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An Intelligent Fisheries Analytics Framework for Sustainable Education, Coastal Governance, and Ecotourism Development

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Abstract

Sustainable fisheries management requires timely, data-driven approaches that support resource conservation, evidence-based policymaking, and stakeholder engagement. This study proposes an Intelligent Fisheries Analytics Framework for Sustainable Education, Coastal Governance, and Ecotourism Development using a Design Science Research (DSR) approach. The framework integrates fisheries production statistics, environmental information, biodiversity records, geospatial data, and ecotourism datasets into a unified analytics architecture. National fisheries production data from the Philippine Statistics Authority were analyzed to demonstrate the applicability of the proposed framework. Descriptive analysis revealed that Philippine fisheries production declined by 15.3% during the first quarter of 2026, largely driven by reductions in seaweed production and several commercially important fish species, while a few commodities exhibited positive growth. These findings highlight the need for intelligent analytical systems capable of identifying production trends, supporting sustainability assessments, and facilitating proactive decision-making. The proposed framework incorporates data preprocessing, artificial intelligence, machine learning, statistical and geospatial analytics, and a decision-support layer that generates actionable insights for multiple stakeholders. Its outputs support sustainable fisheries management, fisheries education, coastal governance, and ecotourism planning through evidence-based recommendations and continuous feedback for adaptive management. The framework provides a scalable foundation for integrating heterogeneous fisheries datasets and demonstrates how intelligent analytics can contribute to resilient fisheries, improved marine resource governance, enhanced educational initiatives, and sustainable blue economy development.

Introduction

Fisheries and coastal ecosystems play a fundamental role in supporting global food security, biodiversity conservation, economic development, and the livelihoods of millions of coastal communities. Sustainable fisheries management has become increasingly important as marine ecosystems face growing pressures from overfishing, habitat degradation, climate change, pollution, and unsustainable coastal development (Bakker, 2022; De Santo et al., 2019). These challenges require evidence-based governance supported by timely, reliable, and data-driven decision-making to ensure the long-term sustainability of marine resources.

Recent advances in artificial intelligence (AI), machine learning, remote sensing, and data analytics have transformed the way marine environments are monitored and managed. AI-enabled systems can process large volumes of ecological and environmental data more efficiently than traditional manual approaches, enabling faster detection of changes in fish populations, coral reef conditions, and ecosystem health (Anton et al., 2021; Ditria et al., 2022). Likewise, automated image analysis and computer vision techniques have demonstrated significant potential for improving the monitoring of benthic habitats and coral reef ecosystems while reducing human error and operational costs (Beijbom et al., 2015; Gonzalez-Rivero et al., 2016, 2020).

The integration of intelligent technologies into marine conservation has also strengthened protected area governance and environmental monitoring. AI applications support biodiversity assessment, habitat mapping, ecological forecasting, and adaptive management, providing valuable information for policymakers and resource managers (Atalay et al., 2025; Bakker, 2022). Furthermore, Earth system governance emphasizes the importance of integrating technological innovation with institutional collaboration to address complex environmental challenges across multiple governance levels (Burch et al., 2019; De Santo et al., 2019).

Beyond conservation, locally based environmental monitoring and citizen science have emerged as effective approaches for increasing stakeholder participation and improving the quality of environmental information. Community engagement not only strengthens data collection but also promotes environmental awareness and shared responsibility for natural resource management (Anton et al., 2021; Danielsen et al., 2021). Such participatory approaches are particularly relevant in fisheries-dependent communities, where local ecological knowledge complements scientific observations and supports adaptive coastal governance.

The availability of intelligent monitoring systems also creates new opportunities for fisheries education and ecotourism development. Educational institutions increasingly recognize the value of integrating real-world environmental data into fisheries, marine biology, and environmental science curricula, allowing students to develop competencies in data analytics, conservation science, and digital technologies. Simultaneously, healthy coastal ecosystems, particularly coral reefs and marine protected areas, serve as major attractions for sustainable ecotourism, generating economic opportunities while promoting conservation awareness (Fan et al., 2023; Gonzalez-Rivero et al., 2020). Effective management of these resources requires continuous monitoring supported by intelligent analytics capable of transforming complex environmental data into meaningful insights for educators, policymakers, researchers, and local communities.

