmed fish species, including European seabass (*Dicentrarchus labrax*), Gilthead seabream (*Sparus aurata*), and Rainbow trout (*Oncorhynchus mykiss*), that is offered as "Turkish salmon" to export and local market at weight over 2.5 kg (Yigit et al., 2024). In 2022, total aquaculture production in Türkiye reached approximately 514,805 tonnes, with marine species comprising a significant portion of this output (EUROFISH, 2024). The expansion of marine aquaculture, particularly cage farming along the Aegean and Mediterranean coasts, has contributed to economic growth but also raised concerns about its potential environmental impacts, particularly regarding nutrient loading and eutrophication (Yücel-Gier et al., 2010; Tuğrul et al., 2019).

Monitoring tools like TRIX are essential for assessing the nutrient dynamics and trophic conditions of aquaculture sites, allowing for informed management strategies to mitigate eutrophication risks. Previous studies have highlighted the applicability of TRIX for evaluating trophic status in both high-nutrient (eutrophic) and low-nutrient (oligotrophic) environments, demonstrating its versatility as a water quality assessment metric (Primpas and Karydis, 2011). However, while TRIX was originally designed for eutrophic systems, its use in oligotrophic and mesotrophic regions, such as parts of the Eastern Mediterranean, necessitates careful interpretation and potential regional adjustments (Pettine et al., 2007; Primpas and Karydis, 2011).

This study aims to evaluate the relationship between TRIX values, and environmental health, that is closely linked to the health and welfare conditions of farmed fish. By analyzing TRIX data from multiple locations in selected aquaculture zone in Türkiye, this research seeks to quantify the extent to which nutrient loading from aquaculture influences eutrophication and to propose sustainable management strategies that balance healthy aquaculture productivity with environmental conservation. The findings of this study will contribute to the broader discussion on sustainable marine aquaculture by providing insights into how nutrient management, water quality monitoring, and regulatory policies can help mitigate the ecological impacts of intensive fish farming.

Material and Method

The Trophic Index (TRIX) methodology calculates the trophic status of aquatic systems through a formula that considers chlorophyll-a concentration and total phosphorus levels, along with empirically derived coefficients. In this study, the formula specified in the 'Environmental Management Regulation for Fish Farms Operating in Marine Waters,' published by the Ministry of Environment, Urbanization, and Climate Change in the Official Gazette dated October 28, 2020, and numbered 31288 (MEU, 2020) has been used in the calculation of the TRIX Index.

$$\text{TRIX Index} = (\text{Log } 10\ (\text{Chl-a} \times \text{DO\%sat} \times \text{DIN} \times \text{TP}) + 1.5) \times 0.833$$

where:

Chl-a = Chlorophyll-a concentration (µg/L) → proxy for phytoplankton biomass
DIN = Dissolved Inorganic Nitrogen (µg/L) → sum of nitrate, nitrite, and ammonium
TP = Total Phosphorus (µg/L) → primarily phosphate
DO%sat = Dissolved Oxygen saturation (%) |DO% – 100|→ indicator of oxygen availability

TRIX values help classify water bodies as oligotrophic (low nutrient levels), mesotrophic (moderate nutrient levels), or eutrophic (high nutrient levels) (Table 1). TRIX provides insight into the nutrient dynamics and potential for eutrophication in the studied area.

Table 1. TRIX Index and Eutrophication Status

TRIX Index (TI)	Eutrophication Status	Explanation
< 4*	No Eutrophication Risk	Aquaculture is permitted
4 - 5*	Low Eutrophication Risk	Aquaculture is allowed for existing facilities; no new facilities
5 - 6*	Eutrophication Risk Present	No new aquaculture facilities; restrictions on existing facilities
> 6*	High Eutrophication Risk	No aquaculture permitted; existing facilities must cease operations

*For the Black Sea, +1 is applied to the index value.

Study Area

Aquaculture along Türkiye's Aegean Sea and Mediterranean coasts have experienced significant growth, contributing to the country's position as a leading producer of farmed fish. The favorable environmental conditions, such as its relatively calm waters and suitable temperatures, have made it a prime location for the aquaculture industry. Additionally Cage aquaculture in the has expanded significantly over the past few decades, driven by increasing global demand for seafood and the region's strategic location near major European markets. Therefore, we have chosen two locations, one in the Aegean Sea (Dikili-North) and another one in the Mediterranean (Sagun-Antalya) for implementing regular TRIX monitoring which can provide valuable insights into the trophic status of coastal waters, enabling stakeholders to make informed decisions and implement effective management strategies.

Designated aquaculture zone location maps of Dikili-North and Sagun-Antalya TRIX Sites are shown in Figures 1 and 2, respectively. Coordinates for the designated aquaculture zones of Dikili-North, and Sagun-Antalya have been given in Tables 2 and 3, respectively. Sampling points for both TRIX sites of Dikili-North, and Sagun-Antalya are illustrated in Figure 3.

