

TECHNICAL PAPER

A reproducible QGIS workflow for visualizing Copernicus Marine Mediterranean temperature data

ANTONIO O. LILLO*

Environmental Biologist, Nova Siri, Matera, Italy. ORCID *Antonio O. Lillo*  <https://orcid.org/0000-0001-7312-2170>



ABSTRACT. This technical document presents a reproducible geospatial workflow for ingesting, rendering, and temporally configuring multidimensional marine oceanographic data using QGIS LTR 3.44. Using the Mediterranean Sea physics numerical analysis and forecast product from the Copernicus Marine Environment Monitoring Service (CMEMS; product MEDSEA_ANALYSISFORECAST_PHY_006_013), which assimilates satellite and *in-situ* observations, this guide illustrates practical operational procedures within an open-source desktop environment. The demonstrated workflow covers NetCDF data loading, surface layer subsetting, range-calibrated singleband pseudocolor symbology, and dynamic temporal control configuration for time-series display across the Mediterranean Basin using an illustrative one-month dataset (August 2026). This step-by-step framework addresses software entry barriers, providing marine researchers and spatial analysts with an open-source protocol for processing multidimensional oceanographic model outputs.

Key words: QGIS, Copernicus Marine Service (CMEMS), NetCDF, sea surface temperature (SST), Mediterranean Sea, marine monitoring.

Flujo de trabajo reproducible en QGIS para visualizar los datos de temperatura marina del Mediterráneo de Copernicus



*Correspondence:
antoniooscar.lillo@gmail.com

Received: 29 September 2026
Accepted: 21 October 2026

ISSN 2683-7595 (print)
ISSN 2683-7951 (online)

<https://ojs.inidep.edu.ar>

Journal of the Instituto Nacional de
Investigación y Desarrollo Pesquero
(INIDEP)



This work is licensed under a Creative
Commons Attribution-
NonCommercial-ShareAlike 4.0
International License

RESUMEN. Este documento técnico presenta un flujo de trabajo geoespacial reproducible para la inclusión, visualización y configuración temporal de datos oceanográficos marinos multidimensionales mediante QGIS LTR 3.44. Utilizando el producto del análisis y pronóstico numérico físico del Mar Mediterráneo, proveniente del Servicio de Vigilancia del Medio Marino de Copernicus (CMEMS; producto MEDSEA_ANALYSISFORECAST_PHY_006_013), el cual asimila observaciones satelitales e *in situ*, esta guía ilustra los procedimientos operativos prácticos en un entorno de escritorio de código abierto. El flujo de trabajo expuesto abarca la carga de datos en formato NetCDF, la extracción de subconjuntos de la capa superficial, la aplicación de simbología de pseudocolor de banda única con rangos calibrados y la configuración de control temporal dinámico para la visualización de series temporales en toda la cuenca mediterránea, empleando un conjunto de datos ilustrativo correspondiente a un mes (agosto de 2026). Este marco de trabajo paso a paso aborda las barreras de acceso al *software*, proporcionando a investigadores marinos y analistas espaciales un protocolo de código abierto para el procesamiento de resultados de modelos oceanográficos multidimensionales.

Palabras clave: QGIS, Servicio Marino de Copernicus (CMEMS), NetCDF, temperatura de la superficie del mar (SST), Mar Mediterráneo, vigilancia marina.

INTRODUCTION

In recent decades, the assessment and monitoring of marine ecosystems have become critically important in the face of escalating anthropogenic pressures, climate change, the introduction of alien species, the overexploitation of biological resources, and environmental pollution (Tiralongo 2019; Von Schuckmann et al. 2019). Understanding the complex dynamics of oceans and seas requires high-resolution, reliable, and timely data to identify environmental stressors and evaluate ecosystem responses over time (Semeraro et al. 2020). To address these challenges, the European Union has championed flagship initiatives such as the Copernicus program. Within this framework, the Copernicus Marine Environment Monitoring Service (CMEMS) provides scientifically validated information on the physical and biogeochemical states of global oceans and seas (Le Traon et al. 2019). Rather than relying exclusively on direct satellite observations, CMEMS integrates diverse oceanographic sources through advanced numerical modeling. Specifically, operational physical products such as the Mediterranean Sea Analysis and Forecast system (MEDSEA_ANALYSISFORECAST_PHY_006_013) combine hydrodynamics with data assimilation techniques, merging satellite-derived Sea Surface Temperature (SST) and sea level anomalies with *in situ* profiles to generate continuous model analyses and short-term forecasts (Von Schuckmann et al. 2016). These multidimensional marine products are distributed in scientific open standards such as Network Common Data Form (NetCDF), which store multidimensional arrays of geospatial and oceanographic variables (Okladnikov et al. 2016). Effectively processing and visualizing these multidimensional datasets requires accessible geospatial software. Over recent decades, Geographic Information Systems (GIS) have evolved into essential platforms for environmental data handling (Duarte and Teodoro 2021). Among open-source solutions, QGIS provides a robust desktop environment supporting dynamic raster and mesh