Despite the growing adoption of AI in marine monitoring, existing studies primarily focus on specific applications such as coral reef image classification, biodiversity assessment, or automated environmental monitoring (Beijbom et al., 2015; Ditria et al., 2022; Gonzalez-Rivero et al., 2020). Comparatively fewer studies have proposed an integrated framework that simultaneously supports fisheries education, coastal governance, environmental conservation, and ecotourism planning through a unified intelligent analytics platform. Bridging these domains is essential because sustainable fisheries management requires interdisciplinary collaboration among academic institutions, government agencies, conservation organizations, tourism stakeholders, and coastal communities.

To address this gap, the present study proposes An Intelligent Fisheries Analytics Framework for Sustainable Education, Coastal Governance, and Ecotourism Development. The framework integrates artificial intelligence, environmental analytics, and fisheries information to support evidence-based decision-making, enhance experiential learning, strengthen coastal resource governance, and promote sustainable ecotourism. By synthesizing intelligent monitoring, educational applications, and governance mechanisms into a comprehensive analytical framework, the study aims to contribute to sustainable fisheries management and demonstrate how digital transformation can support the long-term resilience of coastal ecosystems and communities.

Material and methods

This study employed a Design Science Research (DSR) methodology to develop the Intelligent Fisheries Analytics Framework for Sustainable Education, Coastal Governance, and Ecotourism Development. DSR is an appropriate research approach for designing and evaluating innovative frameworks that address practical problems through the integration of existing knowledge and data-driven technologies. The study focused on developing a conceptual decision-support framework that demonstrates how intelligent analytics can facilitate sustainable fisheries management and support education, governance, and ecotourism initiatives.

The study utilized secondary data obtained from the Philippine Statistics Authority (PSA), specifically the Volume of Production of Agriculture and Fisheries, January to March 2026 (Reference No. 2026-145). The dataset contains national fisheries production statistics for major fisheries commodities across the commercial, municipal, inland, and aquaculture subsectors. These official government statistics served as the primary empirical basis for examining production trends and identifying areas requiring intelligent analytical support.

Data preparation involved organizing and validating the production statistics prior to analysis. Commodity production values were compiled and categorized according to fisheries subsectors, and percentage changes between the first quarters of 2025 and 2026 were calculated to determine production increases and declines. Descriptive statistical techniques, including frequency summaries, percentage change analysis, and comparative trend analysis, were employed to identify significant variations in fisheries production among major commodities.

The analytical findings served as the foundation for the development of the proposed framework. A synthesis of literature on artificial intelligence, machine learning, geospatial analytics, fisheries management, coastal governance, and sustainable development was conducted to identify the essential functional components of an intelligent fisheries analytics system. These components were then integrated into a conceptual architecture consisting of four major layers: data acquisition, data preprocessing, intelligent analytics, and decision support, which collectively generate evidence-based outputs for sustainable fisheries management, fisheries education, coastal governance, and ecotourism development.

The proposed framework was developed conceptually to illustrate how heterogeneous fisheries-related datasets, including production statistics, environmental information, biodiversity records, and geospatial data, may be integrated into a unified analytics platform. Although the present study demonstrates the framework using national fisheries production statistics, the architecture is designed to accommodate additional datasets that can support future predictive analytics, sustainability assessment, and intelligent decision-making.

This study relied exclusively on publicly available government data and published scientific literature. Since no human participants were involved and no personal or confidential information was collected, formal ethical clearance was not required. The study adhered to principles of research integrity through accurate data reporting, proper citation of sources, and transparent presentation of the proposed framework.

Results

1. Overall Fisheries Production Trend

The results revealed a substantial contraction in Philippine fisheries production during the first quarter of 2026. Total production decreased from 1.01 million metric tons in 2025 to 856.29 thousand metric tons in 2026, equivalent to a year-on-year decline of 15.3%. This represented an absolute reduction of approximately 154.50 thousand metric tons. The decrease also reversed the 2.0% growth recorded in the corresponding period of 2025, indicating a significant deterioration in fisheries output during the most recent quarter analyzed. The figures for 2026 are preliminary and should therefore be interpreted as an initial assessment of sector performance (Philippine Statistics Authority [PSA], 2026).