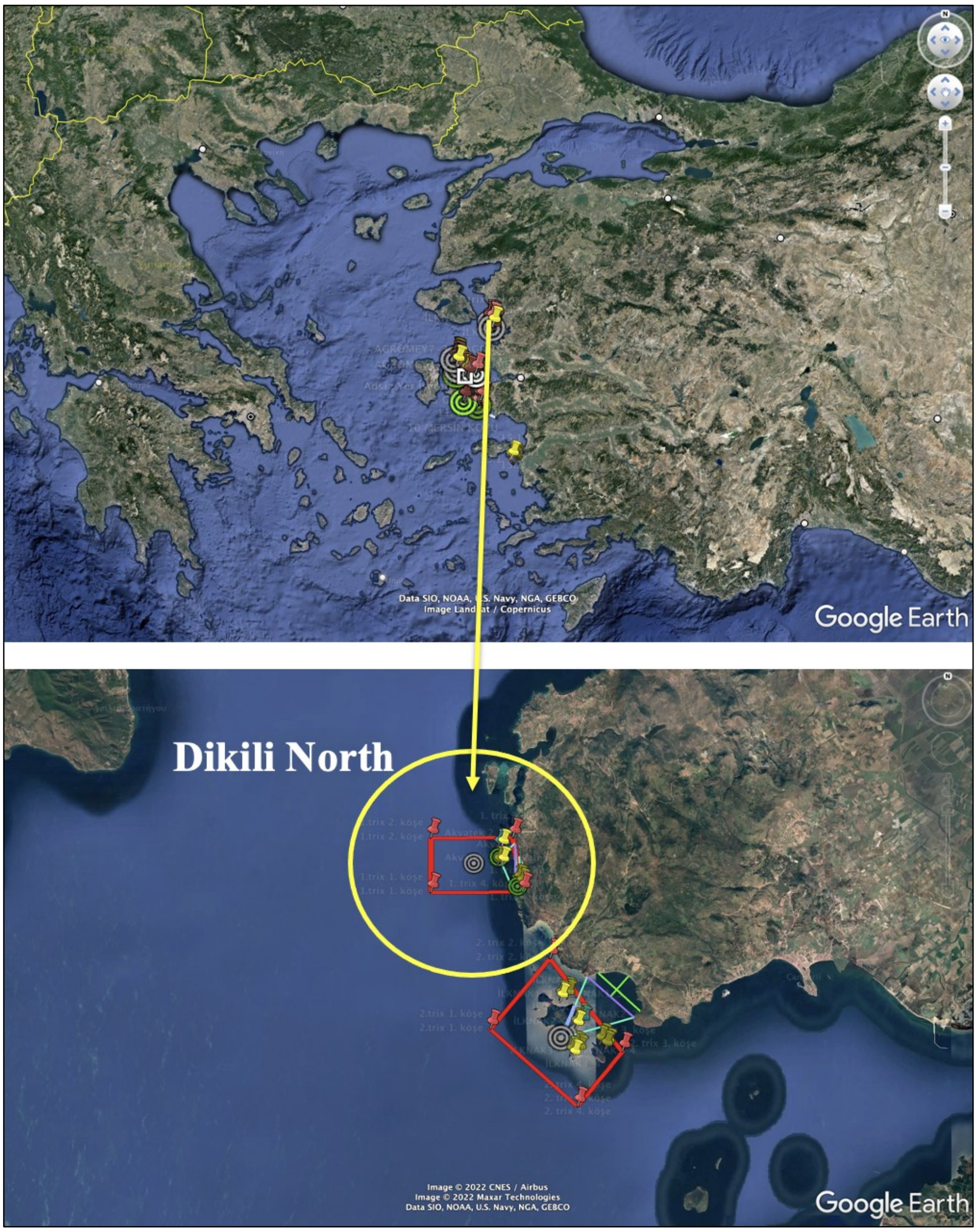

Figure 1. Aquaculture zone location map of Dikili-North TRIX Site (GE, WGS-84)

Table 2. Geographical Coordinates for Dikili-North TRIX Site

Points	Geographical Coordinates (degree-minutes-seconds) DATUM: WGS-84	
	Longitute	Latitute
1	26°45'24"E	38°59,5'39"N
2	26°47,27'54"E	38°59,5'83"N
3	26°45,24'34"E	38°57'55,03"N
4	26°47,28'42"E	38°57'52.71"N
AREA	17.380.000 m^2 (1738 hectar)	

