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DEC	Websites, patents, filing, etc.	
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NAUTILOS - New Approach to Underwater Technologies for Innovative, Low-cost Ocean observation is an H2020 project funded under the Future of Seas and Oceans Flagship Initiative, coordinated by the National Research Council of Italy (CNR, Consiglio Nazionale delle Ricerche). It brings together a group of 21 entities from 11 European countries with multidisciplinary expertise ranging from ocean instrumentation development and integration, ocean sensing and sampling instrumentation, data processing, modelling and control, operational oceanography and biology and ecosystems and biogeochemistry such, water and climate change science, technological marine applications and research infrastructures.

NAUTILOS will fill-in marine observation and modelling gaps for chemical, biological and deep ocean physics variables through the development of a new generation of cost-effective sensors and samplers, the integration of the aforementioned technologies within observing platforms and their deployment in large-scale demonstrations in European seas. The fundamental aim of the project will be to complement and expand current European observation tools and services, to obtain a collection of data at a much higher spatial resolution, temporal regularity and length than currently available at the European scale, and to further enable and democratise the monitoring of the marine environment to both traditional and non-traditional data users.

NAUTILOS is one of two projects included in the EU´s efforts to support the European Strategy for Plastics in a Circular Economy by supporting the demonstration of new and innovative technologies to measure the Essential Ocean Variables (EOV).

More information on the project can be found at: http://nautilos-h2020.eu/.

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EXECUTIVE SUMMARY

The main objectives of Task 7.1 (Fisheries and Aquaculture Observing Systems) were to demonstrate the use of the dissolved oxygen and Chlorophyll *a* sensors, developed in ST3.1.2, on commercial fishing vessels and in aquaculture facilities, lay the foundation for a new Aquaculture Observing Systems integrated approach and to trial the deployment of Acoustic Marine Mammal Monitoring System by fishermen. A first Deliverable (D7.1) was produced in January 2024, providing the rationale behind the use of the above mentioned approaches and details on the implementation of demonstrations involving the AdriFOOS infrastructure, commercial fishing vessels, ferries and aquaculture facilities. The present document is the final report of Task 7.1 and reports updates and results of the work carried out by partners from M40 up to M57, illustrates further developments, issues encountered, solutions adopted and data exchange with the NAUTILOS data stream services.

Therefore, it is organised in 6 main sections:

Chapter I: Introduction, provides a brief summary of the activities carried out in T7.1 up to M40;

Chapter II: Fisheries Observing Systems Demonstration Report, contains details on the prosecution and conclusion of demonstrations relating to the use of commercial fishing vessels, carried out by CNR and Ifremer in the Adriatic Sea and the Bay of Biscay respectively, with the support of NKE;

Chapter III: Novel approach to Aquaculture Observing Systems Demonstration Report, describes the demonstrations in aquaculture facilities carried out by NIVA in coastal Norway, the machine learning-based event detection developed by DFKI for that area, as well as the low-cost infrared sea surface temperature sensor use in Greek Seas proposed by HCMR;

Chapter IV: Demonstration of Acoustic Marine Mammal Monitoring System Report describes the demonstrations carried out in Swedish and Italian waters, to assess the effectiveness of the AQUAclick Sound Passive Acoustic Sensor in recording marine mammal sounds under different conditions;

Chapter V: Ethical Considerations, updates what already reported in Deliverable 7.1;

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List of Acronyms and Abbreviations

Abbreviation	Definition
4G	Fourth-generation of cellular network technology
AC	Alternate Current
AdriFOOS	Adriatic Fisheries and Oceanography Observing System
AIS	Automatic Identification System
AS	Aksjeselskap
BCD	Buoyancy Compensator Device
Chl-*a*	Chlorophyll *a*
CNR-IRBIM	Institute for Biological Resources and Marine Biotechnology of the National Research Council
CSV	Comma-Separated Values
CTD	Conductivity, Temperature, and Depth
D	Deliverable
DFKI	German Research Center for Artificial Intelligence
DO	Dissolved Oxygen
EMODnet	European Marine Observation and Data network
EOVs	Essential Ocean Variables
ERDDAP	Environmental Research Division's Data Access Program
EU	European Union
EUSAIR	European Union Strategy for the Adriatic and Ionian Region
fDOM	fluorescent Dissolved Organic Matter
FTP	File Transfer Protocol
GPS	Global Positioning System
HAB	Harmful Algal Bloom