rendering, cross-platform stability, and multidimensional file drivers. Although general software documentation and basic platform tutorials exist, applied marine literature often lacks end-to-end, reproducible workflows demonstrating how to bridge raw CMEMS NetCDF outputs directly with native QGIS dynamic temporal controls. To address this technical entry barrier, the objective of this technical document is to provide a step-by-step operational protocol for opening, subsetting, styling, and animating Copernicus Marine model outputs in QGIS. By presenting an integrated workflow applied to Sea Surface Temperature across the Mediterranean Basin, this guide provides a standardized, code free technical contribution for researchers and environmental managers processing multidimensional oceanographic data.

MATERIALS AND METHODS

Software architecture and working environment

To achieve the objectives of this study, the processing and visualization pipeline relies exclusively on open-source tools to ensure full reproducibility. The reference GIS environment adopted is QGIS (LTR 3.34/3.44), operating on 64-bit architecture and natively integrated with the Geospatial Data Abstraction Library (GDAL/OGR) for multidimensional NetCDF driver handling. The inputs, configurations, and outputs of the processing environment are defined as follows:

- Input Data Oceanographic NetCDF (.nc) files retrieved from Copernicus Marine.
- Software Settings: Coordinate Reference System set to WGS 84 (EPSG:4326), raster rendering configured to Singleband Pseudocolor, and temporal filtering managed via the native QGIS Temporal Controller.
- Outputs: calibrated single-frame surface temperature maps (exported at 300 DPI in PNG format) and dynamic temporal sequence animations.

Data sources: Copernicus Marine Service (CMEMS)

The input dataset was retrieved from the Copernicus Marine Environment Monitoring Service (CMEMS) online platform (<https://marine.copernicus.eu/access-data/>). The selected oceanographic product corresponds to the Mediterranean Sea Physics Analysis and Forecast system (MEDSEA_ANALYSISFORECAST_PHY_006_013, DOI: <https://doi.org/10.48670/mds-00359>). Data retrieval was performed via the Copernicus Marine Data Store subsetting protocol with the following explicit query parameters:

- Spatial bounding box: bounded within latitude 30.0° N to 46.0° N and longitude 6.0° W to 36.0° E, covering the entire Mediterranean Basin.
- Extracted variable and depth: Sea Surface Temperature (SST), represented by potential temperature (thetao), extracted exclusively at the surface depth level.
- Temporal interval and aggregation: monthly averaged product corresponding to the full calendar month of August 2026 (temporal window: August 1, 2026, 00:00:00 UTC to August 31, 2026, 23:59:59 UTC).
- File metadata and technical specifications: the downloaded file (cmems_mod_med_phy-tem_an_fc_4.2km_P1M-m.nc, download date: September 1, 2026) has an overall file size of approximately 18.4 MB.

This operational model features a regular computational grid with an actual native spatial resolution of 1/24° ($\sim 0.042^\circ \times 0.042^\circ$, or ~ 4.2 km), enabling an accurate representation of thermal gradients across the Mediterranean Basin.

General methodological procedure

The operational protocol is structured into three consecutive phases:

1. Data acquisition and subsetting: targeted selection via the Copernicus Marine online catalog subsetting protocol, defining the geographic bounding box of the Mediterranean Basin and restricting temporal extraction to August 2026 to optimize NetCDF file size and computational processing.
2. GIS import and multidimensional structuring: importing the NetCDF raster layer into QGIS LTR using the GDAL multidimensional driver, verifying spatial metadata, selecting the thetao variable at surface level, and assigning the global geographic coordinate reference system (WGS 84 / EPSG:4326) (Figure 1).
3. Symbolology calibration and dynamic visualization: applying a continuous Singleband Pseudocolor ramp calibrated to the minimum and maximum surface temperature values (16.77 °C to 32.64 °C), configuring the QGIS Temporal Controller for time-frame rendering, and generating high-resolution cartographic layouts.

