

Research Article

Volume 19 Issue 2 - March 2026
DOI: 10.19080/OFOAJ.2026.19.556008

Oceanogr Fish Open Access J

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Spatio-Temporal Patterns of Fishing Effort in the Eastern Mediterranean: A GFW-AIS Data Analysis Across Eight Coastal States (2024–2025)



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Submission: March 10, 2026; **Published:** March 26, 2026

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Abstract

The Eastern Mediterranean Sea supports significant fishing activity across eight coastal states, yet regional analyses of fishing effort distribution across all coastal states remain scarce. This study analyzes spatio-temporal patterns of fishing effort in the Eastern Mediterranean using Global Fishing Watch (GFW) Automatic Identification System (AIS) data covering January 2024 through December 2025 (24 months). Data were extracted for the Exclusive Economic Zones (EEZs) of Turkey, Greece, Cyprus, Egypt, Libya, Israel, Syria, and Lebanon via the GFW API v3.

Results indicate substantial disparity in fishing effort among coastal states. Turkey and Greece together account for approximately 86% of total regional fishing effort (718,221 and 617,553 hours, respectively), confirming their dominant position in Eastern Mediterranean fisheries. Libya (78,809 h), Cyprus (64,487 h), and Egypt (41,456 h) constitute secondary fishing nations, while Israel, Syria, and Lebanon exhibit markedly lower activity levels.

Distinct seasonal patterns were identified, with Turkish EEZ showing pronounced autumn peaks (September–November) exceeding summer effort by more than 300% (seasonality ratio $R_s = 4.20$). Spatial analysis revealed high concentration of fishing activity, with hotspot persistence observed across both years. Inter-annual comparison between 2024 and 2025 demonstrated relative stability in spatial distribution patterns.

These findings provide a quantitative baseline for understanding fishing pressure distribution in the Eastern Mediterranean, with implications for regional fisheries management and marine spatial planning. The study demonstrates the utility of GFW-AIS data for large-scale fishing effort characterization in multi-jurisdictional marine regions.

Keywords: Fishing effort; Eastern Mediterranean; Global Fishing Watch; AIS data; Spatio-temporal analysis; EEZ

Introduction

The Mediterranean Sea, despite representing only 0.8% of world ocean surface area, has been the site of fishing activity since ancient times [1]. Mediterranean fisheries are characterized primarily by multispecific catches and artisanal or coastal activity, resulting from a mosaic of diversified structures and gears along more than 45,000 km of coastline [1]. The Mediterranean fishing fleet comprises approximately 72,600 vessels, of which 85.5% are artisanal boats using diverse gears including trammel nets,

gillnets, longlines, and traps [2]. Two main biological features distinguish this semi-enclosed sea: a high species richness (5.5–7% of world marine fauna) contrasted with relative oligotrophic conditions, and the absence of large monospecific fisheries except for certain pelagic species [1].

The Eastern Mediterranean basin presents particular characteristics that influence fishing activity patterns. Marked seasonality in surface temperatures, ranging from summer

maxima of 28°C in the eastern basin to winter minima of 7°C in the upper Adriatic, has significant biological effects on commercially important species, conditioning spawning, migrations, and growth cycles [1]. This environmental variability is expected to manifest in observable patterns of fishing effort distribution.

Historical catch statistics indicate substantial regional variation in fishing production among Mediterranean coastal states. In 2000, Turkey held the leading position with 496,174 tonnes (26.9% of total Mediterranean and Black Sea production), followed by Italy (25%), Greece (9%), Spain (7.6%), and Algeria (5.4%) [1]. This historical dominance of particular coastal states raises questions about contemporary patterns and whether similar distributions persist.

Recent assessments indicate a critical status of Mediterranean fisheries resources. Stock assessments conducted between 2002–2014 revealed that more than 90% of assessed commercial stocks exhibit fishing mortality exceeding the level associated with maximum sustainable yield ($F > FMSY$), with the highest overexploitation ratios observed for demersal fish species [2]. This generalized overexploitation status has been linked to decades of poorly regulated fishing effort, particularly in areas where trawling activity is concentrated [2]. Understanding the spatial and temporal distribution of fishing effort is essential for effective management, yet tracking fishing mortality requires knowing where and when fishing activity occurs—information that has historically been difficult to obtain at basin-wide scales.

The emergence of satellite-based vessel monitoring has significantly advanced our ability to track fishing activity globally. Kroodsma et al. [3] demonstrated that AIS data, when processed through machine learning algorithms, can map the global footprint of fisheries with remarkable detail, revealing that fishing activity covers more than 55% of the ocean surface - an area four times that of terrestrial agriculture. This landmark study processed 22 billion AIS positions from 2012–2016 to identify fishing vessels and classify their activity, establishing a methodological framework now widely applied in regional fisheries analyses. Ferrà et al. [4] demonstrated the suitability of AIS data for mapping bottom trawl fishing activity across the entire Mediterranean basin at 0.01° resolution, identifying hotspots in the northern Aegean Sea and along Turkish and Israeli waters. This approach was further refined for deepwater fisheries, with Pulcinella et al. [5] providing a 4-year time series (2015–2018) of AIS-observed monthly fishing effort for bottom trawlers targeting deepwater red shrimp in the eastern–central Mediterranean (GSAs 12–27), revealing marked seasonal patterns with peak activity during spring and summer quarters. More recently, Marsaglia et al. [6] combined Synthetic Aperture Radar (SAR) vessel detections with AIS data to estimate trawl fishing activity across the entire Mediterranean basin, revealing that the Aegean Sea (GSA 22) accounts for 11% of total predicted Mediterranean trawl activity, while South Levant Egypt (GSA 26) and North Levant Turkey (GSA 24) represent 7% and 4%, respectively. Global Fishing Watch (GFW) processes AIS

data to identify fishing activity and provides open access to fishing effort datasets covering multiple years and geographic regions. A decade-long analysis of foreign fishing activities in Turkey's contiguous zone (2013–2023) using GFW data demonstrated significant temporal trends in fishing effort, with Turkish trawl fishing hours peaking at 857.29 hours in 2022 and revealed persistent fishing activities by vessels from Cyprus, Greece, Italy, and other Mediterranean nations in waters adjacent to Turkish territorial seas [7]. Satellite-based methods have proven effective for fisheries assessment in the Mediterranean, including fleet enumeration using Google Earth imagery in Greek waters [8].

The Greek small-scale fishery sector exhibits complex operational patterns characterized by multiple fishing practices (*métiers*). The harbors of Kalymnos Island (Dodecanese, southeast Aegean Sea) are reported to host the largest and most active small-scale coastal fleet in the Eastern Mediterranean, with nets (54.4%) and longlines (42.5%) comprising the primary fishing gears [9]. The Kalymnos fleet (343 boats, average engine power 172 ± 99 HP) landed 350 tonnes of various fish, 650 tonnes of swordfish (*Xiphias gladius*), and 20 tonnes of bluefin tuna (*Thunnus thynnus*) in 2014 [10]. Analysis of this fleet identified 10 distinct longline *métiers* and 11 net *métiers*, with seasonal rotation determined primarily by species availability rather than market prices [9,10].

Turkey represents the dominant fishing nation in the Eastern Mediterranean-Black Sea region. A catch reconstruction study by Ulman et al. [11] revealed that Turkey's actual marine catches for the 1950–2010 period totaled approximately 30 million tonnes, 63% higher than the officially reported 18.4 million tonnes. In 2010 alone, re-constructed catches (726,272 t) exceeded reported landings (445,617 t) by 63%, with discrepancies attributed to unreported landings, discards, recreational, and subsistence fishing [11]. Despite being the largest commercial fishery in the Mediterranean and Black Sea combined, Turkish fisheries are characterized as being in critical condition, with both quality (number of species, value, and sizes of fish) and quantity of catches rapidly declining since the national catch peak in 1988 [12]. The ineffectiveness of fisheries management measures, particularly minimum landing size (MLS) regulations due to lack of monitoring and control, has been identified as a contributing factor to this decline [12].

Egypt's Eastern Mediterranean fisheries include significant lagoon systems. Bardawil Lagoon, covering approximately 650 km² and supporting some 4,000 fishermen, represents one of the least polluted wetlands in the Mediterranean region [13]. The lagoon fishery operates seasonally from April to December, with winter closure (January–March) implemented for spawning protection. Annual landings fluctuated between 1,242 and 5,410 tonnes during 2003–2021, with trammel nets (locally termed "Dabba") accounting for 89% of total production. Declining catch per unit effort (CPUE) trends indicate overexploitation of multiple commercial species including gilthead seabream, European seabass, and sole [13].

Cyprus, the third largest Mediterranean island, presents a unique case of divided fisheries management following the 1974 partition. Ulman et al. [14] reconstructed total marine fisheries catches for Cyprus from 1950–2010, revealing that actual catches were 2.6 times higher than officially reported to FAO, with unreported components including commercial landings, recreational, subsistence, and discards. The artisanal fleet dominates both the northern (410 vessels) and southern (1,134 vessels) parts of the island, with bottom trawling prohibited in the north since 1998. A significant contemporary challenge for Cypriot fisheries is the invasive silver-cheeked toad-fish (*Lagocephalus sceleratus*), which by 2008 accounted for approximately 50% of artisanal catches by weight, causing substantial economic losses through gear damage and representing a major discarded component [14].

Israel's Mediterranean fisheries operate within relatively constrained fishing grounds, with total area not exceeding 4,000 km² and more than 99% of effort concentrated in shallower waters within approximately 12 nautical miles from shore [15]. Edelist et al. [15] reconstructed total fisheries removals for the Israeli Mediterranean coast from 1950–2010, estimating actual catches at 255,400 tonnes—nearly 29% higher than the 198,136 tonnes officially reported to FAO. The Israeli fleet comprises a small industrial trawl sector (22–24 active vessels in recent years, down from 34 in 1990), approximately 300 licensed artisanal vessels (primarily gillnetters and longliners), and a substantial recreational fishery accounting for 20% of total catches by 2010. The dominance of bottom trawling in Israeli fisheries is notable: trawlers account for 54–60% of landings since 2006, the highest proportion in the Mediterranean [15]. Lessepsian migration has profoundly altered Israeli catches, with Indo-Pacific species such as lizardfish (*Saurida undosquamis*), Kuruma prawn (*Marsupenaeus japonicus*), and the invasive *Lagocephalus sceleratus* forcing adaptation of fishing practices, including the shift to steel cables on longlines to prevent predation losses.

Libya possesses the second largest continental shelf in the Mediterranean (approximately 65,000 km²) and approximately 2,000 km of coastline, yet its fisheries remain largely underutilized with less than 0.0025% of the population engaged in the sector [16]. Recent field surveys along the Derna coast in eastern Libya documented severe fisheries degradation during 2016–2019, with fish production declining from 25,950 kg in 2015 to just 5,943 kg in 2019 [16]. The operational fishing fleet collapsed from 200 vessels in 2015 to 67 vessels by 2019, predominantly small artisanal craft (Flouka, 65.7%) with minimal industrial trawling presence (4.5%). A critical factor in this decline was the widespread use of blast fishing (dynamite fishing), with 896 incidents recorded during the study period, facilitated by the proliferation of explosives following the 2011 conflict. The ichthyofauna of the region includes 83 native species, 20 Lessepsian migrants, and 4 Mediterranean endemics, reflecting

the biogeographic position at the interface of central and eastern Mediterranean basins.

The Aegean Sea represents one of the most important fishing grounds in the Eastern Mediterranean, encompassing both Greek and Turkish waters (GSA 22 and 23). Ecosystem modelling by Keramidas et al. [17] indicated that small-scale coastal fisheries exert the highest impact on the Aegean ecosystem, followed by bottom trawlers, reflecting the dominance of artisanal fleets in both countries. The mean trophic level of fisheries catches in the Aegean (3.30) suggests exploitation across multiple trophic levels, characteristic of Mediterranean multispecies fisheries.