The decline in fisheries production was considerably greater than the changes observed in the other agricultural subsectors. Crops production decreased by 4.6%, while livestock and poultry production increased by 5.0% and 7.0%, respectively. These contrasting results indicate that fisheries experienced the most severe production challenge among the major agriculture and fisheries sectors during the period. This pattern demonstrates the need for a fisheries-specific analytics framework capable of identifying vulnerable commodities, monitoring production changes, and supporting timely interventions rather than relying solely on aggregated agricultural indicators.

2. Production Performance by Fisheries Commodity

Seaweed remained the largest fisheries commodity in the first quarter of 2026, accounting for 29.7% of total fisheries production. However, its output declined sharply from 385.69 thousand metric tons in 2025 to 254.66 thousand metric tons in 2026. This represented a reduction of approximately 131.03 thousand metric tons or 34.0%. Seaweed alone contributed −13.0 percentage points to the overall fisheries growth rate of −15.3%, making it the principal source of the sector-wide contraction.

The magnitude of the seaweed decline indicates that national fisheries performance was highly sensitive to changes in this single commodity. Seaweed accounted for approximately 85% of the total absolute reduction in fisheries output between 2025 and 2026. This concentration highlights the importance of monitoring farming conditions, disease incidence, water quality, climatic disturbances, farm inputs, postharvest systems, and market conditions in major seaweed-producing areas. Although the dataset does not provide causal variables, the production pattern suggests that an intelligent fisheries analytics system should include commodity-level early-warning functions that can detect abnormal decreases and identify locations requiring technical or policy intervention.

Tilapia was the second-largest individually identified commodity, contributing 12.7% of total fisheries production. Its output declined moderately from 111.42 thousand metric tons in 2025 to 108.77 thousand metric tons in 2026, equivalent to a 2.4% reduction. Milkfish production similarly decreased from 62.28 thousand metric tons to 59.21 thousand metric tons, resulting in a 4.9% decline. Both commodities contributed −0.3 percentage points to the overall fisheries growth rate. These reductions are smaller than the decrease in seaweed production, but they remain important because milkfish and tilapia are major aquaculture products that contribute to domestic food supply, employment, and fisheries education.

Several commercially important capture fisheries commodities also recorded declines.

Skipjack production decreased by 8.7%, from 64.40 thousand metric tons to 58.83 thousand metric tons, and contributed −0.6 percentage points to total fisheries growth. Big-eyed scad declined by 24.9%, from 27.09 thousand metric tons to 20.36 thousand metric tons, contributing −0.7 percentage points. Yellowfin tuna decreased by 13.6%, Bali sardinella by 12.1%, Indian mackerel by 12.9%, and squid by 5.4%. These commodity-level contractions indicate that the overall decline was not limited to aquaculture but was also evident among several marine capture species.

Crustacean production generally exhibited unfavorable trends. Mud crab recorded a 31.7% decline, while blue crab decreased by 23.6%. Tiger prawn and Penaeus vannamei declined by 2.8% and 3.5%, respectively. Although their individual shares of total production were relatively small, these commodities often have high economic value and are relevant to coastal livelihoods, aquaculture enterprises, restaurants, and tourism-related markets. Their declining output may therefore have economic implications beyond their contribution to production volume.

3. Commodities With Positive Growth

Despite the overall decline, several commodities registered production increases. Round scad showed the highest growth among the listed commodities, increasing from 33.91 thousand metric tons in 2025 to 50.38 thousand metric tons in 2026. This represented an increase of 48.6%, or approximately 16.47 thousand metric tons, and contributed 1.6 percentage points to total fisheries growth. Fimbriated sardines also increased substantially by 44.7%, from 8.37 thousand metric tons to 12.12 thousand metric tons, contributing 0.4 percentage points.

Other commodities that recorded positive growth included bigeye tuna at 16.7%, threadfin bream at 12.0%, grouper at 8.2%, and frigate tuna at 1.0%. However, their relatively small production shares limited their ability to offset the large losses in seaweed and other major commodities. These results illustrate why both growth rate and production share must be considered in fisheries analysis. A commodity may register rapid percentage growth but make only a limited contribution to the total sector when its production base is small.