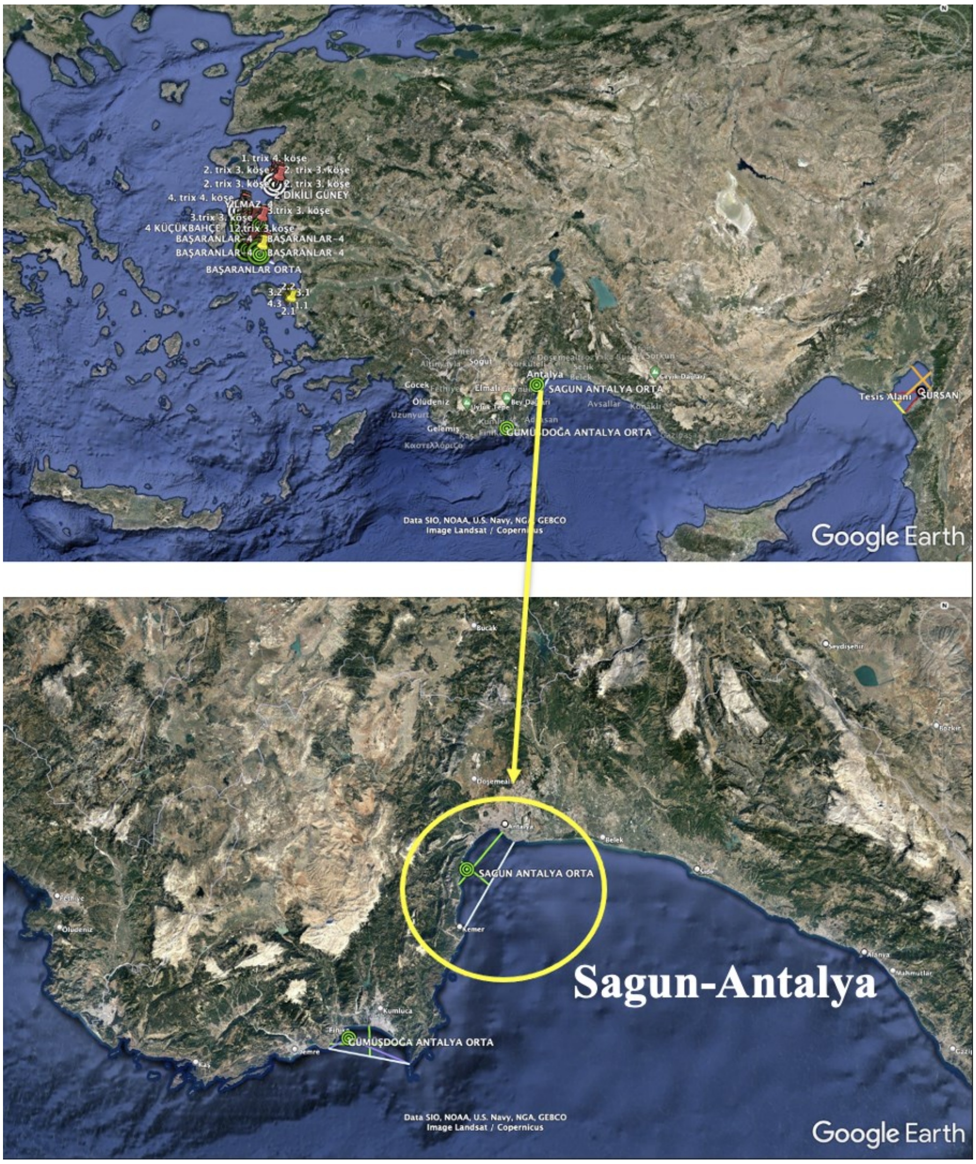

Figure 2. Aquaculture zone location map of Sagun-Antalya TRIX Site (GE, WGS-84)

Table 3. Geographical Coordinates for Sagun-Antalya TRIX Site

Points	**Geographical Coordinates (degree-minutes-seconds) DATUM: WGS-84**	
	Longitute	**Latitute**
1	30°35'26.91"E	36°46'0.96"N
2	30°35'39.01"E	36°46'0.98"N
3	30°35'39.01"E	36°45'48.00"N
4	30°35'26.91"E	36°45'48.02"N
AREA	120.000 m^2 (12 hectar)	

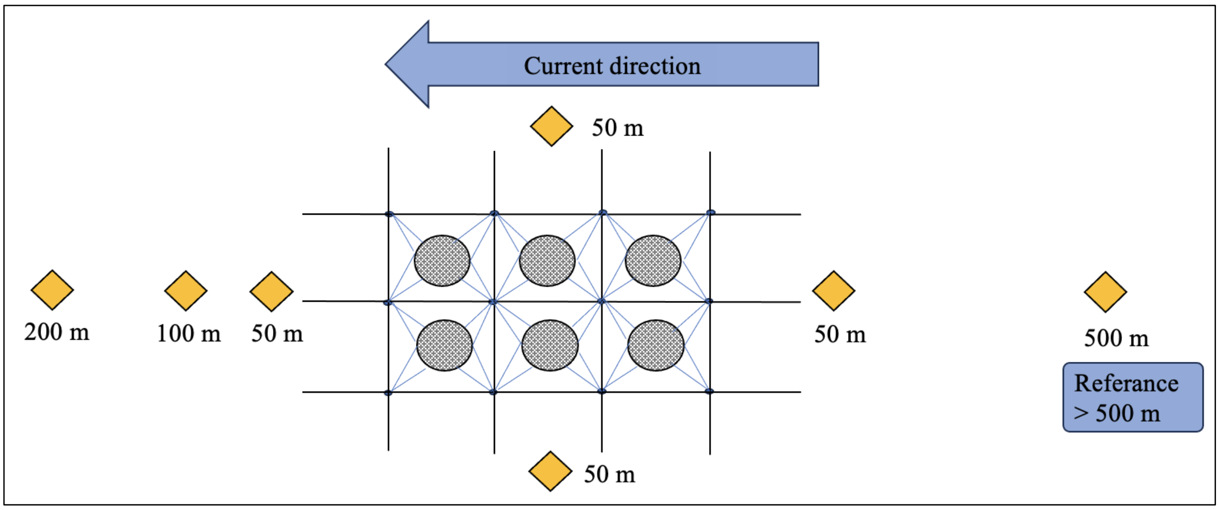

Figure 3. Illustrated sampling stations for both TRIX sites of Dikili-North, and Sagun-Antalya.