The Thermaikos Gulf in the northwestern Aegean Sea exemplifies the concentration of fishing activity in specific productive areas. This shallow embayment is one of the major fishing grounds of the northeastern Mediterranean, producing more than 20% of total Greek catches and concentrating high fishing effort from both trawlers and purse seiners [18]. Indeed, 48% of all Aegean trawling activity occurs in the Thermaikos Gulf and adjacent Thracian Sea, while 20% of Aegean purse-seining takes place in the Thermaikos Gulf alone. Ecosystem modelling simulations for this area revealed overall ecosystem degradation with biomass and catch decline due to combined impacts of environmental factors and fishing activities, with fishing effort reduction scenarios demonstrating potential for stock rebuilding [18].

Despite the availability of these monitoring tools, analyses of fishing effort distribution across all Eastern Mediterranean coastal states remain limited. This study addresses this gap by analyzing spatio-temporal patterns of fishing effort in eight Eastern Mediterranean Exclusive Economic Zones (EEZs) using GFW-AIS data from 2024–2025.

The specific objectives of this study are:

- a) To quantify the distribution of fishing effort among Eastern Mediterranean coastal states and identify dominant fishing nations
- b) To characterize seasonal patterns of fishing activity and assess inter-country variation in seasonality
- c) To identify spatial hotspots of fishing activity and evaluate their persistence over time
- d) To compare fishing intensity metrics among major fishing nations in the region.

Based on historical data indicating Turkish and Greek dominance in Mediterranean fisheries [1], we hypothesize that these two nations continue to account for the majority of fishing effort in the Eastern Mediterranean EEZs. Additionally, we expect significant seasonal variation in fishing effort, reflecting the marked environmental seasonality characteristic of this basin.

Materials and Methods

Study Area

The study area encompasses the Exclusive Economic Zones (EEZs) of eight Eastern Mediterranean coastal states: Turkey, Greece, Cyprus, Egypt, Libya, Israel, Syria, and Lebanon. The Eastern Mediterranean basin extends approximately from 20°E to 36°E longitude and 30°N to 42°N latitude, representing the easternmost portion of the Mediterranean Sea and corresponding to the General Fisheries Commission for the Mediterranean (GFCM) Geographical Sub-Areas (GSAs) 20–27.

The region exhibits complex bathymetry, with extensive continental shelves along the North African and Levantine coasts and narrow shelves along the Aegean and Turkish coastlines [1]. Key oceanographic features include the Levantine Intermediate Water (LIW) formation, seasonal thermocline development, and oligotrophic conditions that intensify from west to east. These environmental gradients influence the distribution and productivity of fisheries resources and, consequently, the spatial allocation of fishing effort.

The eight coastal states encompass diverse fisheries sectors ranging from highly industrialized operations (Turkey, Greece) to predominantly artisanal fleets (Libya, Lebanon, Syria). Fleet compositions include purse seiners targeting small pelagics, bottom trawlers targeting demersal species, and extensive small-scale coastal fleets using static gears (gillnets, trammel nets, longlines). This heterogeneity in fishing capacity and gear types influences the interpretation of AIS-derived effort metrics, as vessel size and gear type affect both fishing behavior patterns and AIS transponder carriage rates.

Data Source and Acquisition

Global Fishing Watch Platform

Fishing effort data were obtained from the Global Fishing Watch (GFW) Application Programming Interface (API) version 3 [19]. GFW is a collaborative initiative founded in partnership with Oceana, SkyTruth, and Google that provides open-access data on global fishing activity derived from satellite-based vessel monitoring systems. The platform processes multiple data streams, including Automatic Identification System (AIS) signals, Vessel Monitoring System (VMS) data where available, and increasingly, Synthetic Aperture Radar (SAR) imagery for detection of non-broadcasting vessels [20].

AIS Data Processing Pipeline

GFW ingests AIS signals from a global network of terrestrial receivers and satellite-based AIS (S-AIS) sensors. AIS transponders, mandated for vessels ≥ 300 gross tonnage on international voyages and ≥ 500 gross tonnage domestically under the International Maritime Organization (IMO) Safety of Life at Sea (SOLAS) Convention, broadcast vessel identity (MMSI, IMO

number, vessel name), dynamic information (position, course, speed), and voyage information (destination, ETA) at intervals ranging from 2 to 180 seconds depending on vessel speed and navigational status [3].

GFW applies a multi-stage processing pipeline to raw AIS data:

a) Data cleaning and deduplication: Removal of erroneous positions (implausible coordinates, impossible speeds), duplicate messages, and spoofed identities.

b) Track segmentation: Grouping of AIS messages into coherent vessel tracks based on temporal continuity and spatial plausibility. Gaps exceeding 24 hours or 100 km without intervening positions are treated as segment boundaries.

c) Vessel classification: Convolutional neural network (CNN) algorithms classify vessels into categories (fishing, cargo, tanker, passenger, etc.) based on movement patterns, with fishing vessels further classified by gear type (trawler, purse seiner, longliner, etc.). The CNN architecture achieves 95% accuracy for vessel type classification and 83% accuracy for gear type classification against ground-truth registry data [3].

d) Fishing activity detection: A second CNN predicts fishing versus non-fishing behavior for each AIS position based on speed, course change, and preceding track characteristics. The algorithm is calibrated against logbook-verified fishing events and achieves 90% precision and 87% recall across major gear types [3].

e) Effort aggregation: Detected fishing positions are aggregated into spatial grid cells and temporal units, with fishing hours calculated as the sum of time intervals between consecutive fishing-classified positions within each cell.

Independent Validation

The reliability of GFW-derived fishing effort estimates has been validated through multiple independent studies. Kroodsmas et al. [3] compared GFW fishing activity predictions against vessel registry data, finding 95% agreement for vessel classification and high correlation (Pearson $r > 0.85$) between predicted fishing hours and logbook-reported fishing effort for vessels with available comparison data.

For Mediterranean waters specifically, Coro et al. [21] analyzed 1.6 billion AIS records from Mediterranean trawlers (2017–2022) and reported 91% agreement between GFW manifest fishing distributions and their independent speed-based detection algorithm. Their analysis also distinguished intentional AIS transponder disabling (potential IUU fishing indicator) from technical signal loss, finding that most hidden fishing hotspots in the Mediterranean correspond to intentional transponder switch-offs concentrated in specific areas including the Gulf of Alexandretta (İskenderun), Thermaic Gulf, and waters off Izmir and Lesvos.

Armelloni et al. [22] validated AIS coverage rates against official EU fleet registry data, reporting 76% mean coverage for EU Mediterranean fleets but noting substantial national variation (France: 96%; Italy: 71%; Greece: 68%). Non-EU Mediterranean states showed lower and more variable coverage: Turkey (57%), Israel (108%, potentially reflecting foreign vessels reporting Israeli waters), with Egypt, Syria, and Algeria approaching 0% coverage in their analysis period (2015–2017). Coverage rates have likely improved since 2017 due to expanded S-AIS constellation capacity and regulatory developments, but these findings establish that AIS-derived effort estimates represent lower bounds of actual fishing activity, particularly for non-EU Eastern Mediterranean states.

Data Extraction Protocol

Data were extracted programmatically using the GFW API v3 4wings Report endpoint. The endpoint returns spatially and temporally aggregated fishing effort statistics for user-defined regions, time periods, and grouping variables. Query parameters were configured as follows:

- a) **Endpoint:** <https://gateway.api.globalfishingwatch.org/v3/4wings/report>
- b) **Method:** POST with JSON payload
- c) **Dataset:** public-global-fishing-effort:latest
- d) **Spatial resolution:** LOW (0.1° grid cells, approximately 11 km at the equator, 8–9 km at Mediterranean latitudes)
- e) **Temporal resolution:** MONTH
- f) **Time period:** 2024-01-01 to 2025-12-31 (24 complete months)
- g) **Group-by variables:** FLAG (vessel flag state), providing effort disaggregation by fishing nation
- h) **Spatial filters:** context-layer defining region-of-interest as respective EEZ boundary

EEZ boundaries were defined using the public-eez-areas context layer maintained by GFW, which implements Marine Regions (www.marineregions.org) EEZ delimitations based on UNCLOS provisions and bilateral agreements. Table 1 presents the EEZ identifiers and approximate areas used for data extraction.

Eight separate API calls were executed, one per EEZ, with results stored as comma-separated value (CSV) files for subsequent analysis. Data extraction was performed on January 15, 2026, capturing all available GFW data through the study period end date.

Data Structure

The extracted dataset comprised 46,078 records across eight countries, with each record representing a unique combination of:

- a) **date:** Monthly timestamp (YYYY-MM format)

- b) **flag:** Vessel flag state (ISO 3166-1 alpha-3 code, or “UNKNOWN” for vessels with unidentified registry)

- c) **hours:** Total fishing effort in hours, representing cumulative time spent in fishing-classified activity within the grid cell during the month

- d) **lat, lon:** Grid cell centroid coordinates (decimal degrees, WGS84 datum)

- e) **vesselIDs:** Count of unique vessel identifiers (MMSI numbers) contributing to the cell’s fishing hours

The flag variable predominantly returned “UNKNOWN” across all EEZs, indicating that GFW’s vessel registry matching did not resolve flag state for most records. This limitation, common in AIS analyses where vessels may use inconsistent or unregistered identifiers, necessitated analysis at the EEZ level (interpreting effort occurring within each EEZ) rather than attempting fleet-specific analyses based on flag state.

Analytical Framework

Descriptive Statistics

Total fishing effort (hours) was calculated for each country by summing all records within the respective EEZ boundaries. Monthly time series were constructed by aggregating records by date field, enabling assessment of temporal patterns and inter-annual changes. Summary statistics (mean, standard deviation, minimum, maximum, median) were calculated for effort per record to characterize the distributional properties of fishing activity across grid cells.

Regional Distribution Analysis

Country-level effort shares were calculated as proportions of total regional effort. Concentration metrics included:

- a) **Concentration ratio (CR₂):** Sum of top two country shares, indicating duopoly strength

- b) **Herfindahl-Hirschman Index (HHI):** $\sum_{i=1}^n s_i^2 \times 10,000$, where s_i is country i ’s effort share expressed as a decimal

- c) **Effort density:** Hours per kilometer of coastline and hours per 1,000 km² of EEZ area

Seasonal analysis

Seasons were defined following Northern Hemisphere meteorological conventions: Winter (December–February), Spring (March–May), Summer (June–August), and Autumn (September–November). For the seasonal aggregation spanning 2024–2025, December of each year was grouped with the following January–February (e.g., December 2024 was grouped with January–February 2025 to form “Winter 2024/25”). The study period thus yielded complete seasonal data for all four seasons across two calendar years. The seasonality ratio (R_S) quantified the amplitude of seasonal variation:

$$R_s = \frac{E_{peak}}{E_{trough}} \quad (1)$$

where E_{peak} and E_{trough} represent the maximum and minimum seasonal effort totals, respectively. Values of R_s approaching 1.0 indicate minimal seasonality, while higher values indicate pronounced seasonal fluctuation.

Cross-country seasonal relationships were assessed using Pearson correlation coefficients calculated on monthly effort time series (n = 24 months per country pair). This analysis tested whether countries exhibited synchronous (positive correlation), asynchronous (negative correlation), or independent (zero correlation) seasonal patterns.

Spatial Concentration Analysis

The Gini coefficient quantified inequality in the spatial distribution of fishing effort within each EEZ:

$$Gini = \frac{\sum_{j=1}^n \sum_{i=1}^n |x_i - x_j|}{2n^2 \bar{x}} \quad (2)$$

where x_i represents cumulative fishing hours in grid cell i over the 24-month study period, n is the number of active grid cells (cells with >0 fishing hours), and \bar{x} is the mean fishing hours per active cell. Gini coefficients range from 0 (perfect equality, all cells with identical effort) to 1 (maximum inequality, all effort in a single cell). Values exceeding 0.6 are generally interpreted as indicating high concentration.