The growth in round scad and fimbriated sardines may provide opportunities for targeted value-chain development, processing, marketing, and livelihood diversification. Nevertheless, increased catch volumes should not automatically be interpreted as evidence of improved ecosystem condition. Without information on fishing effort, catch per unit effort, stock abundance, seasonality, and environmental conditions, the sustainability of the observed increases cannot be determined. An intelligent analytics framework should therefore integrate production statistics with ecological and operational indicators before generating management recommendations.

4. Implications for Sustainable Fisheries Education

The production patterns provide relevant empirical material for fisheries and marine education. The sharp decline in seaweed production can be incorporated into courses on aquaculture management, aquatic ecology, fishery economics, climate resilience, and coastal resource management. Students may use the data to identify production trends, calculate commodity contributions, compare aquaculture and capture fisheries, and develop possible evidence-based interventions. In this manner, the proposed framework can transform official production statistics into learning resources for data analytics, sustainability assessment, and fisheries planning.

The results also demonstrate the importance of strengthening digital and analytical competencies among fisheries students. Traditional production reporting describes what happened, but an intelligent analytics approach can help students investigate where declines occurred, which commodities contributed most strongly, and what environmental or socioeconomic variables may explain the changes. Integrating dashboards, temporal graphs, geospatial maps, and predictive models into fisheries curricula may therefore enhance experiential and problem-based learning.

However, the current dataset contains only national commodity-level production records. It does not include student outcomes, educational usage data, or measures of learning effectiveness. Consequently, the educational value of the framework remains conceptual and should be evaluated in future studies through student usability assessments, competency tests, classroom implementation, and expert validation.

5. Implications for Coastal Governance

The results support the need for more responsive and commodity-sensitive coastal governance. The overall 15.3% reduction indicates that national-level fisheries planning should not rely only on total production figures because individual commodities showed substantially different patterns. Seaweed required the greatest attention because of its dominant share and contribution to the decline, while decreases in big-eyed scad, blue crab, mud crab, yellowfin tuna, and Bali sardinella may require localized investigation and monitoring.

An intelligent fisheries analytics framework could assist local government units, fisheries agencies, and coastal resource managers by displaying commodity-specific production changes, identifying abnormal trends, and linking production records with municipal, environmental, and fishing-effort data. Such integration could support the allocation of technical assistance, aquaculture inputs, livelihood programs, habitat rehabilitation, enforcement efforts, and climate-adaptation measures.

The data nevertheless cannot establish whether the decreases resulted from resource depletion, unfavorable weather, reduced fishing activity, disease, market conditions, changes in reporting, or other factors. The analysis is descriptive rather than causal. Governance decisions should therefore be supported by additional information such as sea surface temperature, rainfall, salinity, water quality, fishing effort, vessel activity, farm area, disease reports, prices, and regional production records.

6. Implications for Ecotourism Development

The reduction in several marine commodities also has implications for coastal ecotourism because fisheries production, marine biodiversity, community livelihoods, and tourism are interconnected. Coastal destinations often depend on healthy marine ecosystems, attractive seascapes, local seafood availability, and traditional fishing activities. Continued decreases in ecologically and economically important species may weaken community livelihoods and reduce the authenticity or attractiveness of fisheries-related tourism experiences.

Conversely, the production increases observed in selected species should be managed cautiously. Ecotourism development should not encourage excessive harvesting merely because a commodity recorded short-term growth. Instead, fisheries analytics can support sustainable tourism by identifying suitable areas for community-based tours, seaweed farm visits, marine conservation education, responsible seafood promotion, and livelihood diversification while monitoring ecological limits.

The proposed framework may therefore connect fisheries production indicators with tourism statistics, marine protected area conditions, biodiversity records, and community livelihood information. Such integration could help determine whether tourism activities contribute to conservation and local development or create additional pressure on coastal resources. However, no tourism data were included in the analyzed file, so the relationship between fisheries production and ecotourism performance cannot yet be tested empirically.