HCMR	Hellenic Centre for Marine Research
IMR	Institute for Marine Research
IR	Infrared
LED	Light Emitting Diodes
MHW	Marine Heatwave
MS	Motor Ship
MSFD	Marine Strategy Framework Directive
NIVA	Norwegian Institute for Water Research
NRT	Near Real Time
ODV	Ocean Data Viewer
OEM	Original Equipment Manufacturer
PAS	Acoustic Passive Sensor
pCO2	partial pressure of carbon dioxide
QC	Quality Control
R/V	Research Vessel
RWT	ppb Rhodamine WT
SLU Aqua	Department of Aquatic Resources at the Swedish University of Agricultural Sciences
SO	Specific Objective
SST	Sea Surface Temperature
TRL	Technology Readiness Levels
UTC	Coordinated Universal Time
Wi-Fi	Wireless Fidelity
WP	Work Package
WT	Water Tracer

I. INTRODUCTION

The rationale behind the development of the demonstrations planned in Task 7.1 (Fisheries and Aquaculture Observing Systems) of the NAUTILOS project is described in Deliverable 7.1 (Martinelli et al. 2024). Details on the planning and first implementation phase of demonstrations involving the Adriatic Fisheries and Oceanography Observing System (AdriFOOS) infrastructure, commercial fishing vessels, ferries and aquaculture facilities were also reported in Deliverable 7.1.

In summer 2023, demonstrations planned in Sub Task 7.1.1 (Fisheries Observing Systems), involving the Dissolved Oxygen (DO) and Chlorophyll *a* (Chl-*a*) prototypes developed by NKE in Sub Task 3.1.2 (Malardé et al. 2022), started both in the Adriatic Sea and the Bay of Biscay respectively conducted by CNR-IRBIM and Ifremer. Since then the functioning of the instruments was constantly monitored by the NAUTILOS partners involved. This allowed some mechanical and software updates to the previously designed and tested instruments. The data produced in the Adriatic Sea during the first phase of the demonstration were showcased on NAUTILOS data portals since autumn 2023. Then the activities of Sub Task 7.1.1 (e.g. battery duration verification, sensor drift check, data collection, data validation and analysis, additional activities) continued until March 2025 and are reported in the following sections.

By January 2024, demonstration plans were defined for the activities to be carried out in Norway and Greece in Sub Task 7.1.2 (Novel Approach to Aquaculture Observing Systems Demonstration) and in Sweden and Italy in Sub Task 7.1.3 (Demonstration of Acoustic Marine Mammal Monitoring System).

For Sub Task 7.1.2, NAUTILOS DO, Chl-*a*, pH and pCO2 low-cost sensors were deployed from March 2025 to June 2025 in a fish farm located in Herdlefjord (Norway). Data from three FerryBoxes operating in the area were annotated by NIVA's experts for phytoplankton blooms for the 2023-2025. The event detection concept developed by DFKI was tested on and adapted for this dataset provided in May 2025. Final evaluations on these data was done in June 2025 and are presented in this deliverable.

Low-cost infrared sensor sea surface temperature data collected in Greek waters on board the HCMR R/V Philia as part of NAUTILOS Task 7.2 from September to October 2024 were also analysed by HCMR. The aim was to assess the potential for integration of this type of sensors into future sampling strategies, including deployment on ships of opportunity in coastal areas with data gaps, with a view to using the data for a sustainable development of aquaculture.

Demonstration planned in Sub Task 7.1.3 started in August 2024, with an Acoustic Passive Sensor (PAS) unit deployed in Portofino. This was followed by the deployment of four additional units at the Kolmarden dolphinarium in September. Sub Task 7.1.3 activities continued until June 2025 with new deployments in Italy and Swedish waters to gather valuable data.

II. FISHERIES OBSERVING SYSTEMS DEMONSTRATION REPORT

1 BACKGROUND

This section is described in Deliverable 7.1 section II.1.