Dikili-North aquaculture zone with a total surface area of 1738 hectars, encompasses two aquaculture project areas one of which is Akvatek Facility, located 650 meters from the shore at a depth of 50 meters, and water currents flowing from north to south at a speed of 0.12 m/s. Ergin Ersin Facility is positioned 150 meters offshore at a depth of 42 meters, also with a north-to-south current direction of 0.12 m/s speed.

The Sagun-Antalya TRIX Site includes one aquaculture facility, which is located 1800 meters from the shore at a depth between 55 and 60 meters with water currents from north to south direction at a speed of 0.15 m/s. Surface water samples were collected from a depth of 1 meter at all stations. For bottom water samples, depths varied by location. In Dikili-North, samples were taken from 41 meters at S1-N1 100 and S1-N1 200, 59 meters at S1-N2, 53 meters at S1-N3 100, 52 meters at S1-N1 200, and 44 meters at S1-Ref. In Sagun-Antalya, bottom samples were collected from 47 meters at S-1, 48 meters at S-2, S-4, and S-Ref, 49 meters at S-3, and 48 meters at S-5 (100), while S-6 (200) was sampled at 47 meters.

The analyses were carried out by authorized sampling personnel from Çevtest Ölçüm Laboratuvarı Tic. Ltd. Şti., which is accredited by the Turkish Accreditation Agency (TÜRKAK) and authorized by the Ministry of Environment, Urbanization, and Climate Change's General Directorate of EIA, Permits, and Inspections (MEU, 2020).

In the TRIX Sites, surface water and bottom water measurements taken from the water column were evaluated to determine the trophic status. The TRIX index was calculated using measurements of chlorophyll-a, dissolved oxygen saturation (%), total dissolved inorganic nitrogen (DIN), and total phosphorus (TP). Then, the TRIX index values calculated in 2021, 2022, 2023 and 2024 were evaluated in both TRIX Sites.

The results of the studies conducted at the sampling stations and depths of the TRIX sites Dikili-North and Sagun-Antalya were evaluated and presented in the figures below. It was determined that the TRIX Index measurements for May 2021 and May 2024 did not exceed 4, in accordance with the Circular on Environmental Management of Fish Farms Operating in Seas (MEU, 2020) in both TRIX Project areas (Figure 4 and Figure 5).