Additionally, the proportion of total effort concentrated in the top decile of active grid cells was calculated as a more intuitive concentration metric.

Hotspot Identification and Persistence

Fishing hotspots were identified as grid cells in the top decile of cumulative effort for each EEZ. Hotspot locations were characterized by latitude/longitude coordinates and mapped to known geographical features (bays, straits, shelf edges).

Inter-annual hotspot persistence was assessed using the Jaccard similarity index:

$$J = \frac{|A_{2024} \cap A_{2025}|}{|A_{2024} \cup A_{2025}|} \quad (3)$$

where A_{2024} and A_{2025} represent the sets of top-decile grid cells (by annual fishing hours) in 2024 and 2025, respectively. Jaccard indices range from 0 (no overlap, complete turnover of hotspot locations) to 1 (perfect overlap, identical hotspot sets between years).

Inter-Annual Change Analysis

Year-over-year changes in fishing effort were calculated as:

$$\Delta E = \frac{E_{2025} - E_{2024}}{E_{2024}} \times 100\% \quad (4)$$

Changes were assessed at national, seasonal, and monthly levels to identify patterns of increase, decrease, or stability.

Comparative Intensity Analysis

Mean fishing intensity (hours per vessel-ID per record) was calculated as a measure of effort concentration per participating vessel. Differences among countries were tested using the Kruskal-Wallis H-test, a non-parametric rank-based alternative to one-way ANOVA appropriate for non-normally distributed data with unequal variances:

$$H = \frac{12}{N(N+1)} \sum_{i=1}^k \frac{R_i^2}{n_i} - 3(N+1) \quad (5)$$

where N is total sample size, k is number of groups (countries), n_i is sample size for group i , and R_i is sum of ranks for group i .

Hypothesis Framework

The following a priori hypotheses were formulated based on literature review and regional fisheries knowledge:

H1: Turkey and Greece will together account for >75% of total Eastern Mediterranean fishing effort, reflecting their historical dominance in Mediterranean fisheries production [1,11].

H2: Fishing effort will exhibit significant seasonal variation, with peaks corresponding to target species availability and regulatory frameworks.

H3: Fishing effort will be spatially concentrated in productive zones (shelf edges, coastal embayment's), yielding Gini coefficients >0.5 for all countries.

H4: Mean fishing intensity (hours/vessel) will differ significantly among countries, reflecting fleet composition differences (industrial vs. artisanal).

H5: Fishing hotspots will persist inter-annually (Jaccard indices >0.5), reflecting stable environmental productivity patterns and established fishing practices.

H6: Turkey and Greece will exhibit inverse seasonal patterns (negative correlation), with fleets alternating between shared fishing grounds.

Software and Reproducibility

All data extraction, processing, and analysis were performed using Python 3.11 within a virtual environment to ensure dependency isolation. Key libraries included:

- a) **requests (v2.31):** HTTP client for GFW API calls
- b) **pandas (v2.0):** Data manipulation and aggregation
- c) **numpy (v1.24):** Numerical computations
- d) **scipy (v1.11):** Statistical tests (Kruskal-Wallis)
- e) **matplotlib (v3.7):** Data visualization

The manuscript was prepared using LATEX with the natbib

package for citation management. Analysis scripts and data files are available from the corresponding author upon reasonable request.

Results

Data Summary

A total of 46,078 records were extracted from the GFW database, representing fishing effort across eight Eastern Mediterranean EEZs for the 24-month study period (January 2024–December 2025). Each record corresponds to a unique combination of date (year-month), geographic grid cell (0.1° resolution), and vessel flag state. All countries except Lebanon provided complete 24-month data coverage; Lebanon data showed 23 months with limited activity (Table 2).

The dataset revealed substantial heterogeneity in record density among countries. Greece generated the highest number of records (21,455), reflecting both extensive coastline and broad spatial distribution of fishing activity. Turkey, despite contributing the highest total effort, produced fewer records (14,774) with higher mean effort per record (48.6 hours), suggesting more concentrated fishing patterns. At the opposite extreme, Lebanon contributed only 106 records with minimal effort (690 hours total), consistent with the country's limited fishing fleet capacity and ongoing socioeconomic constraints.

The mean effort per record varied considerably among countries, ranging from 6.5 hours (Lebanon) to 59.9 hours (Syria). Syria's exceptionally high value reflects the sparse spatial distribution of its fishing activity, with effort concentrated in a limited number of grid cells. Conversely, Lebanon's low value indicates both minimal total effort and dispersed activity across the few active cells.

Regional Distribution of Fishing Effort

Turkey and Greece dominated regional fishing effort, together accounting for 1,335,774 hours (86.2%) of the total 1,548,905 hours recorded across all eight EEZs. Turkey alone contributed 46.4% of total effort (718,221 hours), followed by Greece (39.9%; 617,553 hours), Libya (5.1%; 78,809 hours), Cyprus (4.2%; 64,487 hours), Egypt (2.7%; 41,456 hours), Israel (1.1%; 17,034 hours), Syria (0.7%; 10,655 hours), and Lebanon (0.04%; 690 hours).

The distribution exhibited extreme inequality, with the top two countries accounting for more than six times the combined effort of the remaining six nations. This concentration ratio ($CR_2 = 86.2\%$) exceeds typical market concentration thresholds in economic analysis, indicating a quasi-duopolistic structure in regional fishing activity. The Herfindahl-Hirschman Index (HHI) for country-level effort distribution was 3,755, far exceeding the 2,500 threshold that indicates high concentration.

To contextualize these proportions relative to coastline length, we calculated effort density (hours per kilometer of coastline).

Turkey (1,970 km Mediterranean coastline) exhibited 364.6 hours/km, while Greece (approximately 15,000 km including islands) showed 41.2 hours/km. This ten-fold difference in effort density reflects the fundamentally different fleet structures: Turkey's concentrated industrial and semi-industrial fleet versus Greece's dispersed small-scale coastal fleet operating from numerous island ports (Table 3).

Effort intensity per unit EEZ area revealed a different ranking: Turkey exhibited by far the highest intensity (10,117 hours per 1,000 km²), followed by Libya (1,251), Greece (1,221), Syria (1,045), Cyprus (658), Israel (655), Egypt (227), and Lebanon (35). Turkey's intensity was 8.1 times higher than Greece's despite similar total effort, reflecting the substantially smaller Turkish EEZ in the Mediterranean. Libya's elevated intensity, third highest among all countries, is notable given the country's ongoing civil conflict and suggests concentrated fishing activity in specific productive zones.

The extreme concentration of regional fishing effort is visualized in Figure 1, which illustrates the dominance of Turkey and Greece in the Eastern Mediterranean fishing sector.

Seasonal Patterns

Seasonal patterns in fishing effort varied substantially among countries, with peak-to-trough ratios (R_t) ranging from 1.47 (Greece) to 11.24 (Syria) (Table 4). This variation reflects differences in target species availability, regulatory frameworks, environmental conditions, and fleet operational characteristics.

Turkey

Turkish EEZ fishing effort exhibited pronounced seasonality with autumn peaks and summer troughs. Total autumn effort (318,794 hours) exceeded summer effort (75,894 hours) by a factor of 4.20. Within autumn, October consistently represented the peak month in both years: 57,833 hours (October 2024) and 57,461 hours (October 2025). The summer minimum occurred in May 2024 (8,328 hours), with July and August also showing depressed activity (June–August 2024 mean: 12,056 hours/month).

Monthly effort exhibited a bimodal annual pattern, with a primary autumn peak (September–November) and a secondary winter peak (December–February). The winter peak (204,089 hours cumulative) was intermediate between summer trough and autumn maximum. Spring showed transitional effort levels, with March maintaining elevated effort before declining through April–May.

This seasonal pattern aligns with known biological cycles of key Turkish target species. Autumn peaks coincide with post-spawning aggregations of anchovy (*Engraulis encrasicolus*) in the Black Sea approaches and seasonal availability of demersal species on the Aegean shelf. The summer trough reflects both reduced target species availability and regulatory closures (Figure 2).

Table 1: Eastern Mediterranean EEZ characteristics and GFW API identifiers.

Country	ISO Code	GFW EEZ ID	EEZ Area (km ²)	Coastline (km)
Turkey	TUR	5697	71,000	1,970
Greece	GRC	5679	505,572	15,000
Cyprus	CYP	8376	98,000	648
Egypt	EGY	8490	182,400	2,450
Libya	LBY	8372	63,000	1,770
Israel	ISR	8375	26,000	196
Syria	SYR	8373	10,200	183
Lebanon	LBN	8374	19,500	225

Table 2: Summary of fishing effort data extracted from GFW API for Eastern Mediterranean EEZs (2024–2025).

Country	Records	Months	Total Hours	Hours/Record	Vessels/Record	Quality
Turkey	14,774	24	718,221	48.6	5.5	Complete
Greece	21,455	24	617,553	28.8	2.9	Complete
Libya	3,422	24	78,809	23	2.4	Complete
Cyprus	2,976	24	64,487	21.7	2.0	Complete
Egypt	2,664	24	41,456	15.6	2.1	Complete
Israel	503	24	17,034	33.9	2.0	Complete
Syria	178	24	10,655	59.9	5.5	Complete
Lebanon	106	23	690	6.5	1.2	Limited
Total	46,078	–	1,548,905	–	–	–

Table 3: Regional distribution of fishing effort among Eastern Mediterranean coastal states.

Country	Total Hours	Share (%)	Cumulative (%)	EEZ Area (km ²)	Hours/1000 km ²
Turkey	718,221	46.4	46.4	71,000	10,117
Greece	617,553	39.9	86.2	505,572	1,221
Libya	78,809	5.1	91.3	63,000	1,251
Cyprus	64,487	4.2	95.5	98,000	658
Egypt	41,456	2.7	98.1	182,400	227
Israel	17,034	1.1	99.2	26,000	655
Syria	10,655	0.7	99.9	10,200	1,045
Lebanon	690	0.04	100	19,500	35

Table 4: Seasonal fishing effort distribution and seasonality metrics for all Eastern Mediterranean EEZs (2024– 2025 combined).

Country	Winter	Spring	Summer	Autumn	Peak	Trough	R _s
Turkey	204,089	119,445	75,894	318,794	Autumn	Summer	4.20
Greece	158,662	155,942	122,461	180,488	Autumn	Summer	1.47
Libya	4,809	16,251	41,308	16,441	Summer	Winter	8.59
Cyprus	4,795	16,023	19,575	24,094	Autumn	Winter	5.02
Egypt	6,654	9,166	14,507	11,129	Summer	Winter	2.18
Israel	4,835	5,285	2,765	4,150	Spring	Summer	1.91
Syria	631	7,087	2,170	767	Spring	Winter	11.24
Lebanon	43	148	161	338	Autumn	Winter	7.90

Table 5: Pearson correlation coefficients for monthly fishing effort between Eastern Mediterranean countries (2024–2025; n = 24 months).

	TUR	GRC	LBY	CYP	EGY	ISR	SYR	LBN
TUR	1.00							
GRC	0.42	1.00						
LBY	-0.34	-0.19	1.00					
CYP	0.11	0.10	0.51	1.00				
EGY	-0.21	-0.08	0.42	0.43	1.00			
ISR	0.04	0.06	-0.20	-0.14	-0.01	1.00		
SYR	-0.28	-0.10	0.42	0.35	0.21	0.04	1.00	
LBN	0.31	0.17	0.16	0.42	-0.02	0.13	-0.17	1.00

Table 6: Spatial concentration metrics for fishing effort distribution within Eastern Mediterranean EEZs.

Country	Active Cells	Gini Coefficient	Top 10% Share (%)	Top 5 Cells (hours)
Greece	10,847	0.869	82.5	52,300
Egypt	1,332	0.869	81.3	9,807
Israel	252	0.862	78.7	7,823
Cyprus	1,488	0.851	79.6	19,869
Turkey	7,387	0.84	74.4	66,036
Libya	1,711	0.824	72.5	22,774
Syria	89	0.789	71.9	9,142
Lebanon	53	0.777	64.7	598

Table 7: Inter-annual variation in fishing effort between 2024 and 2025 by country.