2 DEMONSTRATION PLAN

This section was also featured in Deliverable 7.1 section II.2. Deviations and updates are described in the following paragraphs.

a. Demonstration on Fisheries Observing Systems in the Bay of Biscay (Ifremer)

- **Specific Objectives**

This demonstration was specifically conceived to quantify the DO and Chl-*a* prototypes drift (every 3 months after their 1st immersion) and evaluate probe measurement cycles.

- **Platform involved**

This section is described in Deliverable 7.1 section II.2.b.

- **Deployment configuration**

The deployment configuration in use from July 2023 to January 2024 is described in Deliverable 7.1 section II.2.b.

A) DO sensor

From February 2024 to the end of the demonstration, in August 2024, the acquisition was still set to the fishing sampling regime.

The sensor was configured to start data recording once immersed in water at a pressure greater than 0.3 bar and stop data recording when reaching a pressure less than 0.2 bar, with a frequency of 2 seconds for 15 minutes, then with a frequency of 10 min (Fig. 1).

Within this sensor, the internal salinity value was still set at 0 because it was deployed in variable conditions (see Deliverable 7.1 section II.2.b) and in the absence of other instruments for measuring salinity on board.

The sensor was secured in a meshbag inside a pot (Fig. 2) as it had been in previous deployments.

B) Chl-*a* sensor

From February 2024 to the end of the demonstration, in August 2024, the Chl-*a* sensor acquisition and sampling regimes were configured as for the DO one, and set to also record temperature and depth (Fig. 3).

For this last stage, the Chl-*a* sensor was not placed in a meshbag so that the field in front of the sensor was free.

C) WiHub

From February 2024 to the end of the demonstration, in August 2024, the Global Positioning System (GPS) acquisition was still set to every 1 min.

Acquisition settings		
Deployment comment		
Sampling interval 2	10 min	
Sampling regime	Fishing	ⓘ
Sampling interval 1	2 sec	
Sampling duration 1	15 min	
Start mode	Condition	
Parameter	Pressure (Keller-100 bar)	
Condition	Start if > 0.3 bar	
Check interval	5 sec	
Stop mode	Condition	
Parameter	Pressure (Keller-100 bar)	
Condition	Stop if < 0.2 bar	

Figure 1: Settings for the sensor DO 1111 deployed in the Bay of Biscay.



Figure 2: Example of a fishing trap used to deploy the DO 1111 and Chl-a 59dd prototypes in the Bay of Biscay.