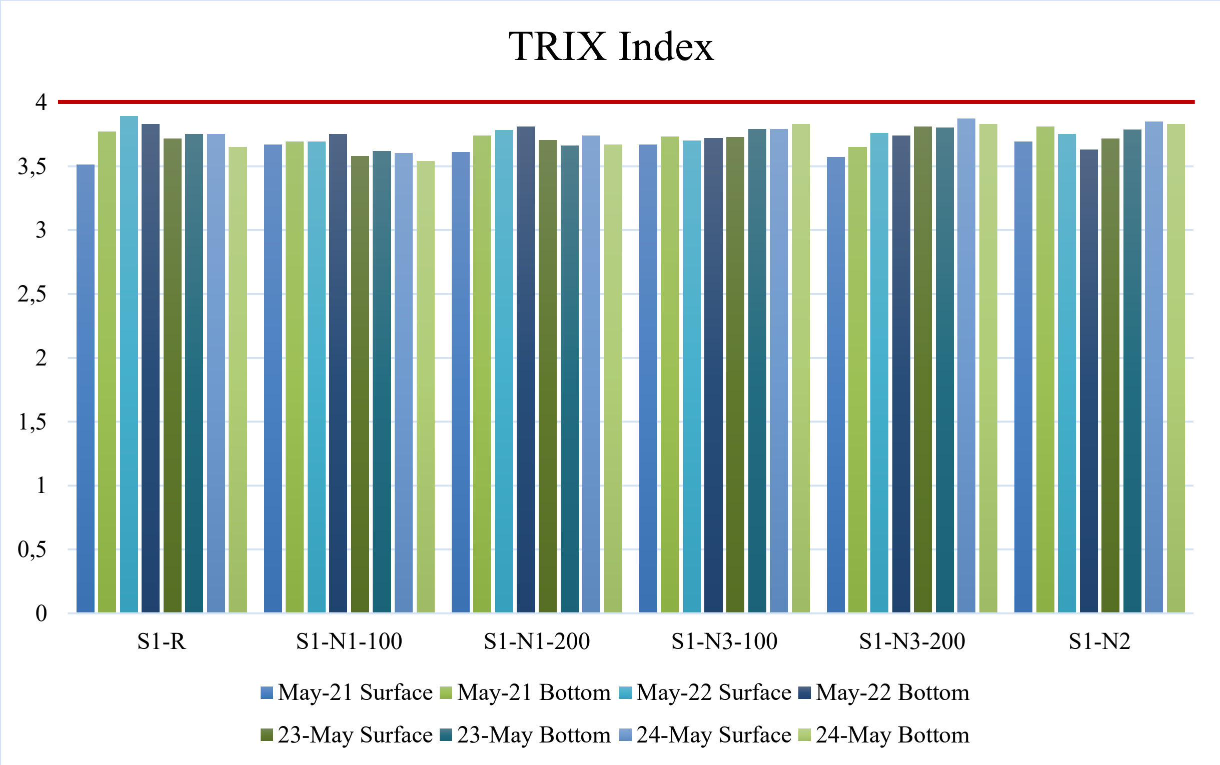

Figure 4. Comparative Evaluation of TRIX Index at Dikili-North TRIX Site Sampling Stations (May 2021 – May 2024).

The TRIX Index across all stations at Dikili-North TRIX site remains close to the threshold value of 4 (marked by the red line), which represents the boundary between "No Eutrophication Risk" and "Low Eutrophication Risk." No significant spikes above the threshold are observed, indicating stable conditions without high eutrophication risks during the observed years (2021-2024).

TRIX values for surface waters are generally marginally higher than bottom waters across most stations and years, which is expected as surface waters tend to accumulate more nutrients from external sources such as feed, waste, and atmospheric deposition.

The difference between surface and bottom layers remains consistent, indicating stable stratification and nutrient distribution within the water column. The reference station (S1-R) serves as a baseline and exhibits similar TRIX values to other stations, indicating that the overall water quality and nutrient levels are consistent across the study area. However, S1-R shows slightly elevated TRIX values in 2021 and 2024 compared to some other stations, suggesting possible external nutrient inputs near the reference point.

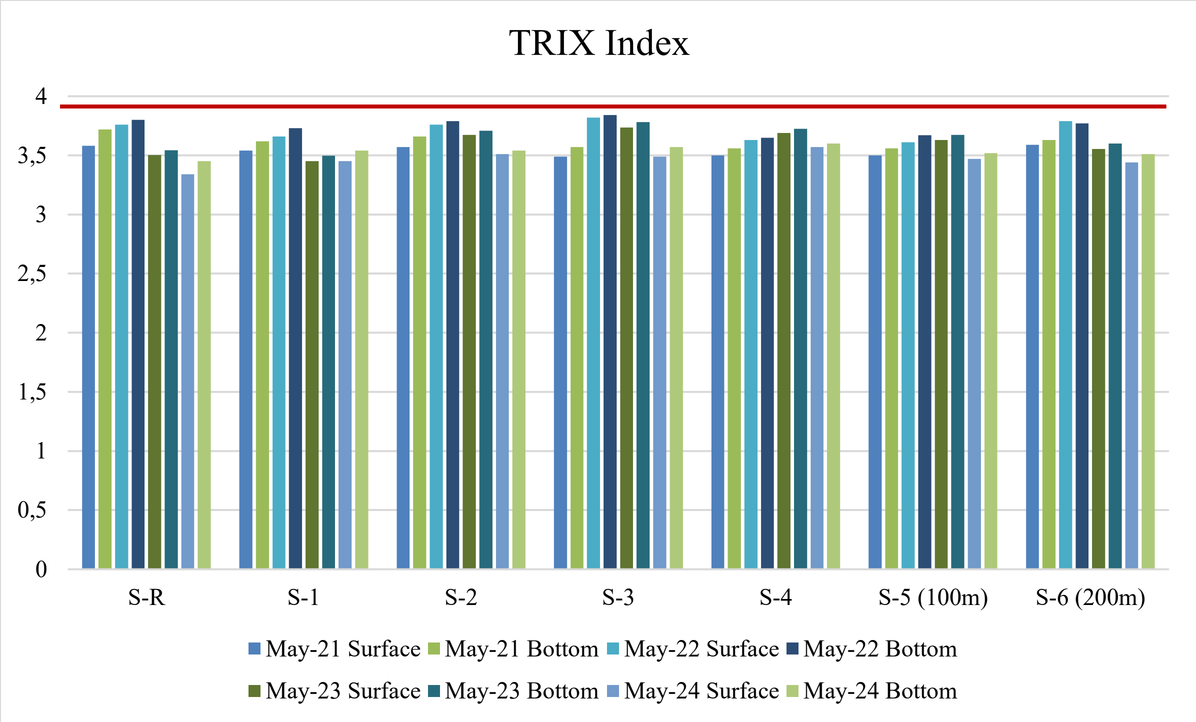

Figure 5. Comparative Evaluation of TRIX Index at Sagun-Antalya TRIX Site Sampling Stations (May 2021 – May 2024).

Considering the Sagun-Antalya aquaculture zone, comprising a total surface area of 12 hectars, the TRIX index remained consistently below the threshold value of 4 across all stations and years, indicating that the eutrophication risk is low in this area. The values are relatively stable, with no significant spikes or drops, suggesting a well-maintained aquatic environment over the study period from May 2021 to May 2024. TRIX values exhibit minor fluctuations over the years, but overall, they remain within a narrow range.