7. Proposed Intelligent Fisheries Analytics Framework

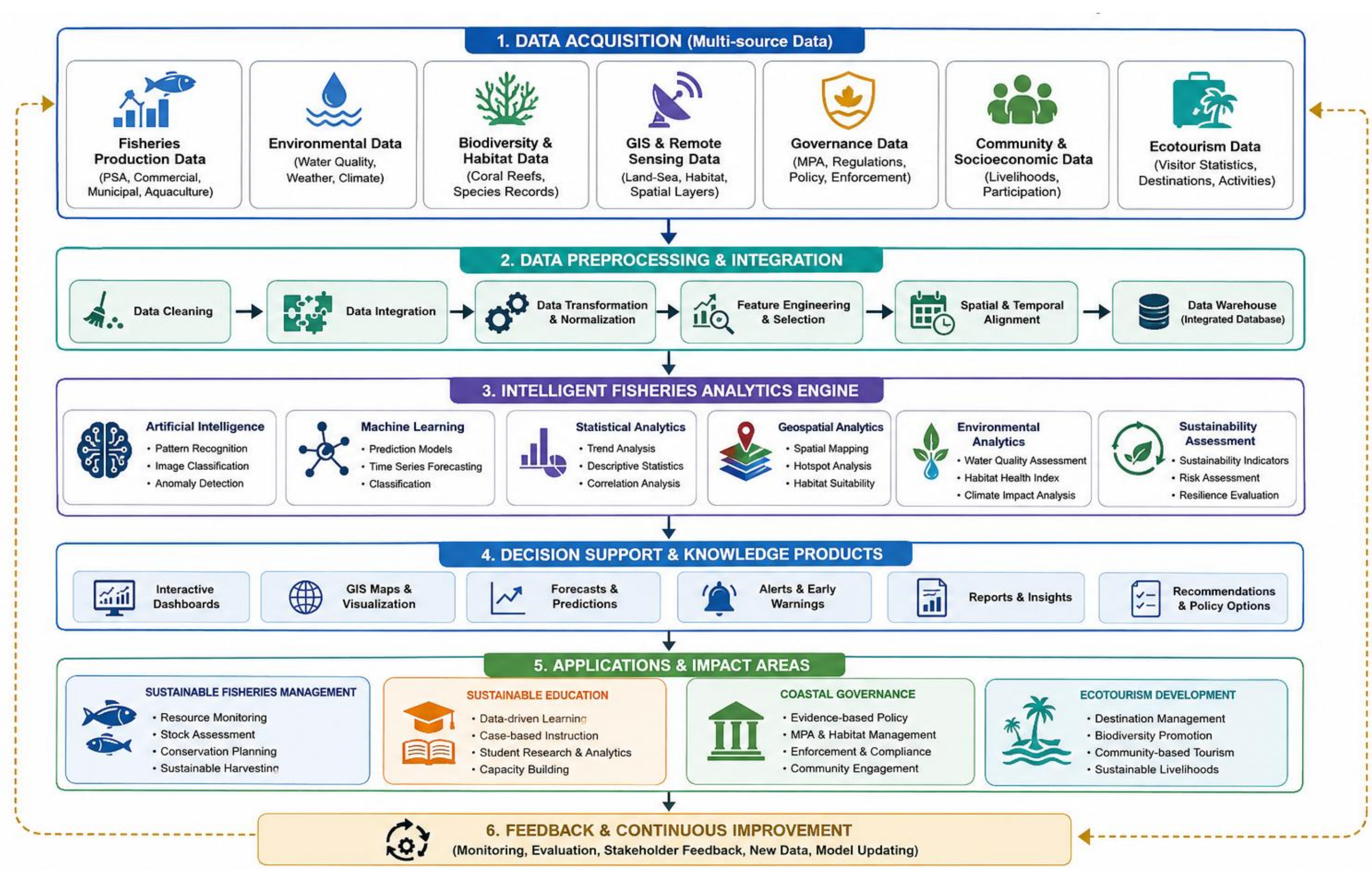

Fig.1. Proposed Intelligent Fisheries Analytics Framework for Sustainable Education, Coastal Governance, and Ecotourism Development.

Figure 1 illustrates the overall architecture of the proposed Intelligent Fisheries Analytics Framework. The framework begins with the collection of data from multiple fisheries-related sources, including production statistics, environmental information, biodiversity records, geospatial data, and ecotourism information. These datasets undergo preprocessing through data cleaning, integration, and transformation to ensure consistency and quality.

The processed data are then analyzed using the Intelligent Fisheries Analytics Engine, which integrates artificial intelligence, machine learning, statistical analysis, and geospatial analytics to identify trends, generate predictions, and produce meaningful insights. The analytical results are presented through a decision support layer that provides dashboards, forecasts, and evidence-based recommendations for stakeholders.