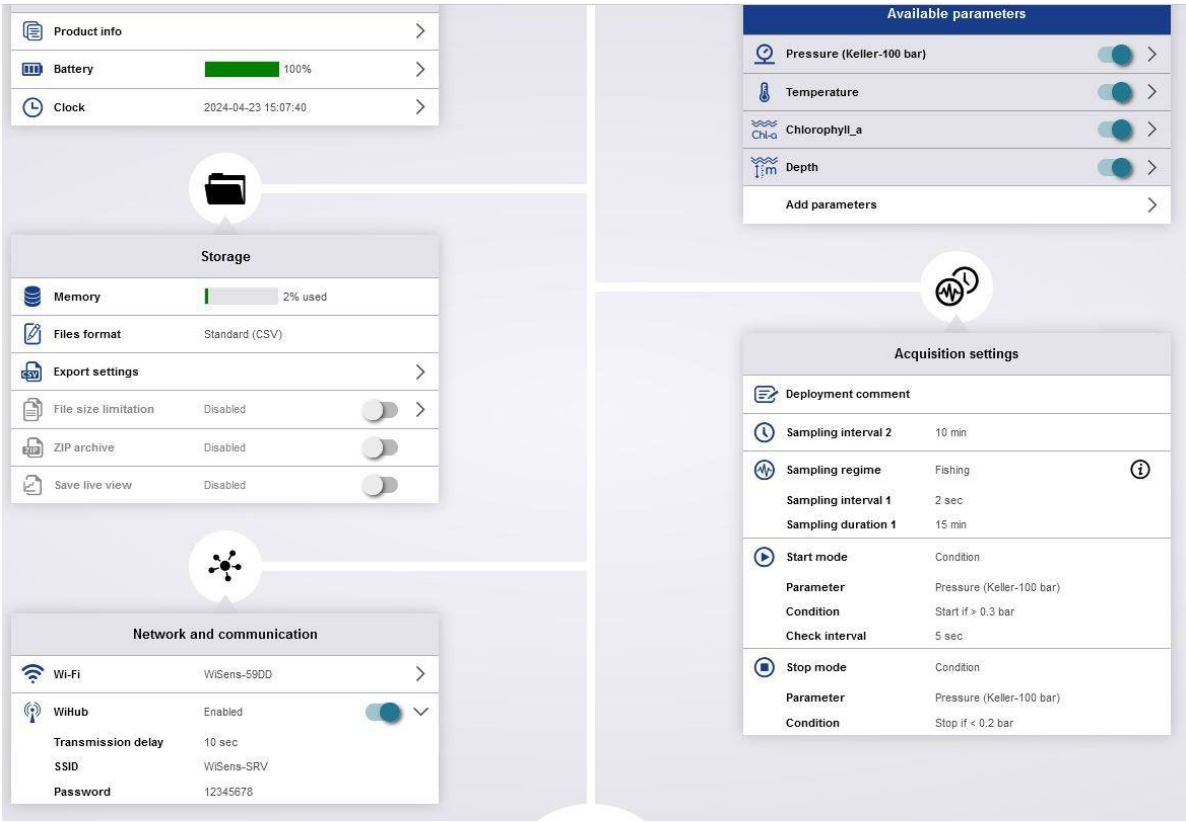


Figure 3: Settings for the sensor Chl-a 59dd deployed in the Bay of Biscay.

- **Location**

This section is described in Deliverable 7.1 section II.2.b.

- **Period of occurrence**

Ifremer received training on the WiHub use in June 2023 and tested integration and data flow in July 2023, together with installation of DO 1111 prototype. Chl-*a* 59dd prototype built in July 2023 was installed at the end of October 2023. Sensors were removed from the vessel at the end of August 2024.

- **Maintenance, events/issues occurred and actions taken**

Events occurred from July 2023 to January 2024 are described in Deliverable 7.1 section II.2.b.

A) <u>DO sensor</u>

The prototype 1111 was deployed for the second time in a pot in mid-December 2023 (with 99% battery level) and was removed in mid-February 2024. It did not record any data since early February 2024 (however the vessel did not work much due to bad weather conditions) (Fig. 4). The DO sensor did not react to activation by the magnet, and a battery check with a multimeter in the metrology laboratory revealed 0% battery (however the last recorded file ([15/01/2024-02/02/2024]) showed 64.6 % of battery). According to an inspection by NKE, it is reasonable that the sensor, despite not having recorded any more data, consumed battery power while attempting to connect to the WiHub.