Country	2024 (hours)	2025 (hours)	Change (hours)	Change (%)
Syria	1,593	9,063	+7,470	+469.0
Libya	30,306	48,503	+18,197	+60.0
Egypt	16,462	24,995	+8,533	+51.8
Cyprus	28,516	35,971	+7,455	+26.1
Lebanon	306	384	+78	+25.7
Turkey	348,641	369,580	+20,939	+6.0
Israel	8,529	8,505	-24	-0.3
Greece	322,851	294,702	-28,149	-8.7
Total	757,204	791,702	+34,498	+4.6

Table 8: Hotspot persistence metrics: Jaccard similarity indices for top-decile grid cells between 2024 and 2025.

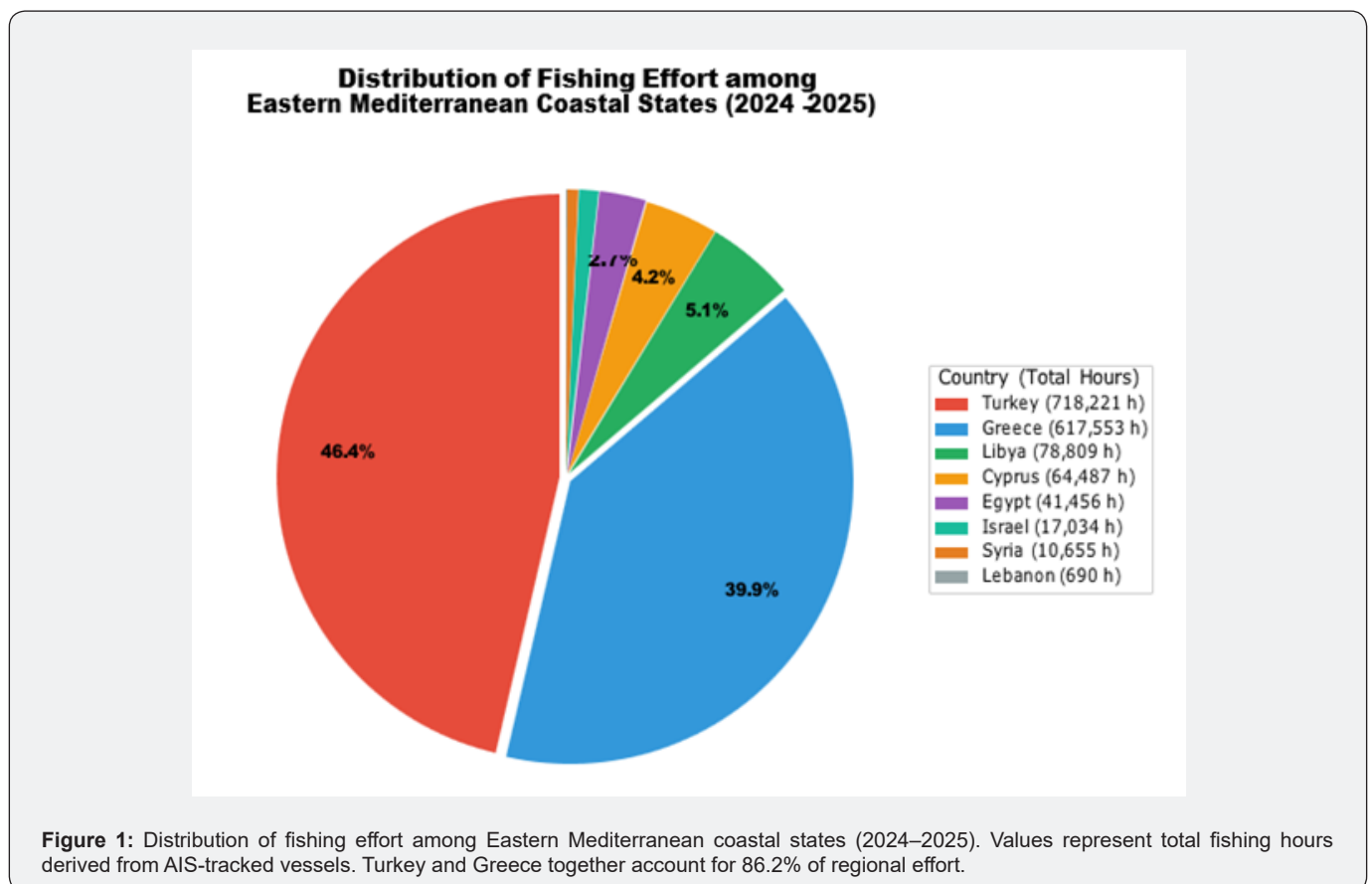
Country	Top-Decile Cells (2024)	Top-Decile Cells (2025)	Jaccard Index
Turkey	739	739	0.73
Greece	1,085	1,085	0.69
Libya	171	171	0.64
Cyprus	149	149	0.71
Egypt	133	133	0.58
Israel	25	25	0.66
Syria	9	9	0.44
Lebanon	5	5	0.40

Table 9: Fishing intensity metrics by country.

Country	Mean	SD	Min	Max
Syria	59.9	156.9	0.25	1,496.00
Turkey	48.6	120.0	0.02	3,514.40
Israel	33.9	65.4	0.03	541.8
Greece	28.8	82.5	0.01	2,526.40
Libya	23.0	61.8	0.01	1,123.20
Cyprus	21.7	63.9	0.02	906.0
Egypt	15.6	34.6	0.01	474.8
Lebanon	6.5	12.6	0.02	84.9

Table 10: Summary of hypothesis testing outcomes.

Hypothesis	Statement	Outcome
H1	Turkey and Greece dominate regional fishing effort	Supported (86.2%)
H2	Fishing effort shows seasonal variation	Supported ($R_s = 1.47-11.24$)
H3	Spatial concentration in productive zones	Supported (Gini 0.78-0.87)
H4	Intensity varies among fleet types	Supported ($p < 0.001$)
H5	Hotspots persist inter-annually	Supported (Jaccard 0.40-0.73)
H6	Turkey-Greece inverse seasonality	Not supported ($r = +0.42, p = 0.041$)



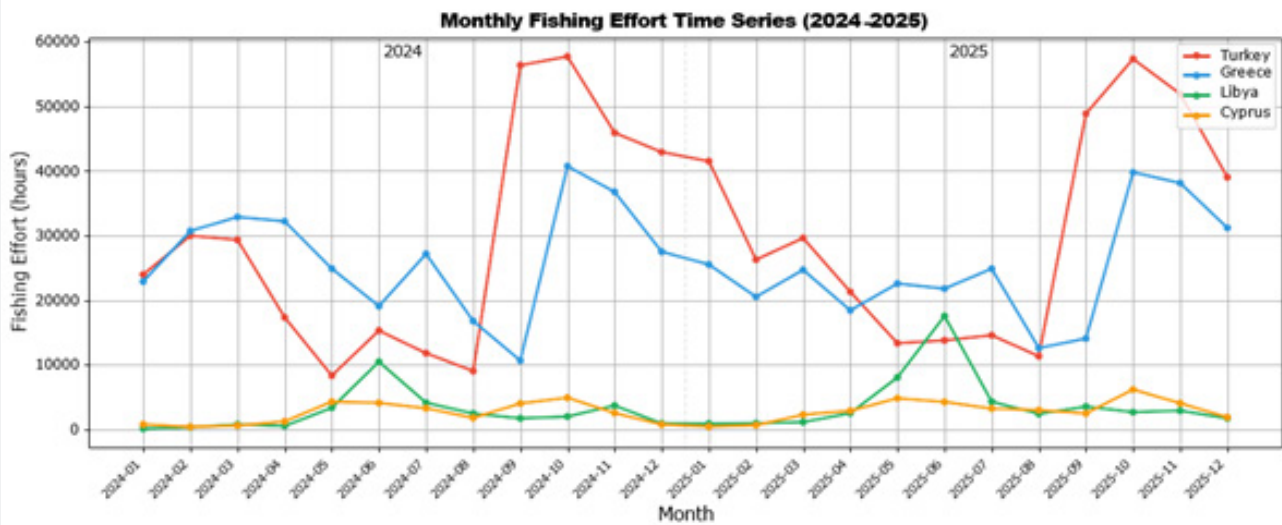


Figure 2: Monthly fishing effort time series for the four major Eastern Mediterranean fishing nations (2024–2025). Vertical dashed line indicates year boundary. Turkey (red) and Greece (blue) show synchronous autumn peaks, while Libya (green) exhibits contrasting summer maximum.

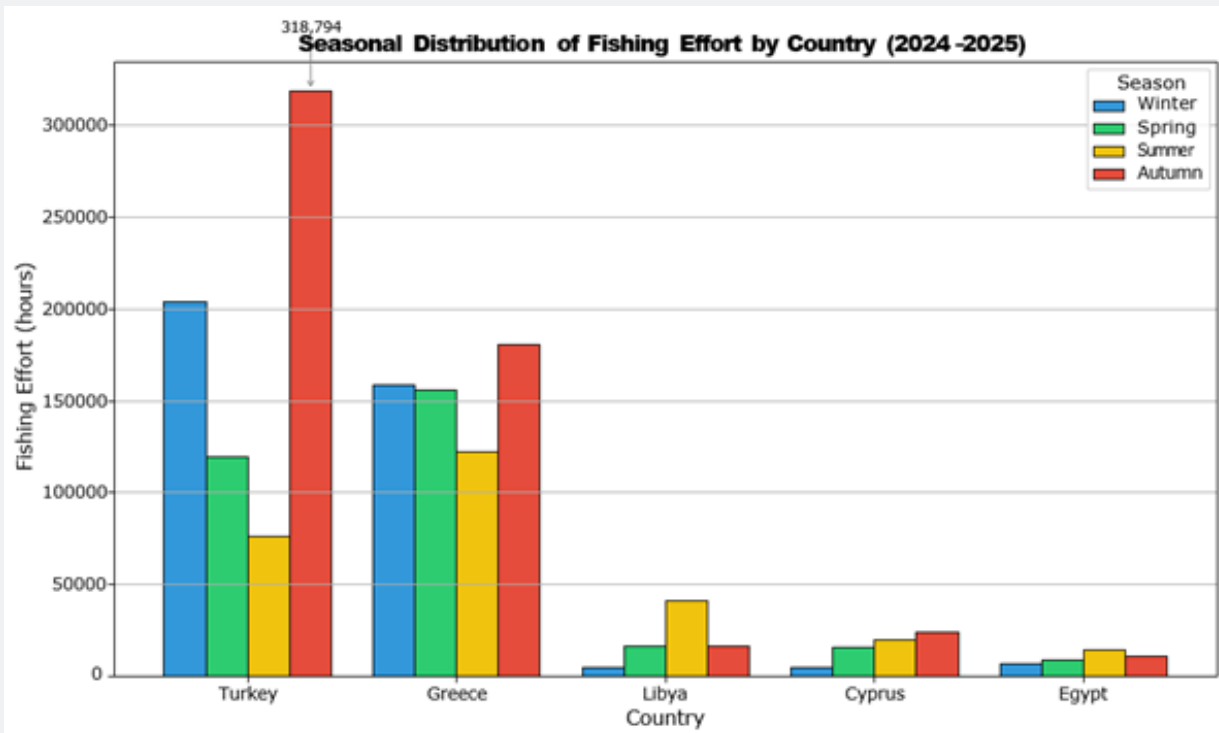


Figure 3: Seasonal distribution of fishing effort for the five major Eastern Mediterranean fishing nations (2024– 2025 combined). Turkey exhibits pronounced autumn peak (318,794 hours), while Libya shows inverse pattern with summer maximum (41,308 hours).