RESULTS

Loading CMEMS oceanographic layers in QGIS

The QGIS LTR operating interface (Figure 1) illustrates the initial phase of the data loading procedure, focusing on opening the oceanographic dataset in NetCDF format extracted from the Copernicus Marine portal. As highlighted by the software's menu tree, access to spatial datasets is achieved through native raster layer management by selecting the file path of the georeferenced data.

Preliminary visualization of Sea Surface Temperature (SST) in the Mediterranean Sea

The QGIS interface (Figure 2) shows the outcome of loading the monthly-mean oceanographic dataset corresponding to the Mediterranean Sea

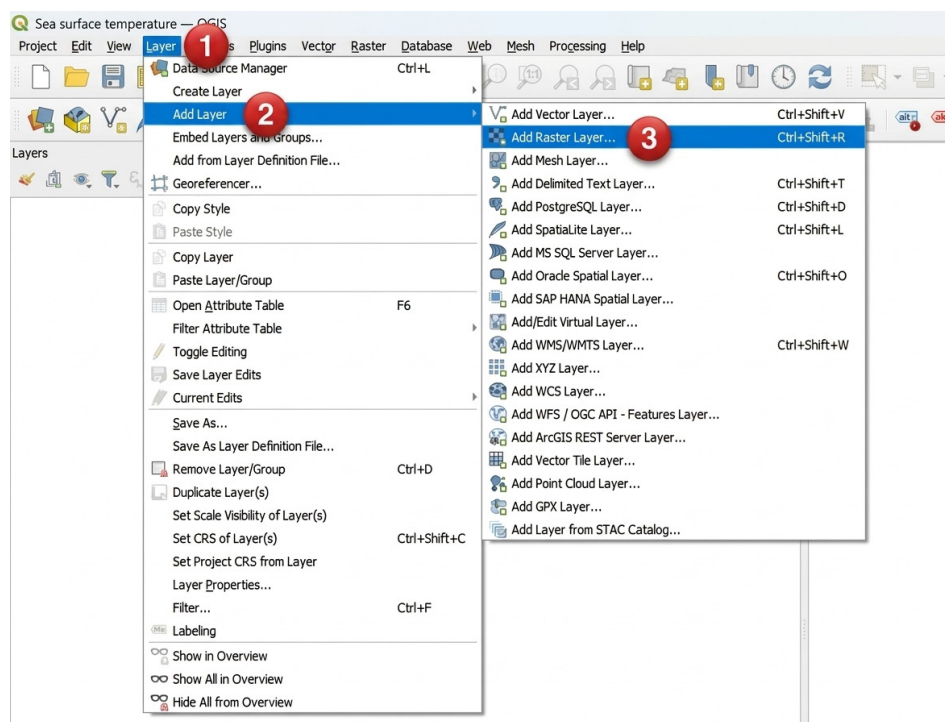


Figure 1. Data loading procedure in QGIS LTR (v3.44 on Windows OS). The annotated click path highlights the native raster ingestion sequence: Layer (1) > Add Layer (2) > Add Raster Layer (3).