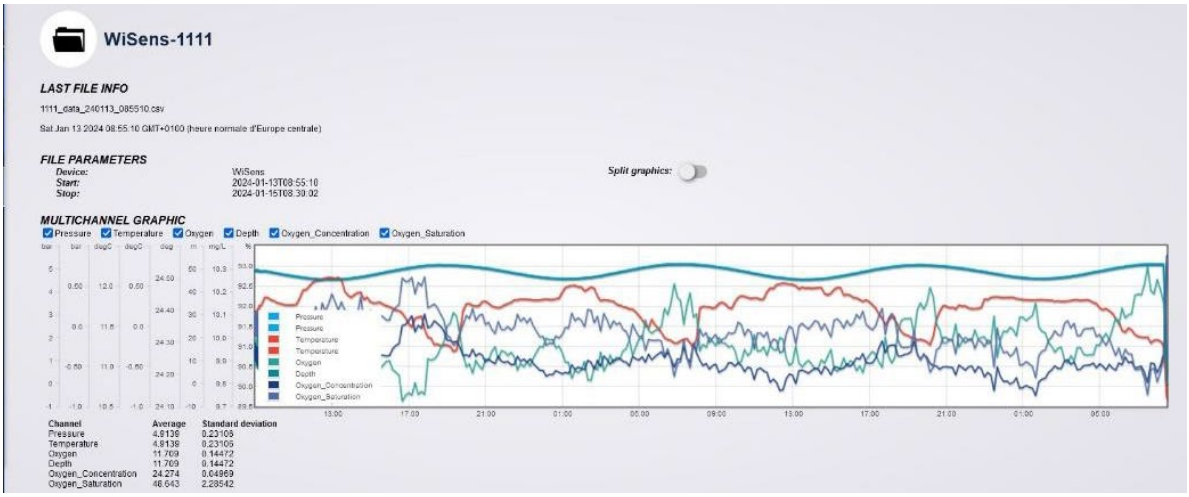


Figure 4: Last DO sensor file recorded after the 2nd setting period.

Using a new battery, the 2nd drift check took place on 21 February 2024, namely after 2 months underwater instead of 3 months, because of a stop in the vessel pot fishing activity until the end of May. It was noticed that less fouling occurred than the previous time (Fig. 5a), probably due to the usage during the winter season, less profitable for organism colonization. NKE replaced the battery in March 2024 and checked that the oxygen sensor was still operational. The sensor was deployed again for the third and last time in a pot at the end of May 2024 (with 98.4 % battery).

After 1.5 months, the DO sensor stopped recording data (the last file ([12/07/2024-12/07/2024]) showed 23.7 % of battery) and was definitively removed at the end of August 2024. Unfortunately no oxygen data was recorded from the start of this third deployment. Figure 5b shows the biofouling on the instrument at the end of the 3rd demonstration period. The third and last drift check planned in mid-September 2024 could not occur.

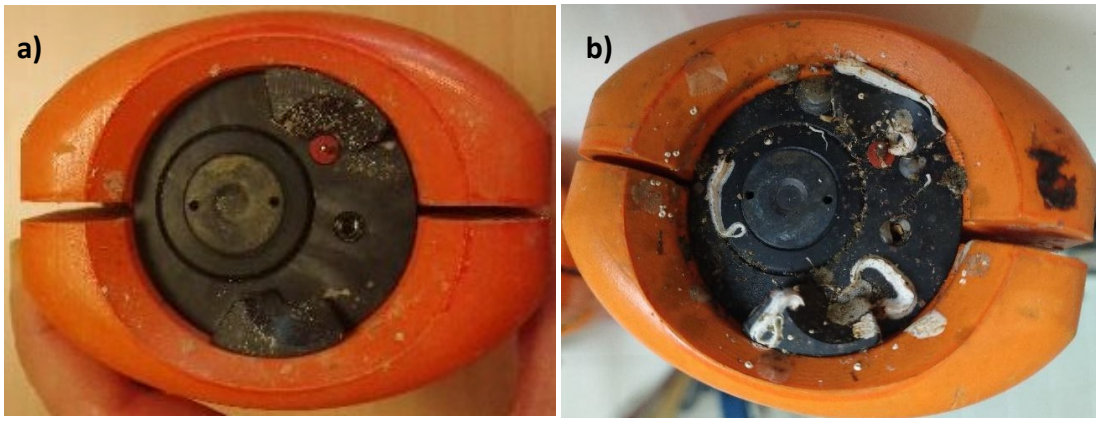


Figure 5: DO 1111 sensor fouling in February 2024 after 2 Winter months underwater (a) and in August 2024 after 3 Summer months underwater (b).

Table 1 below summarizes the DO 1111 sensor events and battery levels (in grey events previously reported in Deliverable 7.1).

Table 1: DO 1111 sensor events and battery level from February 24 to September 2024.