May 2024 values appear slightly higher than previous years at some stations, particularly in S-3 and S-6, suggesting a slight increase in nutrient levels or biological activity over time. May 2021 TRIX values tend to be slightly lower than those of 2023 and 2024, which could indicate gradual nutrient accumulation over the years.

The surface water TRIX values are slightly higher than bottom water values at most stations, which is expected as nutrient accumulation and algal activity tend to be more pronounced near the surface. The difference between surface and bottom TRIX values remains relatively small, indicating a well-mixed water column with no strong stratification effects.

The reference station (S-R) shows similar TRIX values to most other stations, meaning the overall eutrophication risk is evenly distributed across the monitored area. The slightly higher values at S-3 and S-6 compared to S-R suggest localized variations in nutrient input, possibly influenced by aquaculture activities or water circulation patterns.

Discussion

Developed for the Italian coastal waters, TRIX has been widely applied in various European seas, including the Adriatic, Tyrrhenian, Baltic, Black, and North Seas, to monitor eutrophication levels (Giovanardi and Vollenweider, 2004). Considering the present study the consistent TRIX values below 4 at both sites align with findings from other Mediterranean regions. Several studies have examined the trophic conditions of coastal waters and aquaculture zones in Türkiye, providing valuable context for understanding long-term changes. For instance, Yücel-Gier et al. (2010) assessed TRIX values in the Izmir Bay, reporting mean values of 3.6 in aquaculture areas and 2.5 in non-aquaculture zones, indicating no eutrophication risk. Similarly, Tuğrul et al. (2019) evaluated northeastern Mediterranean coastal waters and highlighted the importance of eutrophication classification tools for regulatory frameworks.

However, there remains a deficiency in systematically tracking TRIX evolution from the beginning of aquaculture activities to the present. While our study provides a multi-year assessment, a broader historical perspective would help contextualize current conditions. Future research should focus on long-term TRIX trends, particularly in high-production aquaculture zones like the Aegean and Mediterranean coasts, where nutrient loading varies due to fish farm expansion (EUROFISH, 2024). Moreover, an evaluation of different aquaculture systems (e.g., open-net cages, recirculating systems) would offer insights into how farming practices influence eutrophication risks (Troell et al., 2009).

The number of studies addressing TRIX in Turkish waters is limited compared to European counterparts. Giovanardi and Vollenweider (2004) demonstrated the applicability of TRIX in the Adriatic and Tyrrhenian Seas, while Salas et al. (2008) assessed its use in transitional ecosystems. In Türkiye, Yigit et al. (2024) recently explored TRIX applications in salmon aquaculture, emphasizing the need for refined nutrient management. These findings suggest that incorporating TRIX-based monitoring into national aquaculture regulations (MEU, 2020) could enhance environmental sustainability efforts.

TRIX and Environmental Health

Eutrophication and water quality are closely linked, as high TRIX values indicate nutrient over-enrichment, leading to excessive algal growth and ecological imbalances. Algal blooms result in oxygen depletion, which negatively impacts biodiversity and can cause habitat loss (Bricker et al., 2008). The decomposition of these algal blooms depletes oxygen, potentially leading to hypoxic or anoxic conditions, which have been associated with mass fish mortality events in coastal regions (Piedrahita, 2003). Additionally, elevated chlorophyll-a concentrations are often indicative of harmful algal blooms (HABs), which produce toxins that can be detrimental to marine life and pose risks to human health (Ferreira et al., 2011).

Nutrient imbalances further contribute to shifts in species composition, often favoring opportunistic species over ecologically important ones, thereby reducing biodiversity and altering trophic interactions (Naylor et al., 2000).

TRIX and Cultured Fish Welfare

High TRIX values not only signal poor water quality but also present serious challenges for aquaculture facilities. Deteriorating water conditions stress farmed fish, leading to reduced growth rates, weakened immunity, and an overall decline in health conditions (Primpas and Karydis, 2011). Hypoxia, often linked to fluctuating dissolved oxygen saturation, increases the likelihood of fish mortality, particularly in high-density aquaculture systems (Troell et al., 2009). It has been reported that unfavorable conditions in water quality significantly affect fish behavior and fish exhibits various complex adaptation responses to combat for survival (Wong and Candolin, 2015; Menon et al., 2023). Fluctuations in water temperature, may cause in irregulated behavioral changes in schooling due to search of preferred temperature levels, thus uncomfort individuals due to loss of their safety areas of schools (Cooper et al., 2018). Further, osmoregulation imbalance may occur in cases of unfavourable water quality (Kültz, 2015; Leduc et al., 2010), and stress to which fish are exposed may lead to irregular feed intake, loss of appetite and irregular and agitated swimming behaviour (Becker et al., 2016; Wing et al., 2021). These kind of stressors driven by undesirable water quality conditions may also cause reduced fish welfare and health status of fish under farm conditions.