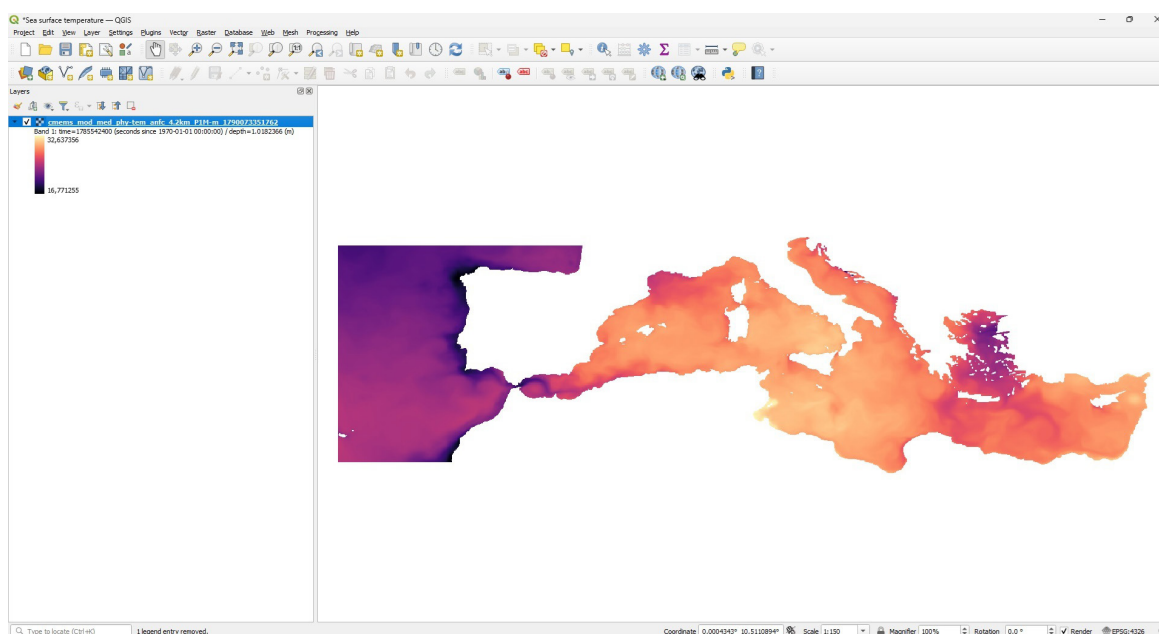


Figure 2. Initial visualization of Sea Surface Temperature (SST) across the Mediterranean Basin within QGIS.

Physics Analysis and Forecast product (cmems_mod_med_phy-tem_anfc_4.2km_P1M-m.nc). The map displays the surface potential temperature variable (*thetao*) filtered for the surface depth level (approximately 1 m). The application of the default color ramp highlights the spatial distribution of monthly surface temperatures across the Mediterranean Basin and adjacent Atlantic areas, with values ranging from a minimum of 16.77 °C to a maximum of 32.64 °C.

Advanced configuration of symbology and raster rendering in QGIS

The layer properties interface (Figure 3) provides the parameters for raster rendering of Copernicus Marine multidimensional oceanographic data. Within the *Symbology* panel (accessible via layer *Properties*), the following visual rendering parameters are set:

- Singleband pseudocolor rendering: converts

raw numerical data into a continuous chromatic representation. The user selects the target raster band corresponding to the sea surface temperature variable (*thetao*) at a surface depth level of approximately 1 m.

- Min./max. value calibration: sets the lower and upper limits of the raster data histogram. For this dataset, limits are configured from 16.77 °C to 32.64 °C to map the full range of surface temperatures observed across the Mediterranean Basin.
- Color ramp management: applies a continuous or interpolated color gradient across the calibrated temperature range to display spatial thermal variations. .
- Layer rendering section: controls layer blending modes (set to Normal) and display adjustments (brightness, contrast, and saturation) without modifying underlying dataset values.
- Resampling options: sets resampling parameters (such as *Nearest Neighbour*) to control pixel rendering during map zooming and panning operations across the study area.