Finally, the generated knowledge supports four key application areas: sustainable fisheries management, sustainable education, coastal governance, and ecotourism development. A continuous feedback mechanism enables the framework to incorporate new data, stakeholder input, and monitoring results, allowing the system to improve its analytical performance and support adaptive, data-driven decision-making over time.

8. Analytical Interpretation of the Framework

The dataset demonstrates the usefulness of the descriptive analytics component of the proposed framework. Commodity-level growth rates, production shares, absolute changes, and percentage-point contributions made it possible to identify seaweed as the most influential source of the national fisheries decline. The analysis also distinguished high-growth but relatively small-volume commodities from major commodities whose moderate changes had wider implications.

Nevertheless, the available data were insufficient for implementing the machine learning, geospatial analysis, habitat assessment, water-quality evaluation, and expert-validation procedures described in the Materials and Methods. Only three annual first-quarter observations—2024, 2025, and 2026—were available, and the data were aggregated at the national level. This sample is too limited for reliable predictive modeling because a machine learning model developed from only three time points would likely produce unstable and misleading results.

The present analysis should therefore be regarded as the descriptive and diagnostic stage of the Intelligent Fisheries Analytics Framework. Future implementation should incorporate longer time-series data, regional and municipal disaggregation, fishing-effort measures, environmental variables, market indicators, ecological monitoring, education data, and tourism records. These expanded datasets would permit time-series forecasting, anomaly detection, spatial hotspot analysis, sustainability classification, and evidence-based recommendation generation.

Conclusions

This study proposed the Intelligent Fisheries Analytics Framework for Sustainable Education, Coastal Governance, and Ecotourism Development as a comprehensive decision-support framework for integrating fisheries production data, intelligent analytics, and sustainable resource management. Analysis of the Philippine Statistics Authority data revealed that fisheries production declined by 15.3% during the first quarter of 2026, primarily due to the substantial decrease in seaweed production, while several other economically important fisheries commodities also experienced negative growth. In contrast, a few commodities, including round scad and fimbriated sardines, recorded positive production trends, highlighting the variability of fisheries resources and the need for commodity-specific monitoring and management.

The findings demonstrate that conventional descriptive production reports provide valuable information but are insufficient for proactive fisheries management. Integrating artificial intelligence, machine learning, geospatial analytics, environmental monitoring, and decision-support systems can transform production statistics into actionable insights that support sustainable fisheries development. Such an integrated framework enables the identification of vulnerable commodities, monitoring of production trends, assessment of ecosystem conditions, and generation of evidence-based recommendations for policymakers, educators, researchers, and coastal communities.

From an educational perspective, the proposed framework provides an innovative platform for experiential learning by incorporating real-world fisheries datasets into fisheries science, marine biology, environmental management, and data analytics instruction. For coastal governance, the framework supports data-driven planning, resource allocation, conservation strategies, and adaptive policy formulation. Likewise, the integration of fisheries production with biodiversity, environmental, and tourism information offers opportunities to strengthen sustainable ecotourism while promoting responsible utilization and conservation of coastal resources.

Although the present study successfully demonstrates the conceptual applicability of the framework using national fisheries production statistics, its implementation remains limited by the availability of aggregated production data. Future studies should incorporate longer time-series datasets, regional and municipal fisheries records, water quality indicators, climate variables, remote sensing information, biodiversity assessments, tourism statistics, and socioeconomic data. The integration of these datasets will enable predictive modeling, anomaly detection, spatial hotspot analysis, sustainability forecasting, and real-time decision support, thereby enhancing the capability of intelligent fisheries analytics to promote resilient fisheries, sustainable coastal governance, and inclusive blue economy development.

Declaration on the Use of AI Generative Tools

The authors acknowledged the use of artificial intelligence (AI)-assisted tools, including generative AI technologies, during the preparation of this manuscript. These tools were utilized to support language refinement, grammar checking, formatting assistance, and the organization of the manuscript. All research activities, including the study design, data collection, data analysis, interpretation of results, and final review of the manuscript, were performed and verified by the authors. The authors assume full responsibility for the accuracy, originality, and integrity of the content presented in this paper.

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