DO 1111 sensor events		
Configuration: fishing mode with start>0.2 bar/stop<0.2 bar): T1=2 s/10 min - T2=1 min		
Date	*Events*	
26/07/2023	*1st deployment*	
05/09/2023	*No data record*	
09/11/2023	*Battery change*	
20/11/2023	*1st drift check*	
Configuration: fishing mode with start>0.3 bar/stop<0.2 bar): T1=2 s/15 min - T2=10 min		
Date	**Events**	
14/12/2023	*2nd deployment*	
02/02/2024	No data record	
21/02/2024	2nd drift check	
March 2024	Battery change	
31/05/2024	3rd deployment	
12/07/2024	No data record	
12/09/2024	3rd drift check: not possible (Oxygen sensor in ERROR)	
Battery level information in DO 1111 sensor data file		
Configuration on fishing mode with start>0.2 bar/stop<0.2 bar): T1=2 s/10 min - T2=1 min		
Date	*% battery (eS1 indicator)*	*records nb (eD3 indicator)*
[26/07/2023-29/07/2023]	*94.1 %*	*4 527*
[29/07/2023-01/08/2023]	*88.8 %*	*4 355*
[01/08/2023-09/08/2023]	*83.6 %*	*11 897*
[09/08/2023-11/08/2023]	*68.8 %*	*3 348*
[11/08/2023-14/08/2023]	*64.9 %*	*4 596*
[14/08/2023-16/08/2023]	*59.4 %*	*2 947*
[16/08/2023-29/08/2023]	*56.0 %*	*18 932*
[29/08/2023-05/09/2023]	*32.2 %*	*10 249*
[05/09/2023-05/09/2023]	*19.5 %*	*300*
Configuration on fishing mode with start>0.3 bar/stop<0.2 bar): T1=2 s/15 min - T2=10 min		
Date	**% battery (eS1 indicator)**	**records nb (eD3 indicator)**
[16/12/2023-26/12/2023]	*98.9 %*	*1 877*
[26/12/2023-08/01/2024]	*87.5 %*	*2 317*
[08/01/2024-10/01/2024]	*72.6 %*	*749*
[10/01/2024-13/01/2024]	*70.2 %*	*871*
[13/01/2024-15/01/2024]	*66.9 %*	*734*
[15/01/2024-02/02/2024]	*64.6 %*	*3 005*
[31/05/2024-08/06/2024]	98.4 %	1 602
[08/06/2024-11/06/2024]	84.3 %	880
[11/06/2024-13/06/2024]	78.9 %	724
[13/06/2024-18/06/2024]	75.5 %	1170
[18/06/2024-20/06/2024]	66.7 %	733
[20/06/2024-23/06/2024]	63.2 %	885
[23/06/2024-27/06/2024]	57.8 %	1 028
[27/06/2024-29/06/2024]	50.7 %	725
[29/06/2024-01/07/2024]	47.2 %	732
[01/07/2024-03/07/2024]	43.7 %	744
[03/07/2024-08/07/2024]	40.1 %	1 176
[08/07/2024-12/07/2024]	31.1 %	1 056
[12/07/2024-12/07/2024]	23.7 %	450

Once recovered, the sensor was sent back to NKE for analysis. On opening the sensor, it was noticed that the connector between the original equipment manufacturer (OEM) module and the motherboard was disconnected. This explains why the DO channel showed zero values in the recordings. This could have happened due to human error during battery change or some mechanical shock to which the sensor was inadvertently subjected.

Once reconnected, the battery was changed and the sensor closed. Then the correct functioning of the sensor 1111 was checked again in a solution with a concentration of 100% saturated air.

A) Chl-*a* sensor

The 1st 59dd sensor drift monitoring was carried out on 21 February 2024 (after removal from the pot in mid-January 2024).

NKE replaced the battery in March 2024 and the sensor was deployed again for the second and last time in a pot at the end of May 2024 (with 98.6 % battery) after the stop in the vessel pot fishing activity.

After 1.5 months, the Chl-*a* 59dd sensor stopped recording data (the last file ([12/07/2024-16/07/2024]) showed 22.1 % of battery) and was definitively removed from the pot at the end of August 2024 (Fig. 6).

The second and last drift check occurred mid-September 2024.

Table 2 below summarizes the Chl-*a* 59dd sensor events and battery levels (in grey events previously reported in Deliverable 7.1).



Figure 6: Chl-a 59dd sensor fouling after 3 Summer months underwater.

Table 2: Chl-a 59dd sensor events and battery level from February 24 to September 2024.