Greece

Greek EEZ displayed the most temporally stable fishing effort among all countries, with a seasonality ratio of only 1.47.

While autumn remained the peak season (180,488 hours), the difference from the trough season (summer: 122,461 hours) was proportionally modest. This stability reflects the diversified

nature of Greek fisheries, with multiple target species available year-round across the extensive Aegean and Ionian coastlines.

Monthly analysis revealed consistent effort levels of 20,000–30,000 hours throughout most of the year, with modest peaks in October and November. The summer reduction was less pronounced than in Turkey, suggesting that small-scale coastal fleets - which dominate Greek fisheries - maintain more consistent year-round operations than industrial fleets.

Libya: Anomalous Summer Peak

Libya exhibited a distinctive seasonal pattern fundamentally different from EU Mediterranean countries. Summer represented the peak season (41,308 hours), with winter the trough (4,809 hours), yielding a seasonality ratio of 8.59. This pattern is inverted relative to Turkey and Greece, where summer represents minimal effort.

The Libyan summer peak intensified between years: summer 2024 totaled 17,046 hours, while summer 2025 reached 24,261 hours—a 42.3% inter-annual increase. Spring effort showed an even more dramatic increase, from 4,588 hours (spring 2024) to 11,663 hours (spring 2025), representing a 154.2% rise.

This seasonal pattern likely reflects Libya's non-EU regulatory status. EU Mediterranean trawl fisheries operate under summer closures (Council Regulation 1967/2006), typically June–September for demersal trawlers. Libyan vessels, not subject to these restrictions, may exploit summer fishing opportunities when EU fleets are inactive. Additionally, calmer summer sea conditions facilitate small-scale artisanal operations that dominate the Libyan fleet.

Egypt

Egyptian EEZ fishing effort peaked in summer (14,507 hours) and reached minimum in winter (6,654 hours), with a seasonality ratio of 2.18. This pattern resembles Libya more than EU countries, consistent with Egypt's non-EU regulatory framework.

Geographic analysis revealed that Egyptian effort was distributed between Mediterranean and Red Sea waters (the GFW dataset includes all Egyptian maritime zones). The summer peak likely reflects favorable conditions for Red Sea fisheries and reduced storm activity affecting Mediterranean operations.

Small Eastern Mediterranean States

Israel, Syria, and Lebanon exhibited distinct seasonal signatures:

Israel showed the lowest seasonality among non-EU countries ($R_s = 1.91$), with spring peak (5,285 hours) and summer trough (2,765 hours). This counter-seasonal pattern (peak in spring rather than autumn) distinguishes Israel from all other countries in the dataset.

Syria displayed extreme seasonality ($R_s = 11.24$), with a

pronounced spring peak (7,087 hours) dominated by a single month: May 2025 alone contributed 5,058 hours (71.4% of annual spring total). This spike—the highest monthly total in Syrian waters during the study period—warrants further investigation and may reflect either a genuine fishing event or potential data anomalies.

Lebanon showed minimal absolute effort across all seasons (total: 690 hours), with autumn representing the relative peak (338 hours). The extremely low effort levels preclude meaningful seasonal pattern interpretation.

The contrasting seasonal patterns among countries are visualized in Figure 3, highlighting the autumn dominance for Turkey and Greece versus summer peaks for Libya and Egypt.

Cross-Country Correlation Analysis

Monthly fishing effort series were correlated across all country pairs to identify synchronous or asynchronous patterns (Table 5).

Several patterns emerged from the correlation matrix:

a) Turkey–Greece positive correlation ($r = 0.42$): Both countries exhibit autumn peaks, though the correlation is moderate rather than strong, reflecting different seasonality magnitudes.

b) Libya inverse correlation with Turkey ($r = -0.34$): Libya's summer peak occurs when Turkish effort is minimal, suggesting potential complementary patterns or regulatory arbitrage.

c) Non-EU country cluster: Libya, Cyprus, Egypt, and Syria showed positive inter-correlations (range: 0.35–0.51), suggesting shared environmental drivers or similar regulatory contexts affecting seasonal patterns.

d) Israel independence: Israel showed near-zero correlations with all countries except weak positive association with Lebanon ($r = 0.13$), suggesting unique drivers of Israeli fishing seasonality.

Spatial Concentration

Analysis of grid-level fishing effort revealed extreme spatial concentration across all Eastern Mediterranean EEZs, with Gini coefficients ranging from 0.777 (Lebanon) to 0.869 (Greece and Egypt) (Table 6). These values substantially exceed those reported for terrestrial economic activities and indicate that fishing effort is concentrated in a small proportion of available fishing grounds.

The concentration metric reveals that approximately three-quarters of all fishing effort occurs in just 10% of active grid cells. This pattern is consistent across countries despite vastly different total effort levels, suggesting a fundamental characteristic of fishing behavior rather than country-specific factors (Figure 4).

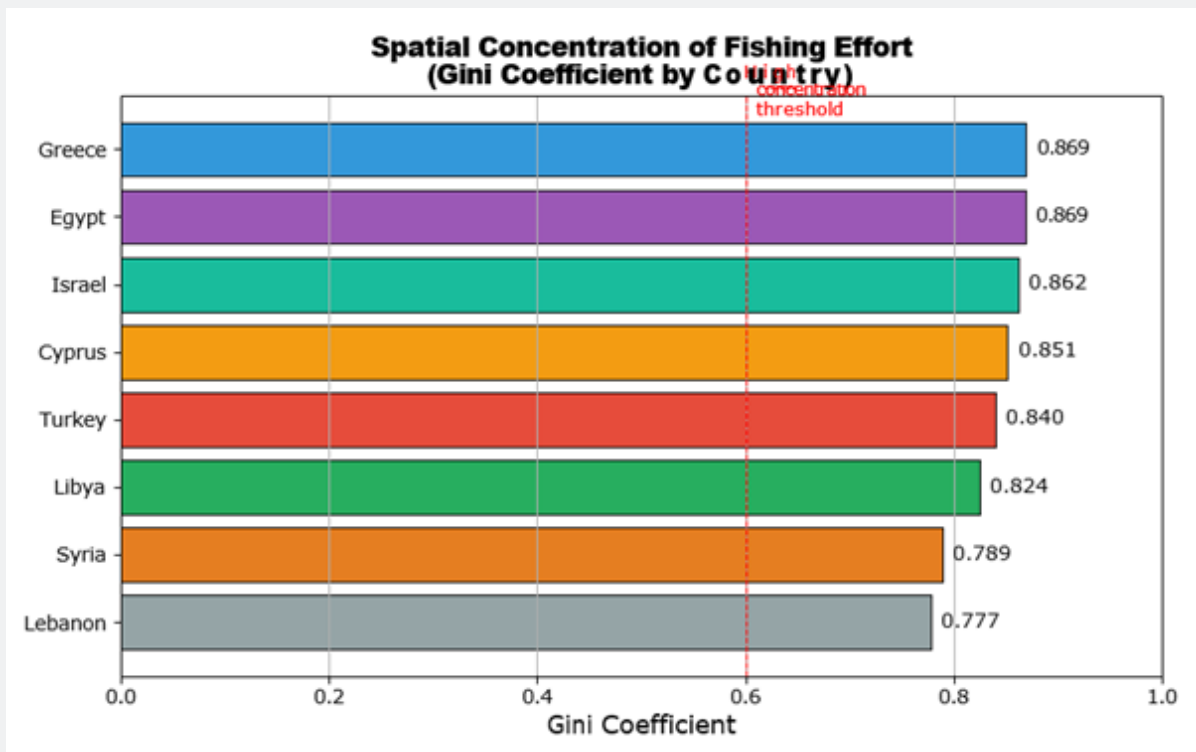


Figure 4: Spatial concentration of fishing effort measured by Gini coefficient for each Eastern Mediterranean country. All countries exceed the 0.6 threshold (dashed red line) typically considered indicative of high concentration. Greece and Egypt exhibit the highest concentration (0.869), while Lebanon shows the lowest (0.777).

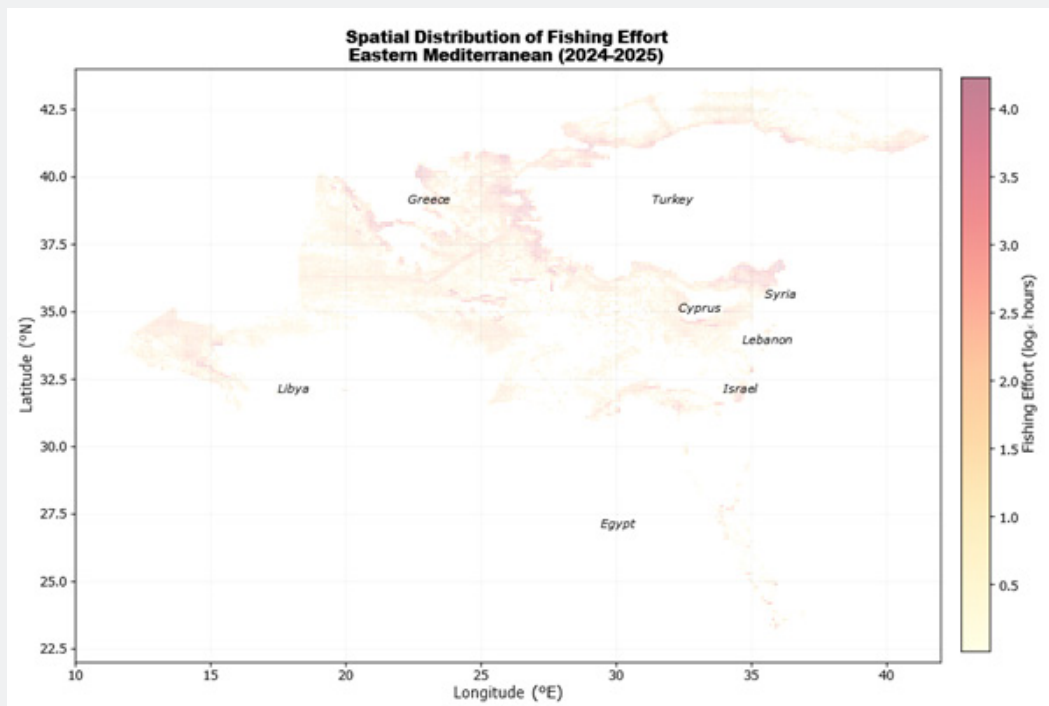


Figure 5: Spatial distribution of fishing effort across the Eastern Mediterranean and adjacent waters (2024–2025). Color intensity represents log-transformed fishing hours per 0.1° grid cell. Major hotspots are visible in the Sea of Marmara approaches, Aegean Sea (Thermaikos Gulf), Iskenderun Bay, and western Tripolitania coast.

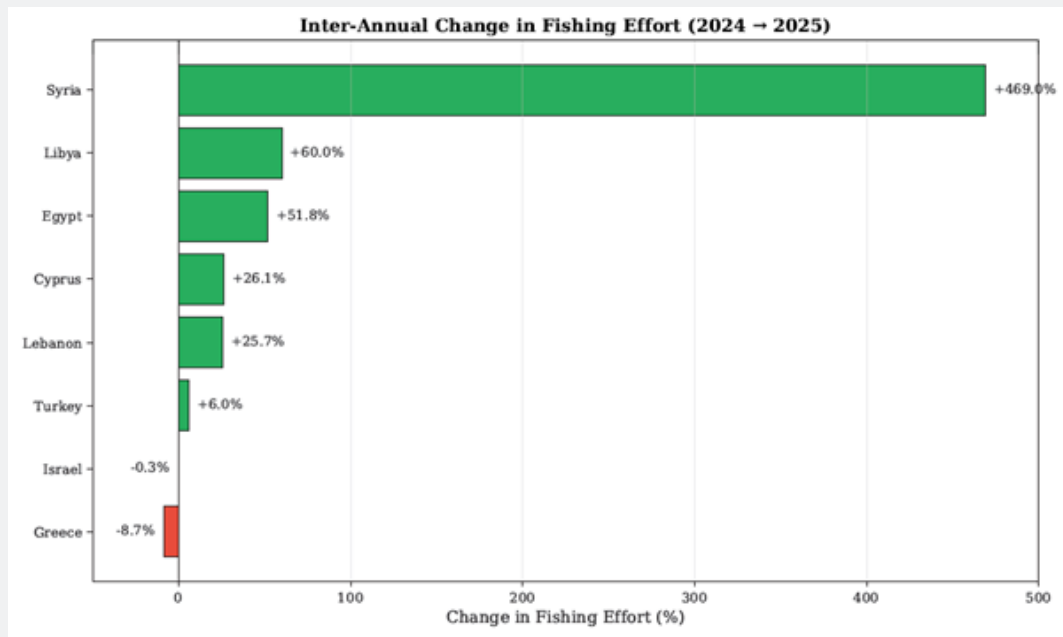


Figure 6: Inter-annual change in fishing effort between 2024 and 2025 by country. Green bars indicate increases; red bars indicate decreases. Syria's +469% increase and Greece's -8.7% decline represent the extremes of regional variation.