Due, monitoring of environmental conditions through TRIX index analyses are encouraged to be coupled by monitoring fish behavior, that may help to optimize water and resource utilization for best aquaculture practice and farm management (Martins et al., 2012; Browning, 2023). Furthermore, algal blooms can inflict gill damage, diminish oxygen availability, and introduce harmful toxins, further compromising fish welfare (Piedrahita, 2003).

Nutrient-rich environments with low oxygen availability also foster pathogen growth, elevating the risk of disease outbreaks in aquaculture settings (Pettine et al., 2007). Fish raised in eutrophic conditions are more prone to infections, which often necessitate increased antibiotic use. This, in turn, raises concerns about antimicrobial resistance and long-term sustainability in aquaculture operations (Naylor et al., 2000).

Mitigating the negative impacts of high TRIX values on aquaculture requires an integrated approach. Improved feeding practices and optimized nutrient management strategies can help reduce nutrient waste and minimize eutrophication risks (Piedrahita, 2003). Maintaining adequate oxygen levels through water exchange and aeration is essential for preventing hypoxic conditions and sustaining fish health (Ferreira et al., 2011). Integrated Multi-Trophic Aquaculture (IMTA) systems, which incorporate species such as filter-feeding mussels and macroalgae, can help absorb excess nutrients and improve overall water quality (Troell et al., 2009). Regular monitoring of TRIX values is also critical in ensuring the suitability of aquaculture sites and implementing proactive environmental management strategies (Primpas and Karydis, 2011).

Conclusion

The TRIX index serves as a crucial tool for assessing trophic status and eutrophication risks in marine and coastal waters. High TRIX values are linked to deteriorating water quality, behavioral disorders in fish and increased disease susceptibility in aquaculture facilities, and broader ecological imbalances, making proactive management strategies essential. Sustainable aquaculture practices, such as nutrient management, aeration, and integrated multi-trophic systems, play a vital role in mitigating eutrophication and maintaining aquaculture productivity. Comprehensive and regular TRIX monitoring is crucial to ensure environmental sustainability and optimize aquaculture practices in nutrient-sensitive marine ecosystems.

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References

Becker, L. J. S., Brooks, E. M., & Gabor, C. R. (2016). Effects of turbidity on foraging behavior in the endangered Fountain Darter (*Etheostoma fonticola*). *American Midland Naturalist, 175*, 55–63. https://doi.org/10.1674/amid-175-01-55-63.1.

Bricker, S.B., Longstaff, B., Dennison, W., Jones, A., Boicourt, K., Wicks, C., & Woerner, J. (2008). Effects of Nutrient Enrichment in the Nation's Estuaries: A Decade of Change. *Harmful Algae, 8*(1), 21-32.

Browning, H. (2023). Improving welfare assessment in aquaculture. *Frontiers in Veterinary Science, 10*, 1060720, https://doi.org/10.3389/fvets.2023.1060720.

Buyukates, Y ., Ergün, S., & Yigit, M. (2024). Sustainable surge in Turkish salmon culture: Prioritizing environmental responsibility. *Aquatic Animal Reports, 2*(2), 20-30. https://doi.org/10.5281/zenodo.13494124.

Cooper, B., Adriaenssens, B., & Killen, S. S. (2018). Individual variation in the compromise between social group membership and exposure to preferred temperatures. *Proceedings of the Royal Society B: Biological Sciences, 285*(1880), 20180884. https://doi.org/10.1098/rspb.2018.0884.

EUROFISH. (2024). The Turkish aquaculture sector has seen impressive growth in production and exports (future demand will be met from fish farming). Eurofish Magazine, February 2024 / 1 (14 February 2024). pp 42-44. https://eurofish.dk/magazine-issues/em-1-2024/

Ferreira, J.G., Andersen, J.H., Borja, A., Bricker, S. B., Camp, J., da Silva, M. C., Garces, E., Heiskanen, A.S., Humborg, C., Ignatiades, L., Lanelot, C., Menesguen, A., Tett, P., & Hoepffner, N. (2011). Overview of Eutrophication Indicators to Assess Environmental Status within the European Marine Strategy Framework Directive. *Estuarine, Coastaland Shelf Science, 93*(2), 117-131.

Giovanardi, F., Vollenweider, R. A. (2004). Trophic conditions of marine coastal waters: Experience in applying the Trophic Index TRIX to two areas of the Adriatic and Tyrrhenian seas. *Journal of Limnology, 63*(2), 199-218.

Kültz, D. (2015). Physiological mechanisms used by fish to cope with salinity stress, *Journal of Experimental Biology, 218*, 1907–1914. https://doi.org/10.1242/jeb.118695.

Leduc, A. O. H. C., Roh, E., Macnaughton, C. J., Benz, F., Rosenfeld, J., & Brown, G. E. (2010). Ambient pH and the response to chemical alarm cues in juvenile Atlantic salmon: Mechanisms of reduced behavioral responses. *Transactions of the American Fisheries Society, 139*, 117–128. https://doi.org/10.1577/T09-024.1.