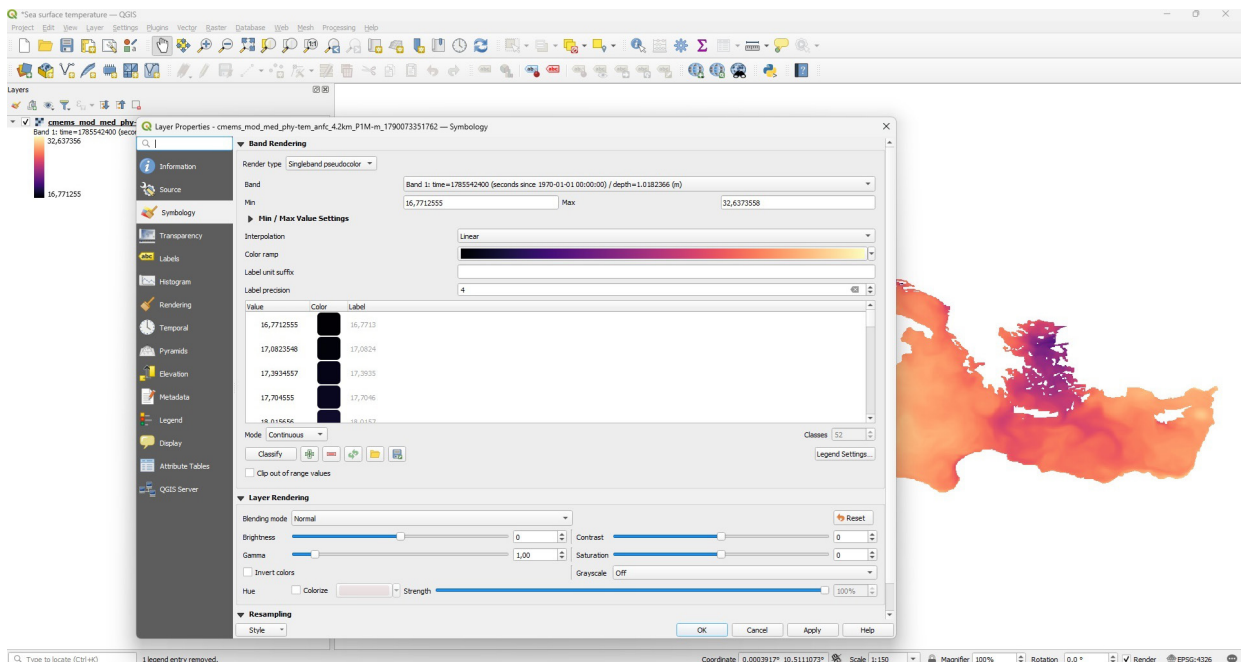


Figure 3. Symbology and raster rendering settings within the QGIS layer properties.

Selection of rendering modes in the symbology panel

Figure 3 illustrates the drop-down menu associated with the *Render type* option in QGIS. This setting determines the visualization mode for the Copernicus Marine NetCDF dataset (*thetao*). Available options include:

- Singleband gray: renders raster data using a monochromatic grayscale palette.
- Singleband pseudocolor: maps continuous numerical values onto an interpolated color palette to represent thermal spatial gradients.
- Multiband color: used for multi-channel rasters (e.g. multispectral imagery).
- Palettes/unique values and single color: applied to categorical datasets or uniform layer displays.
- Hillshade and contours: used for generating relief shading or extracting isothermal isolines.

Configuration of the dynamic temporal control module in QGIS

The layer properties interface displays the Temporal configuration tab in QGIS LTR 3.44 (Figure 4). This module manages the native time component embedded in Copernicus Marine multidimensional datasets. By enabling Dynamic Temporal Control, the user defines the temporal range for spatial rendering. For monthly-mean datasets (P1M-m), the module is configured to recognize the explicit start and end timestamps stored in the NetCDF metadata. Enabling dynamic temporal control restricts layer visibility strictly to the defined validity window (e.g. August 1, 2026, to August 31, 2026). When multiple sequential NetCDF files or higher-frequency outputs (e.g. daily P1D) are loaded into the workspace, the global Temporal Controller panel uses these temporal boundaries to automate time-series transitions across consecutive observation periods.