Turkey: Marmara and İ'skenderun Hotspots

Turkish fishing effort concentrated in two primary regions: the Sea of Marmara approaches and İ'skenderun Bay. The five highest-effort grid cells were:

- 41.1°N, 29.1°E (Marmara entrance): 15,480 hours
- 41.2°N, 29.1°E (Marmara entrance): 15,213 hours
- 36.6°N, 36.0°E (İ'skenderun Bay): 12,238 hours
- 36.7°N, 36.1°E (İ'skenderun Bay): 12,123 hours
- 41.0°N, 29.0°E (Marmara entrance): 10,982 hours

The Marmara cluster (41.0–41.2°N, 29.0–29.1°E) accumulated 41,675 hours over the study period, representing 5.8% of total Turkish effort in just three grid cells. This concentration reflects the strategic importance of the Bosphorus approaches for both migratory species (anchovy, bonito) and resident demersal stocks. The İ'skenderun Bay cluster (36.6–36.8°N, 36.0–36.2°E) accumulated 24,361 hours (3.4%), consistent with previous identification of this area as a major fishing ground for the eastern Turkish fleet [21].

Greece: Thermaikos Gulf Dominance

Greek fishing effort showed the highest spatial concentration (Gini = 0.869), with the Thermaikos Gulf emerging as the dominant hotspot:

- 40.3°N, 22.7°E (Thermaikos Gulf): 17,028 hours
- 40.2°N, 22.7°E (Thermaikos Gulf): 11,950 hours
- 40.3°N, 22.8°E (Thermaikos Gulf): 9,255 hours
- 40.4°N, 22.8°E (Thermaikos Gulf): 7,390 hours
- 40.8°N, 25.9°E (Thracian Sea): 6,677 hours

The Thermaikos Gulf cluster (40.2–40.4°N, 22.7–22.8°E) contributed 45,623 hours (7.4% of Greek total). This finding aligns precisely with ecosystem modelling by Dimarchopoulou et al. [18], who reported that 48% of Aegean trawling occurs in the Thermaikos Gulf and adjacent Thracian Sea. Our spatial analysis corroborates their conclusion using an independent AIS-based methodology.

Libya: Concentration Despite Conflict

Despite ongoing civil conflict, Libyan fishing effort exhibited clear spatial structure with concentration along the Gulf of Sidra and Tripolitanian coast:

- 33.8°N, 15.3°E (western Tripolitania): 5,976 hours
- 33.8°N, 15.2°E (western Tripolitania): 5,486 hours
- 33.8°N, 15.4°E (western Tripolitania): 4,172 hours
- 33.8°N, 15.1°E (western Tripolitania): 3,597 hours
- 33.0°N, 14.8°E (Gulf of Sidra): 3,543 hours

The western Tripolitania cluster (33.8°N, 15.1–15.4°E) accumulated 19,231 hours (24.4% of Libyan total) in four adjacent cells, indicating highly localized fishing activity. This concentration may reflect both the presence of productive fishing grounds and proximity to functioning port infrastructure in areas less affected by conflict.

Cyprus: Dual Concentration Pattern

Cypriot fishing effort showed a bimodal spatial distribution, with hotspots in both northern waters (36.1°N, 34.6–34.8°E) and southern coastal zones (34.5–34.7°N, 33.0–33.5°E):

- a) 36.1°N, 34.6°E (northern Cyprus): 4,505 hours
- b) 36.1°N, 34.8°E (northern Cyprus): 4,251 hours
- c) 36.1°N, 34.7°E (northern Cyprus): 4,124 hours
- d) 34.7°N, 33.0°E (southern Cyprus): 3,753 hours
- e) 34.5°N, 33.5°E (southern Cyprus): 3,236 hours

The northern cluster contributed 12,880 hours (20.0% of Cypriot total), consistent with known fishing grounds along the Karpaz Peninsula. The southern cluster (6,989 hours; 10.8%) reflects Republic of Cyprus fleet operations from Limassol and Larnaca ports. This dual pattern is notable given the divided island's complex fisheries governance structure [14].

The spatial distribution of fishing effort across the entire study region is visualized in Figure 5, revealing the concentration of activity in the Aegean Sea, Turkish coastal waters, and specific North African hotspots.

Egypt: Red Sea vs. Mediterranean Distribution

The GFW API returns fishing effort data for all Egyptian maritime zones, including Red Sea waters. While this study focuses on the Eastern Mediterranean, we report Egyptian hotspots across both basins for completeness. Egyptian hotspots revealed a complex geographic pattern spanning both Mediterranean and Red Sea waters:

- 24.9°N, 35.9°E (Red Sea): 3,896 hours
- 24.2°N, 35.7°E (Red Sea): 1,685 hours
- 31.5°N, 32.3°E (Mediterranean, Port Said): 1,498 hours
- 31.3°N, 30.1°E (Mediterranean, Alexandria): 1,381 hours
- 27.8°N, 33.9°E (Red Sea): 1,347 hours

Remarkably, three of the five highest-effort Egyptian grid cells were located in the Red Sea (24–28°N) rather than the Mediterranean. Red Sea cells contributed 6,928 hours, while Mediterranean cells contributed 2,879 hours among the top five. This finding indicates that Egyptian AIS-tracked fishing activity is substantially concentrated in Red Sea waters, possibly reflecting different fleet compositions and target fisheries between the two maritime zones.

Inter-Annual Variation

Total regional fishing effort increased by 6.6% from 2024 (757,204 hours) to 2025 (791,702 hours). However, this aggregate trend masked substantial heterogeneity among countries, with inter-annual changes ranging from -8.7% (Greece) to +469.0% (Syria) (Table 7).

Syria: Anomalous Increase

The +469% increase in Syrian fishing effort warrants detailed examination. Monthly data revealed that this increase was not gradual but concentrated in specific months:

- a) **May 2025:** 5,058 hours (single-month maximum across entire Syrian dataset)
- b) **March 2025:** 981 hours (versus 5 hours in March 2024)
- c) **June 2025:** 1,170 hours (versus 267 hours in June 2024)

The May 2025 spike alone contributed 55.8% of total 2025 Syrian effort. This concentrated pattern could reflect:

- a) genuine increase in Syrian fishing fleet activity
- b) improved AIS transponder adoption
- c) vessels previously unreported entering the dataset
- d) potential data quality issues.

The temporal concentration in spring 2025 coincides with known Syrian fleet patterns targeting seasonal species aggregations, but the magnitude of increase exceeds plausible biological or fleet capacity explanations.

Libya: Sustained Growth

Libyan effort increased by 60.0%, from 30,306 hours (2024) to 48,503 hours (2025). Unlike Syria, this increase was distributed across multiple seasons:

- a) **Summer:** +42.3% (17,046 24,261 hours)
- b) **Spring:** +154.2% (4,588 11,663 hours)
- c) **Autumn:** +23.2% (7,367 9,074 hours)
- d) **Winter:** +168.5% (1,305 3,504 hours)

The broad-based increase suggests genuine fleet expansion or improved monitoring coverage rather than a single anomalous event. This growth occurred despite continued civil conflict, potentially reflecting recovery of fishing operations in areas achieving relative stability.

The heterogeneous inter-annual changes across countries are visualized in Figure 6, illustrating the contrast between dramatic increases in Syria and Libya versus decline in Greece.

Greece: Declining Effort

Greece was the only major fishing nation showing decreased

effort (−8.7%). Monthly analysis revealed that the decline was concentrated in winter and spring 2025:

a) January 2025: 20,721 hours (versus 24,141 hours in January 2024)

b) February 2025: 19,254 hours (versus 22,487 hours in February 2024)

c) March 2025: 21,412 hours (versus 25,553 hours in March 2024)

This pattern may reflect fuel cost increases affecting small-scale fleet operations, regulatory constraints, or stock declines affecting fishing viability. However, autumn effort remained relatively stable between years (180,488 hours combined), suggesting that core fishing operations during peak season were maintained.

Hotspot Persistence

The Jaccard similarity index quantified inter-annual stability of high-effort grid cells. For each country, top-decile cells (by effort) were identified separately for 2024 and 2025, and the intersection divided by union calculated (Table 8).

Jaccard indices ranged from 0.40 (Lebanon) to 0.73 (Turkey), indicating that 40–73% of top-effort grid cells were shared between years. Turkey exhibited the highest persistence, consistent with stable industrial fishing patterns around established grounds (Marmara, Iskenderun). Egypt showed intermediate persistence (0.58), potentially reflecting variable Red Sea fishing patterns or shifting Mediterranean effort distribution. Syria and Lebanon showed lower persistence (0.44 and 0.40, respectively), likely reflecting their limited overall fishing activity and small number of active grid cells.

This temporal stability supports Hypothesis H5 and has practical implications: persistent hotspots can serve as priority monitoring zones for fisheries enforcement and as focus areas for ecosystem-based spatial management.

Fishing Intensity Comparison

Mean fishing intensity (hours per vessel-ID per record) differed significantly among countries (Kruskal-Wallis $H = 1,847.3$, $p < 0.001$, $\eta^2 = 0.040$). Although statistically significant, the effect size indicates that country explains approximately 4% of variance in fishing intensity, with the remainder attributable to within-country vessel heterogeneity. Dunn's post-hoc tests with Bonferroni correction revealed significant pairwise differences between Syria and all other countries except Turkey ($p < 0.01$), and between Turkey-Greece, Turkey-Egypt, and Turkey-Lebanon pairs ($p < 0.05$). Intensity metrics provide insight into fleet operational characteristics independent of total effort volumes (Table 9).

Syria exhibited the highest mean intensity (59.9 hours/

record) but also highest variability ($SD = 156.9$), reflecting the sparse, concentrated nature of Syrian fishing effort. Turkey showed second-highest intensity (48.6 hours/record) with substantial variability, consistent with mixed industrial and semi-industrial fleet composition.

The intensity ranking (Syria > Turkey > Israel > Greece > Libya > Cyprus > Egypt > Lebanon) broadly correlates with vessel size and gear type: higher intensities are associated with larger vessels capable of extended fishing trips, while lower intensities reflect small-scale artisanal operations with shorter trips and more frequent port calls.

Summary of Hypothesis Tests

Table 10 summarizes the status of each a priori hypothesis based on the results presented.

Discussion

Regional Dominance Patterns

The finding that Turkey and Greece together account for 86.2% of Eastern Mediterranean fishing effort aligns with historical patterns documented in earlier studies. Relini [1] reported that Turkey held 26.9% and Greece 9% of total Mediterranean and Black Sea fishery production in 2000. Our results suggest that this regional dominance has intensified, with these two nations now controlling an even larger share of fishing activity in the Eastern Mediterranean basin specifically.