Martins, C. I. M., Galhardo, L., Noble, C., Damsgard, B., Spedicato, M. T., Zupa, W., Beauchaud, M., Kulczykowska, E., Massabuau, J. C., Carter, T., Planellas, S. R., & Kristiansen, T. (2012). Behavioural indicators of welfare in farmed fish. *Fish Physiology and Biochemistry 38*, 17–41. https://doi.org/10.1007/s10695-011-9518-8.

Menon, S. V., Kumar, A., Middha, S. K., Paital, B., Mathur, S., Johnson, R., Kademan, A., Usha, T., Hemavathi, K. N., Dayal, S., Ramalingam, N., Subaramaniyam, U., Sahoo, D.K., & Asthana, M. (2023), Water physicochemical factors and oxidative stress physiology in Fish, a review. *Frontiers in Environmental Science, 11*, 1240813. https://10.3389/fenvs.2023.1240813.

MEU. (2020). Ministry of Environment, Urbanization and Climate Change. Circular on Environmental Management of Fish Farms Operating in Seas. https://www.resmigazete.gov.tr/eskiler/2020/10/20201028-1.htm

Naylor, R.L., Goldburg, R.J., Primavera, J.H., Kautsky, N., Beveridge, M. C., Clay, J., Folke, C., Lubchenco, J., Mooney, H., & Troell, M. (2000). Effect of Aquaculture on World Fish Supplies. *Nature, 405*, 1017-1024. https://doi.org/10.1038/35016500.

Pérez-Ruzafa, Á., Campillo, S., Fernández-Palacios, J. M., García-Lacunza, A. (2019). Long-term dynamic in nutrients, chlorophyll a, and water quality parameters in a coastal lagoon during a process of eutrophication for decades, a sudden break and posterior hypertrophic conditions. *Frontiers in Marine Science, 6*, 26.

Pettine, M., Casentini, B., Fazi, S., Giovanardi, F., Pagnotta, R. (2007). A revisitation of TRIX for trophic status assessment in the light of the European Water Framework Directive: Application to Italian coastal waters. *Marine Pollution Bulletin, 54*(9), 1413-1426.

Piedrahita, R.H. (2003). Reducing the Potential Environmental Impact of Tank Aquaculture Effluents through Intensification and Recirculation. *Aquaculture, 226*(1-4), 35-44.

Primpas, I., Karydis, M. (2011). Scaling the trophic index (TRIX) in oligotrophic marine environments. *Environmental Monitoring and Assessment, 178*(1-4), 257-269.

Salas, F., Teixeira, H., Marcos, C., Marques, J. C., and Pe´rez-Ruzafa, A. (2008). Applicability of the trophic index TRIX in two transitional ecosystems: the Mar Menor lagoon (Spain) and the Mondego estuary (Portugal). – ICES Journal of Marine Science*, 65*, 1442–1448.

Troell, M., Joyce, A., Chopin, T., Neori, A., Buschmann, A. H., & Fang, J. G. (2009). Ecological Engineering in Aquaculture—Potential for Integrated Multi-Trophic Aquaculture (IMTA) in Marine Offshore Systems. *Aquaculture, 297*(1-4), 1-9. https://doi.org/10.1016/j.aquaculture.2009.09.010

Tugrul S, Ozhan K, & Akcay I. (2019). Assessment of trophic status of the northeastern Mediterranean coastal waters: eutrophication classification tools revisited. *Environmental Science and Pollution Research International, 26*(15), 14742-14754.

Vollenweider, R. A., Giovanardi, F., Montanari, G., & Rinaldi, A. (1998). Characterization of the trophic conditions of marine coastal waters with special reference to the NW Adriatic Sea: Proposal for a trophic scale, turbidity, and generalized water quality index. *Environmetrics, 9*(3), 329-357.

Wing, J. D. B., Champneys, T. S., & Ioannou, C. C. (2021). The Impact of turbidity on foraging and risk taking in the invasive Nile tilapia (*Oreochromis niloticus*) and a threatened Native cichlid (*Oreochromis amphimelas*). *Behavioral Ecology and Sociobiology, 75*, 49. https://doi.org/10.1007/s00265-021-02984-8.

Wong, B. B. M. & Candolin, U. (2015). Behavioral responses to changing environments. *Behavioral Ecology, 26*(3), 665–673. https://doi.org/10.1093/beheco/aru183.

Yigit, Ü., Maita, M., Yigit, Ergün, S., Kusku, H., & Ek, H. (2024). Analysis of the economic performance of salmon farming in submerged and surface cages in the Black Sea. *Aquaculture International, 32*, 101–118. https://doi.org/10.1007/s10499-023-01155-y

Yucel-Gier, G., Pazi, I., & Kucuksezgin, F. (2010). The composite trophic status index (TRIX) as a potential tool for the regulation of Turkish marine aquaculture as applied to the eastern Aegean coast (Izmir Bay). *Journal of Applied Ichthyology, 26*(3), 396-400.

Zhang, K., Ye, Z., Qi, M., Cai, W., Saraiva, J. L., Wen, Y., Liu, G., Zhu, Z., Zhu, S., & Zhao, J. (2025). Water quality impact on fish behavior: A review from an aquaculture Perspective. *Reviews in Aquaculture, 17*, e12985. https://doi.org/10.1111/raq.12985.