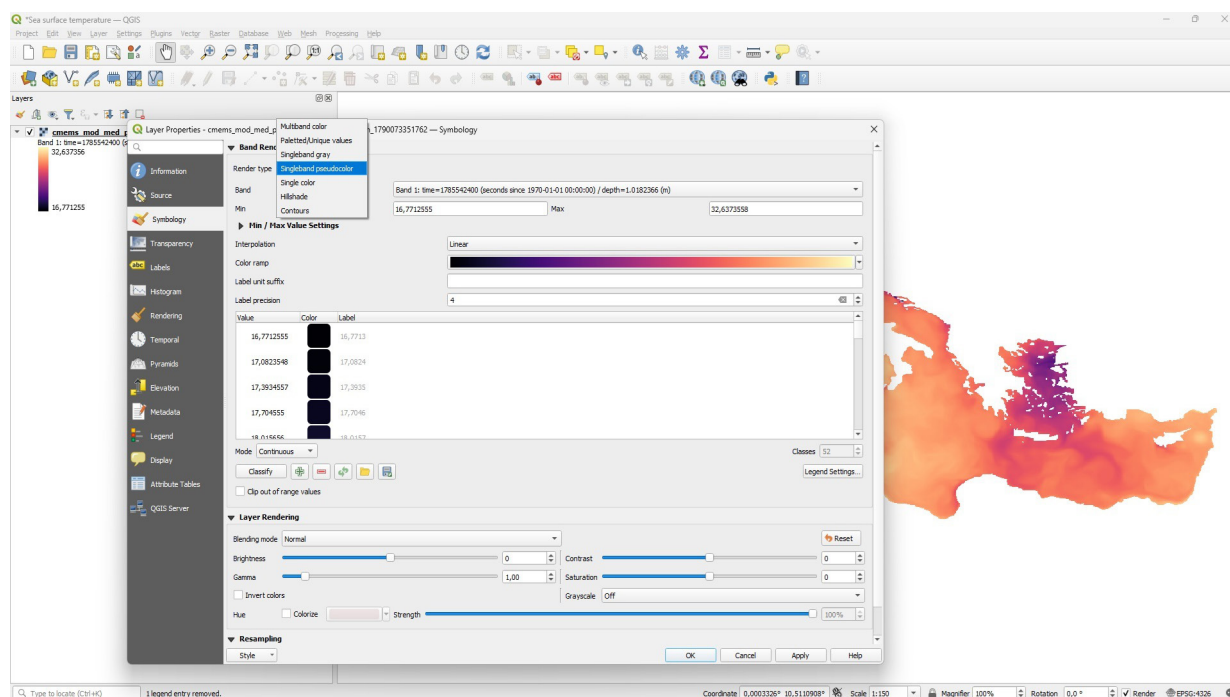


Figure 4. Configuration interface for temporal properties of a Copernicus Marine NetCDF layer in QGIS.

DISCUSSION

This technical document presents a streamlined, code-free QGIS workflow for ingesting, rendering, and temporally configuring Copernicus Marine Environment Monitoring Service (CMEMS) Mediterranean datasets within the open-source QGIS desktop environment (Rosas-Chavoya et al. 2022). While Copernicus Marine offers official documentation and dedicated tools such as the NetCDF2QGIS plugin for NetCDF handling, the procedure detailed here focuses on native QGIS LTR functionality—specifically leveraging GDAL/OGR multidimensional drivers, custom single-band pseudocolor symbology calibration, and the integrated Dynamic Temporal Controller without requiring external plugin dependencies.

Accessibility and software adoption

Utilizing open standard formats (such as NetCDF) alongside open-source platforms like QGIS may reduce software licensing barriers for local environmental authorities, small research institutions, and spatial analysts with limited operational budgets (Flenniken et al. 2020). By utilizing native graphical user interface (GUI) components, this framework enables direct multidimensional raster handling and time-series visualization without requiring custom scripting.

Methodological efficacy and practical application in the Mediterranean

The application to the Sea Surface Temperature (SST) field in the Mediterranean Basin illustrates the step-by-step implementation of the visualization pipeline. Thanks to their rigorous scientific validation and regular spatial coverage, CMEMS numerical model outputs which assimilate *in-situ* and satellite observations (MEDSEA_ANALYSIS_FORECAST_PHY_006_013) provide consistent

physical fields for studying climatic variations and thermal dynamics (Pisano et al. 2020). The practical implementation of the described workflow demonstrates that users can extract targeted spatial subsets and rapidly generate calibrated thematic maps and surface thermal gradients without the need for advanced scripting, although integration with Python tools offers further automation potential. The analysis of oceanographic datasets through GIS technology highlights the remarkable potential of spatial tools in environmental contexts (Petrosillo et al. 2023).

Implications for environmental monitoring and future perspectives

The integration of multidimensional layers with the QGIS Temporal Controller offers a structured protocol for handling time-aware raster metadata (Flenniken et al. 2020). While the present demonstration is limited to a monthly-mean surface temperature dataset, this technical setup can be potentially extended in future work to multi-temporal series or higher-frequency oceanographic model outputs. Looking ahead, open-source desktop GIS platforms combined with advanced geoprocessing tools provide a practical technical foundation for routine environmental mapping and spatial data management.

ACKNOWLEDGEMENTS

The author acknowledges the Copernicus Marine Environment Monitoring Service (CMEMS) for providing open access to the oceanographic dataset used in this study.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Data and code availability

The oceanographic dataset used in this work is freely available from the Copernicus Marine Data Store (MEDSEA_ANALYSISFORECAST_PHY_006_013, DOI: 10.48670/mds-00359). No custom code or programming scripts were used, as all processing was performed using native GUI tools in QGIS LTR.

Conflicts of interest

The author declares no conflicts of interest.

Artificial Intelligence (AI) declaration

AI-assisted tools were used exclusively for language editing, grammar refinement, and manuscript formatting assistance.