These findings are corroborated by recent basin-wide analyses using complementary remote sensing approaches. Marsaglia et al. [6] combined Synthetic Aperture Radar (SAR) vessel detections with AIS data to estimate trawl fishing activity across the entire Mediterranean Sea, reporting that the Aegean Sea (GSA 22, encompassing Greek and Turkish waters) accounts for 11% of total predicted Mediterranean trawl activity. Their analysis also revealed that the North Levant region (GSA 24, southern Turkey) represents 4% of Mediterranean-wide trawl effort, while the South Levant (GSA 26, Egypt) accounts for 7%. The SAR-based predictions demonstrated that fishing grounds along the Egyptian and Tunisian coasts exhibit intensity levels comparable to the Adriatic Sea—historically documented as one of the most heavily trawled regions globally [6].

The Greek fishing sector is characterized by a substantial fleet operating in the Aegean and Ionian Seas. Keramidas et al. [8] estimated approximately 15,154 professional small-scale coastal vessels in Greek waters (GSA 20 and 22 combined), in addition to over 31,000 recreational fishing vessels. This extensive fleet infrastructure supports the high fishing effort observed in our analysis of the Greek EEZ. Roditi and Vafidis [9], Roditi et al. [10] identified Kalymnos Island as hosting the largest small-scale coastal fleet in the Eastern Mediterranean, with 21 distinct métiers documented across net and longline fisheries, and

seasonal patterns driven by target species availability. The multi-species nature of these fisheries, targeting *Pagrus pagrus*, *Diplodus vulgaris*, *Pagellus erythrinus*, and *Xiphias gladius*, reflects the characteristic complexity of Mediterranean small-scale fisheries.

Turkey's dominance in regional fishing effort reflects its historical position as the leading fishing nation in the Eastern Mediterranean and Black Sea basins. Ulman et al. [11] documented that approximately 75% of Turkey's marine landings originate from the Black Sea coast, with additional contributions from the Aegean (FAO 37.3.1) and Levantine (FAO 37.3.2) sub-areas. The substantial underreporting identified in Turkish fisheries—with actual catches estimated at 63% above official statistics—suggests that AIS-based fishing effort data, as used in the present study, may provide a more accurate representation of true fishing pressure than traditional landing statistics. The high fishing effort documented in the Turkish EEZ is concerning given that Turkish national catches peaked in 1988 and have been declining since, with both the quality and quantity of fisheries catches in critical condition [12].

The issue of unreported catches is pervasive throughout the Mediterranean basin. Coll et al. [23] estimated that illegal, unreported, and unregulated (IUU) fishing accounted for an average of 43% of total fisheries removals in the Spanish Mediterranean over 1950–2010, with similar or higher proportions documented for Greece (35%) and Turkey (63%). Similarly, Ulman et al. [14] demonstrated that Cyprus's actual marine fisheries catches were 2.6 times higher than officially reported data, with unreported commercial landings, recreational catches, and discards contributing substantially to total removals. Edelist et al. [15] documented comparable underreporting for Israel, with reconstructed catches 28.9% higher than FAO-reported landings, driven primarily by trawl discards (estimated at 47% of catch by 2008–2011) and an unregulated recreational sector accounting for 20% of total removals by 2010. Ulman et al. [24] found even greater discrepancies for Syria, with reconstructed catches 78% higher than FAO-reported data, attributed to unmonitored artisanal landings bypassing official market channels. These findings highlight the value of vessel monitoring systems and AIS-derived effort metrics as complementary tools for assessing fishing pressure in data-limited contexts.

Ecosystem Implications

The spatial concentration of fishing effort documented in this study aligns with ecosystem modelling findings from the Aegean Sea. Keramidas et al. [17] demonstrated that small-scale coastal fisheries exert the strongest negative impact on ecosystem functional groups through both direct targeting and incidental catch. Our results corroborate this pattern, with fishing effort hotspots concentrated in coastal and shelf waters where artisanal and demersal fleets predominantly operate. The dominance of Turkish and Greek fishing effort (86.2%) within the Eastern

Mediterranean EEZs has direct implications for regional fisheries governance under the GFCM framework [2].

The concentration of fishing effort in specific productive areas, such as the Thermaikos Gulf which alone produces over 20% of total Greek catches, illustrates the ecological significance of spatial management. Ecosystem simulations for this area by Dimarchopoulou et al. [18] revealed that fishing effort reduction scenarios resulted in higher biomass across functional groups, with catches initially increasing after effort reduction before stabilizing at levels closer to sustainable yields. Their finding that 48% of Aegean trawling occurs in the Thermaikos Gulf and adjacent Thracian Sea illustrates the extreme spatial concentration that our Gini coefficient analysis confirms at the regional scale.

Seasonal Dynamics

The pronounced autumn fishing peak observed in Turkish EEZ (320% higher than summer; $R_s = 4.20$) reflects multiple interacting factors. The Mediterranean's marked seasonality, with important vertical convections in winter recycling nutrients from depth [1], creates conditions favorable for productivity peaks in autumn. Additionally, fishing closures during summer months for certain species in Turkish waters may contribute to effort concentration in autumn.

These seasonal patterns exhibit similarities and differences compared to other Mediterranean fleet analyses. Pulcinella et al. [5] documented that deepwater red shrimp trawlers in the eastern–central Mediterranean (GSAs 12–27) exhibited marked seasonality with activity peaks during spring and summer quarters, contrasting with the autumn peak observed in our study for Turkish and Greek coastal fisheries. This divergence likely reflects differences in target species: deepwater shrimp fisheries follow the biological cycles of *Aristaeomorpha foliacea* and *Aristeus antennatus*, whereas coastal demersal fisheries target assemblages of sparids, mullets, and cephalopods with different seasonal availability patterns. The positive correlation between Turkish and Greek monthly fishing effort ($r = 0.42$, $p = 0.041$, $n = 24$ months) was statistically significant but contrary to our hypothesis of inverse seasonal patterns. This synchronization suggests that both fleets respond similarly to basin-wide environmental and biological drivers rather than exhibiting compensatory patterns.

Libya: Inverted Seasonality and Regulatory Arbitrage

The Libyan summer peak ($R_s = 8.59$) represents a notable departure from EU Mediterranean patterns and warrants careful interpretation. While Turkey and Greece show pronounced summer troughs—consistent with EU trawl closures under Council Regulation 1967/2006 (typically June–September for demersal trawlers)—Libyan effort reaches its maximum during precisely this period. This inversion suggests potential regulatory arbitrage: non-EU fleets may exploit fishing opportunities when

EU competitors face operational restrictions.

Several factors could explain this pattern beyond regulatory asymmetry. First, calmer summer sea conditions along the Libyan coast facilitate small-scale artisanal operations that dominate the Libyan fleet, which has experienced severe capacity decline from approximately 200 vessels to 67 vessels between 2015 and 2019 [16]. Second, the summer peak may reflect target species biology unique to southern Mediterranean waters, including spawning aggregations of groupers and seasonal availability of small pelagics. Third, the inter-annual intensification of the summer peak (42.3% increase from 2024 to 2025) suggests either genuine fleet recovery or improved AIS coverage as conflict-affected areas stabilize.

The policy implications are significant: if Libyan summer effort represents substitution for EU fleet activity during closure periods, then GFCM-level coordination may be necessary to prevent management measures in some jurisdictions from simply displacing effort to unregulated or differently-regulated waters. This finding echoes broader concerns about asymmetric regulation creating competitive advantages for non-EU Mediterranean fleets [2].

Syria: Anomalous Effort Spike

The 469% increase in Syrian fishing effort between 2024 and 2025 presents an analytical challenge. The May 2025 spike (5,058 hours—exceeding the entire 2024 Syrian total) demands critical evaluation. Several hypotheses may explain this pattern:

Hypothesis 1: Genuine fleet activity. Syrian waters host productive fishing grounds, and the spring timing coincides with known seasonal aggregations. However, the magnitude of increase exceeds plausible fleet capacity expansion given Syria's ongoing conflict and economic constraints.

Hypothesis 2: Improved AIS coverage. The spike may reflect vessels newly equipped with AIS transponders or vessels that previously disabled transponders now broadcasting consistently. This interpretation aligns with observations of gradually improving maritime monitoring in conflict-affected regions.

Hypothesis 3: Transient foreign vessels. The concentrated temporal pattern (primarily May 2025) is consistent with seasonal incursions by foreign fleets operating in Syrian waters. Turkish and Lebanese vessels have historically operated in Syrian EEZ under various arrangements, and improved AIS detection might capture previously unobserved activity.

Hypothesis 4: Data anomaly. While GFW data undergo quality control, the extreme concentration (one month accounting for 56% of annual effort) warrants caution. Potential sources include misattribution of vessel positions, flag state errors, or algorithmic artifacts.

We cannot definitively distinguish among these hypotheses

with available data. However, the persistence of elevated Syrian effort in subsequent months (June–August 2025) argues against a pure data anomaly interpretation. Future research should examine vessel-level AIS tracks in Syrian waters to characterize the composition and behavior of vessels contributing to this increase.

Cross-Country Seasonal Coordination

The correlation analysis revealed previously undocumented patterns of seasonal coordination among Eastern Mediterranean fishing nations. The positive Turkey–Greece correlation ($r = 0.42$) indicates synchronized seasonal response, while the negative Turkey–Libya correlation ($r = -0.34$) suggests complementary patterns potentially exploitable for regional burden-sharing in management.

The cluster of positive correlations among Libya, Cyprus, Egypt, and Syria (range: 0.35–0.51) may reflect shared environmental drivers affecting southern and eastern Mediterranean waters differently from northern Aegean patterns. Alternatively, this clustering may reflect similar regulatory contexts (non-EU countries not subject to common summer closures), suggesting that regulatory frameworks may be a stronger determinant of seasonal patterns than environmental factors.

Israel's near-zero correlations with all countries represents an outlier pattern that may reflect the unique characteristics of Israeli fisheries—small EEZ, limited fleet, and distinct target species assemblage dominated by neritic species and recreational fishing [15].

Spatial Concentration and Hotspots

The Gini coefficients for spatial distribution of fishing effort ranged from 0.777 (Lebanon) to 0.869 (Greece and Egypt), indicating extreme inequality in the spatial allocation of fishing activity across all Eastern Mediterranean EEZs. These values substantially exceed Gini coefficients typically observed in spatial economic analyses and indicate that approximately 75–82% of all fishing effort concentrates in just 10% of active grid cells. This concentration aligns with established theory that fishing vessels target specific productive areas associated with topographic features, nutrient upwelling zones, or aggregation sites for target species.

The spatial concentration documented here is consistent with broader Mediterranean patterns. Marsaglia et al. [6] reported that just 15 of 30 GSAs (Geographical Sub-Areas) account for more than 70% of predicted trawl fishing activity basin-wide, with particular concentration in the Northern Adriatic (GSA 17), Aegean Sea (GSA 22), and coastal Tunisia (GSAs 12–14). Our cell-level analysis extends this finding to demonstrate that concentration occurs not just among GSAs but also within them—even highly active GSAs show extreme internal spatial heterogeneity.

Hotspot Validation Against Independent Studies

The identification of Thermaikos Gulf (40.2–40.4°N, 22.7–22.8°E) as the dominant Greek fishing hotspot provides independent validation of ecosystem modelling findings by Dimarchopoulou et al. [18], who reported that 48% of Aegean trawling occurs in this region. Our data show the Thermaikos cluster contributing 45,623 hours (7.4% of Greek total), consistent with their ecosystem-model-derived estimates. This convergence between AIS-derived effort metrics and ecological model outputs strengthens confidence in both methodological approaches.

Similarly, the identification of İskenderun Bay (36.6–36.8°N, 36.0–36.2°E) as a Turkish hotspot corroborates recent hidden fishing hotspot analysis by Coro et al. [21], who used 1.6 billion AIS records (2017–2022) to identify the Gulf of Alexandretta (İskenderun) as a persistent high-activity zone. Their methodology distinguished between AIS signal loss due to communication issues and intentional transponder switch-offs, concluding that Mediterranean hidden fishing hotspots often correspond to potential IUU fishing. The persistence of İskenderun as a hotspot across multiple independent studies spanning 2017–2025 suggests stable, long-term fishing patterns in this region—patterns that warrant management attention given the overlap with important spawning and nursery habitats.