Chl-a 59dd sensor events		
Configuration: fishing mode with start>1.5 bar/stop<1 bar): T1=10 s/15 min - T2=1 min		
Date	*Events*	
31/10/2023	*1st deployment*	
Configuration: fishing mode with start>0.3 bar/stop<0.2 bar): T1=2 s/15 min - T2=10 min		
Date	**Events**	
15/12/2023	*No data record*	
20/02/2024	1st drift check	
March 2024	Battery change	
31/05/2024	2nd deployment	
16/07/2024	No data record	
16/09/2024	2nd drift check	
Battery level information in Chl-a 59dd sensor data file		
Configuration on fishing mode with start>1.5 bar/stop<1 bar): T1=10 s/15 min - T2=1 min		
Date	*% battery (eS1 indicator)*	*records nb (eD3 indicator)*
[31/10/2023-07/11/2023]	*89.3 %*	*10 156*
[07/11/2023-11/11/2023]	*74.7 %*	*5 637*
[11/11/2023-15/11/2023]	*66.6 %*	*5 973*
[15/11/2023-23/11/2023]	*58.0 %*	*11 477*
[23/11/2023-25/11/2023]	*41.4 %*	*3 024*
Configuration on fishing mode with start>0.3 bar/stop<0.2 bar): T1=2 s/15 min - T2=10 min		
Date	**% battery (eS1 indicator)**	**records nb (eD3 indicator)**
[30/11/2023-30/11/2023]	*36.5 %*	*367*
[02/12/2023-15/12/2023]	*36.3 %*	*2 316*
[15/12/2023-15/12/2023]	*13.1 %*	*450*
[31/05/2024-06/06/2024]	98.6 %	1 309
[06/06/2024-08/06/2024]	87.8 %	742
[08/06/2024-11/06/2024]	84.1 %	875
[11/06/2024-13/06/2024]	78.7 %	725
[13/06/2024-20/06/2024]	75.2 %	1 456
[20/06/2024-25/06/2024]	62.6 %	1 170
[25/06/2024-27/06/2024]	53.5 %	741
[27/06/2024-29/06/2024]	49.8 %	737
[29/06/2024-03/07/2024]	46.1 %	1 019
[03/07/2024-08/07/2024]	38.9 %	1 177
[08/07/2024-12/07/2024]	29.7 %	1 057
[12/07/2024-16/07/2024]	22.1 %	1 010

A) WiHub

No particular event occurred with the hub.

After the conclusion of the demonstration in the Bay of Biscay, the 1111 and 59dd prototypes and the WiHub were returned to NKE and then sent to CNR to be further tested in the Adriatic Sea on board fishing vessels using different gears and in citizen science applications involving divers (see Deliverable 10.9).

- **Drift check procedure**

This section is described in Deliverable 7.1 section II.2.b.

- **Data recovery**

Once out of the water after the fishing operations, sensors sent the data acquired during the fishing phase to the WiHub *via* Wi-Fi. During the 1st part of the demo, the sensor dataset and the GPS time stamp produced by the latter were retrieved manually *via* Wi-Fi from the WiHub and sent to ETT directly in October 2023. Then, the WiHub started to transfer automatically to the NKE FTP (File Transfer Protocol) server (as a first step) using file transfer protocol FTP port 2221. In a second step, Ifremer staff put the raw data progressively in the data-nautilos-h2020.eu FTP for ETT access as Ifremer downloaded them from the NKE FTP server. The metadata related to the produced dataset indicates that the internal salinity setting for the DO 1111 sensor is set at 0, therefore data should be post processed before usage for purposes external to the project.

Comma-separated values (csv) data files were transferred from data-nautilos-h2020.eu FTP to the ERDDAP™ server. One dataset for each sensor was realised: one for DO 1111[1] and one for Chl-*a* 59dd[2]. In parallel with the data, work was done on the metadata by inserting all the mandatory information (e.g., geographical and temporal information, project, institution, keywords).

b. Demonstration on Fisheries Observing Systems in the Adriatic Sea (CNR)

- **Specific Objectives**

This demonstration was specifically designed to allow verification of sensor robustness, battery life and communication protocols and to showcase data collected in Near Real Time (NRT) on NAUTILOS data portals.