Author contributions

Conceptualization, methodology, GIS processing, data curation, and writing original draft preparation were performed solely by the author.

REFERENCES

- CONCOLIS BMM. 2025. High-resolution reanalysis biological ocean data from the Copernicus Marine Service Information for Philippine marine research. Data Brief. 111913.
- DMYTRO H, ARKADII S, TETIANA A, DMYTRO K, DENYS Y. 2023. Advantages of using QGIS to solve spatial planning tasks. Baltic Surveying. 50.
- DUARTE L, TEODORO AC. 2021. GIS open-source plugins development: a 10-year bibliometric analysis on scientific literature. Geomatics. 1 (2): 206-245.
- EUROPEAN SPACE AGENCY. 2026. Earth observation missions. [https://www.esa.int/Applications/](https://www.esa.int/Applications/Observing_the_Earth)
- Observing_the_Earth.
- FLENNIKEN JM, STUGLIK S, IANNONE B. V. 2020. Quantum GIS (QGIS): an introduction to a free alternative to more costly GIS platforms: FOR359/FR428, 2/2020. Edis. (2): 7.
- LE TRAON PY, REPPUCCI A, ALVAREZ FANJUL E, AOUF L, BEHRENS A, BELMONTE M, BENTAMY A, BERTINO L, BRANDO VE, et al. 2019. From observation to information and users: The Copernicus Marine Service perspective. Front Mar Sci. 6, 234. DOI: <https://doi.org/10.3389/fmars.2019.00234>
- OKLADNIKOV IG, GORDOV EP, TITOV A. G. 2016. Development of climate data storage and processing model. In: IOP Conference Series: Earth and Environmental Science. IOP Publishing. 48 (1): 012030.
- PETROSILLO I, SCARDIA AMS, UNGARO N, SPECCHIULLI A, FANELLI G, CENTODUCATI G, DE SERIO F, CARLUCCI R, VALENTE D, BARBONE E, et al. 2023. Towards sustainable marine spatial planning of aquaculture. Ecol Indic. 154: 110542. DOI: <https://doi.org/10.1016/j.ecolind.2023.110542>
- PISANO A, MARULLO S, ARTALE V, FALCINI F, YANG C, LEONELLI FE, SANTOLERI R, BUONGIORNO NARDELLI B. 2020. New evidence of Mediterranean climate change and variability from sea surface temperature observations. Remote Sens. 12 (1): 132. DOI: <https://doi.org/10.3390/rs12010132>
- ROSAS-CHAVOYA M, GALLARDO-SALAZAR JL, LÓPEZ-SERRANO PM, ALCÁNTARA-CONCEPCIÓN PC, LEÓN-MIRANDA AK. 2022. QGIS a constantly growing free and open-source geospatial software contributing to scientific development. Cuad Investig Geogr. 48 (1): 197-213.
- SEMERARO T, LUVISI A, LILLO AO, ARETANO R, BUCCOLIERI R, MARWAN N. 2020. Recurrence analysis of vegetation indices for highlighting the ecosystem response to drought events: an application to the Amazon forest. Remote Sens. 12 (6): 907.
- TIRALONGO F, LILLO AO, TIBULLO D, TONDO E,

- MARTIRE CL, D'AGNESE R, MACALI A, MANCINI E, GIOVOS I, COCO S, et al. 2019. Monitoring uncommon and non-indigenous fishes in Italian waters: one year of results for the AlienFish project. *Reg Stud Mar Sci.* 28: 100606. DOI: <https://doi.org/10.1016/j.rsma.2019.100606>
- VON SCHUCKMANN K, LE TRAON PY, ALVAREZ-FANJUL E, AXELL L, BALMASEDA M, BREIVIK LA, BREWIN RJW, BRICAUD C, DREVILON M, DRILLET Y, et al. 2016. The Copernicus marine environment monitoring service ocean state report. *J Oper Oceanogr.* 9 (2): 235-320. DOI: <https://dx.doi.org/10.1080/1755876X.2016.1273446>
- VON SCHUCKMANN K, LE TRAON PY, SMITH N, PASQUAL A, DJAVIDNIA S, GATTUSO JP, GRÉGOIRE M, NOLAN G. 2019. Copernicus Marine Service Ocean State Report, Issue 3. *J Oper Oceanogr.* 12 (1): 1-123. DOI: <https://doi.org/10.1080/1755876X.2019.1633075>