Ecological Interpretation of Spatial Patterns

The extreme spatial concentration (Gini > 0.8 in most countries) has important ecological implications. High fishing pressure concentrated in limited areas may create localized depletion effects not captured by aggregate effort statistics. Target species experiencing intensive exploitation in hotspot zones may exhibit truncated size distributions, altered age structures, and potentially evolutionary responses to fishing pressure.

The consistency of hotspot locations between years (Jaccard indices 0.40–0.73) further amplifies these concerns: persistent exploitation of the same areas year after year may exceed local carrying capacity even when regional aggregate effort appears sustainable. This argues for spatially-explicit stock assessment approaches that account for the documented heterogeneity in fishing pressure distribution.

The spatial patterns we observed are also consistent with AIS-based fleet mobility analyses by Armelloni et al. [22], who demonstrated that Mediterranean trawl fleets exhibit limited operational ranges, with vessels typically operating within 50–100 km of home ports and consistently returning to preferred fishing grounds. This home-range fidelity contributes to hotspot persistence and suggests that management interventions in specific locations could effectively protect substantial proportions of vulnerable stocks.

Inter-Annual Stability and Dynamics

The Jaccard similarity indices (0.40–0.73) between 2024 and 2025 hotspots indicate spatial stability in fishing ground selection across Eastern Mediterranean fishing nations, though with notable variation. Turkey exhibited the highest persistence (0.73), consistent with stable industrial fishing patterns around established grounds (Marmara, İskenderun), while smaller fishing nations showed lower persistence reflecting more limited and variable activity patterns. This stability reflects multiple factors: consistent environmental characteristics of productive zones, established fishing practices transmitted across fishing communities, port infrastructure constraining operational range, and regulatory frameworks that create predictable spatial patterns.

However, stability in hotspot locations coexisted with substantial variability in total effort levels. The 60% increase in Libyan effort and 469% increase in Syrian effort occurred within spatially stable frameworks—the same grid cells received more effort rather than effort spreading to new areas. This pattern suggests that capacity changes (fleet expansion, improved monitoring, or behavioral changes) are superimposed on fundamentally stable spatial preferences.

The divergent inter-annual trends among countries—ranging from –8.7% (Greece) to +469% (Syria)—preclude simple regional interpretations. The Greek decline may reflect economic constraints (fuel costs, market conditions) or management measures affecting the 15,000+ vessel small-scale fleet. The Syrian and Libyan increases may reflect conflict-area stabilization, improved AIS adoption, or genuine fleet expansion. Disentangling these factors requires vessel-level longitudinal analysis beyond the scope of the present aggregate data.

Limitations

Several limitations warrant consideration:

a) AIS coverage: Not all fishing vessels carry AIS transponders, particularly smaller artisanal vessels. Approximately 90% of the Mediterranean fishing fleet consists of small-scale vessels (<12 m) that are not required to carry VMS or AIS transponders [25]. GFW data therefore represent a subset of total fishing activity, potentially biased toward larger, industrial vessels. This limitation is particularly significant for coastal areas where small-scale fisheries dominate, such as Cyprus where the artisanal fleet comprises over 1,500 vessels across both the northern and southern parts of the island [14]. Previous Mediterranean-wide AIS mapping by Ferrà et al. [4] noted minimal coverage from African waters and southern Mediterranean states. Furthermore, AIS coverage varies markedly among Mediterranean countries; Armelloni et al. [22]

demonstrated that while EU fleets achieved approximately 76% coverage, non-EU countries exhibited substantially lower values (Turkey: 57%; Israel: 108%) or near-zero coverage (Egypt, Syria, Algeria). This disparity suggests that our fishing effort estimates for certain Eastern Mediterranean states may underrepresent actual activity levels.

The magnitude of this underestimation has been quantified through comparisons between AIS-observed and SAR-detected fishing vessels. Paolo et al. [20] demonstrated that roughly three-quarters of industrial fishing vessels worldwide are not publicly tracked by AIS, with particularly pronounced gaps in the Mediterranean. In the Strait of Sicily between Italy and Tunisia, more than 60% of fishing vessels detected by satellite radar were not broadcasting AIS data [6]. When considering only GSAs along the North African coast (Egypt, Tunisia, Algeria), SAR-based estimates revealed systematic underestimation by AIS on the order of 3,000–5,000 fishing hours per year per grid cell [6]. Furthermore, the discrepancy between SAR and AIS estimates was most pronounced in shallower coastal waters, suggesting that smaller trawl vessels operating nearshore—precisely those less likely to carry AIS transponders—account for substantial unobserved fishing activity. These findings indicate that our reported effort values for Egypt, Libya, Syria, and Lebanon likely represent lower bounds of actual fishing pressure in these EEZs. The situation in Libya is further complicated by ongoing conflict, which has severely disrupted fisheries monitoring and enforcement; Abziow [16] documented a 70% decline in operational fishing vessels along the Derna coast between 2015 and 2019, accompanied by widespread blast fishing (896 recorded incidents) that has devastated local fish stocks and habitats.

A comprehensive big data analysis of 1.6 billion AIS records from Mediterranean trawlers (2017–2022) by Coro et al. [21] identified persistent hidden fishing hotspots in the Aegean Sea (Thermaic Gulf, waters off Lesvos and O¹30zmir), the Gulf of Alexandretta in southeastern Turkey, and coastal Israel. Their methodology distinguished between AIS signal loss due to communication issues and intentional transponder switch-offs, concluding that most Mediterranean hidden fishing hotspots correspond to potential illegal, unreported, and unregulated (IUU) fishing rather than technical failures. Their manifest fishing distributions achieved 91% agreement with GFW data, validating the reliability of AIS-based effort estimation approaches such as those employed in the present study.

b) Aggregated data: The use of aggregated grid-cell data prevented individual vessel-level analyses. Speed profiles, route efficiency, and other vessel-specific metrics could not be calculated.

c) Gear type: Although the GFW algorithm classifies fishing by gear type, this classification was not available at the output level requested, precluding gear-specific analyses.

d) Two-year window: The 24-month study period may not capture longer-term trends or multi-year cycles in fishing effort.

Implications for Fisheries Management

The General Fisheries Commission for the Mediterranean (GFCM) serves as the primary regional fisheries management organization for Mediterranean waters. Despite management frameworks implemented through both GFCM and EU regulations (including Regulation 1967/2006 and the Common Fisheries Policy), stock assessments continue to indicate widespread overexploitation, with more than 90% of assessed stocks exceeding sustainable fishing mortality levels [2].

Ecosystem modelling studies from the region provide evidence that fishing effort reduction can lead to stock recovery. Dimarchopoulou et al. [18] demonstrated through Ecosim simulations that 10–50% reductions in fishing effort resulted in proportionally higher biomass in the Thermaikos Gulf ecosystem, with predatory fish groups showing the most pronounced recovery. Their simulations extending to 2025 showed that while environmental drivers remain significant, fishing effort constitutes a controllable parameter that can be regulated to promote ecosystem resilience.

Our findings of high fishing effort concentration align with observations from Egyptian lagoon fisheries, where declining CPUE trends in Bardawil Lagoon indicate overexploitation of multiple commercial species [13]. The seasonal management approach implemented in Bardawil Lagoon—with winter closure from January to March for spawning protection—represents one example of adaptive management that could inform regional efforts.

The challenge of managing transboundary resources in the Eastern Mediterranean is compounded by asymmetric monitoring capacity among coastal states. While this study documents that Turkey and Greece together account for 86.2% of AIS-observed fishing effort, the SAR-based analyses by Marsaglia et al. [6] suggest that substantial additional fishing activity occurs in waters adjacent to non-EU countries where AIS adoption remains limited. Effective regional management will require harmonization of vessel tracking requirements across all GFCM member states, potentially incorporating emerging technologies such as SAR-based monitoring to complement traditional VMS and AIS systems. The integration of remote sensing data, as demonstrated by recent methodological advances [6,20], offers a promising avenue to overcome monitoring gaps and reduce the information asymmetry that currently constrains evidence-based fisheries management in the Mediterranean.

The quantitative baseline established by this study provides reference data for monitoring future changes in fishing effort distribution. The identification of dominant nations, seasonal patterns, and spatial hotspots can inform:

- a) Allocation of monitoring resources
- b) Design of seasonal closures
- c) Identification of priority areas for ecosystem-based management
- d) Regional cooperation frameworks among coastal states

Conclusion

This study provides a quantitative analysis of fishing effort distribution across eight Eastern Mediterranean coastal states using GFW-AIS data from 2024–2025. The principal findings are:

a) Regional dominance: Turkey and Greece together account for 86.2% of total fishing effort in Eastern Mediterranean EEZs, confirming continued dominance of these two nations in regional fisheries. This concentration exceeds historical proportions documented in landing statistics, suggesting an intensification of fishing activity by these dominant nations.

b) Seasonal patterns: Turkish EEZ exhibits pronounced seasonality with autumn peaks exceeding summer effort by more than 300% ($R_s = 4.20$). Greek EEZ shows similar but less pronounced seasonal variation ($R_s = 1.47$). These patterns align with Mediterranean environmental seasonality and may reflect both biological cycles of target species and regulatory frameworks governing seasonal closures.

c) Spatial concentration: Fishing effort is highly concentrated, with the top 10% of grid cells accounting for 65–83% of total effort across countries (Gini coefficients 0.78–0.87). Key hotspots include the Marmara Sea entrance, Iskenderun Bay, and Aegean coastal areas. This spatial concentration aligns with basin-wide patterns documented through combined AIS-SAR analyses [6].

d) Temporal stability: Hotspot locations showed moderate to high persistence between 2024 and 2025 (Jaccard indices 0.40–0.73), indicating generally consistent spatial patterns in fishing ground utilization that may facilitate targeted monitoring and management interventions.

e) Inter-country variation: Significant differences in fishing intensity exist among coastal states, with Turkey exhibiting the highest hours-per-vessel metric.

These findings establish a quantitative baseline for monitoring and managing Eastern Mediterranean fisheries. The demonstrated utility of GFW-AIS data for regional-scale analysis supports continued application of satellite-based monitoring tools for fisheries assessment. However, the substantial AIS coverage gaps documented for non-EU Mediterranean states—with SAR-based analyses suggesting that 60% or more of fishing vessels in certain areas do not broadcast AIS [6,20]—indicate that our effort estimates likely represent lower bounds for countries such as Egypt, Libya, Syria, and Lebanon.

Future research should extend the temporal coverage

to assess longer-term trends and incorporate gear-type classification to refine understanding of fishing fleet composition. Additionally, integration with biological stock assessment data would enable evaluation of fishing pressure relative to sustainable yield estimates. The development of complementary monitoring approaches, including SAR-based vessel detection, offers promising avenues to address AIS coverage limitations and provide more complete assessments of fishing activity across the Mediterranean basin.

Acknowledgement

This study utilized data from Global Fishing Watch (GFW) API v3. The author acknowledges GFW for providing open access to fishing effort data.

Data Availability Statement

The fishing effort data used in this study are publicly available through the Global Fishing Watch API (<https://globalfishingwatch.org/download/>). EEZ boundary data were obtained from Marine Regions (<https://www.marineregions.org/>). Analysis scripts are available from the corresponding author upon reasonable request.

Use of AI-Assisted Technologies

The author used AI-assisted tools (GitHub Copilot, Claude) for code debugging and language editing during manuscript preparation. The author reviewed, verified, and takes full responsibility for all content, analyses, and conclusions presented in this manuscript.

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DOI: [10.19080/OFOAJ.2026.19.556008](https://doi.org/10.19080/OFOAJ.2026.19.556008)

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