- **Platform involved**

This section is described in Deliverable 7.1 section II.2.a.

- **Deployment configuration**

This section is mainly described in Deliverable 7.1 section II.2.a. Since July 2023, no substantial updates were made to the AdriFOOS infrastructure and to the WiHub and sensors' deployment configuration. In January 2025, the DO 2222 and the Chl-*a* 8888 prototypes were respectively substituted with the DO 1111 and Chl-*a* 59dd ones, previously tested in the Bay

[1] *https://data-nautilos-h2020.eu/erddap/tabledap/dissolved-oxygen_nke_ifremer_test.html*

[2] *https://data-nautilos-h2020.eu/erddap/tabledap/chlorophyll_nke_ifremer_test.html*

of Biscay. Also the acquisition settings for the 2222 and 8888 sensors remained unchanged from January 2024 (Fig. 7) and were subsequently applied to the prototypes 1111 and 59dd as well. The internal salinity setting of the DO probes was periodically changed (Tab. 3) in correspondence with appreciable salinity variations, based on the average salinity values recorded by other AdriFOOS sensors (NKE STPS 300m PR) on board the same vessel in the previous weeks.

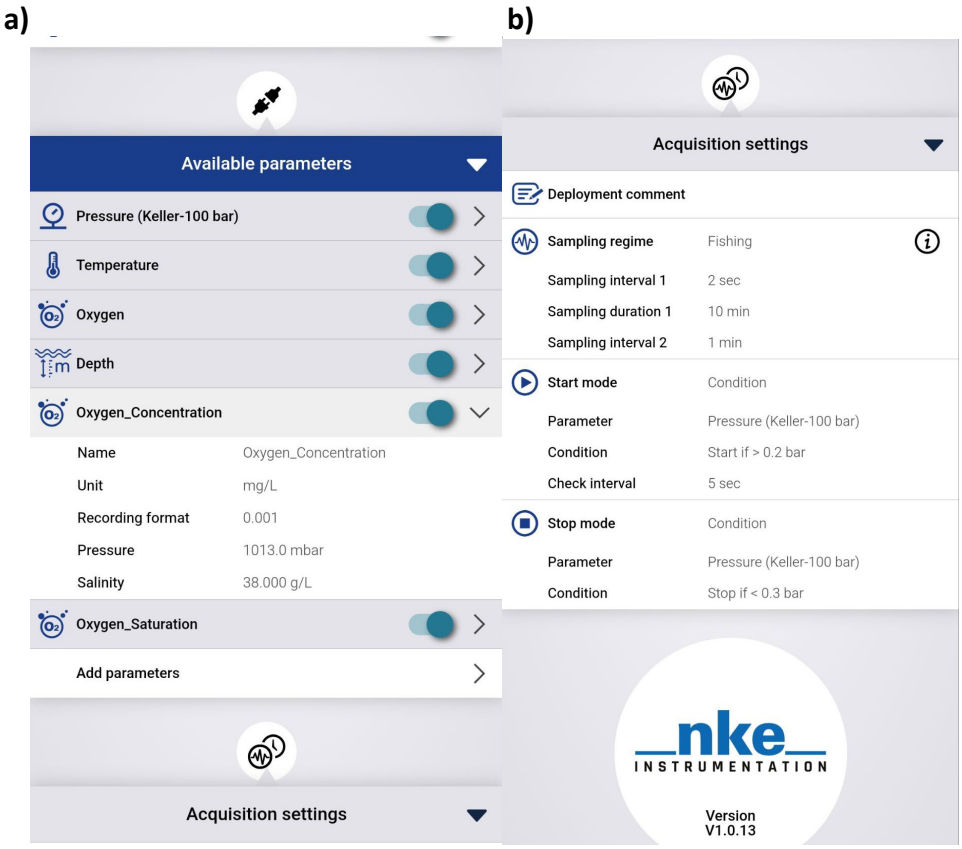


Figure 7: a) Internal salinity setting of the DO sensors; b) Sensor acquisition settings for the "Fishing" sampling regime as of January 2024.

Table 3: DO sensors internal salinity settings changes during the demonstration period.

Sensor	Date	Internal salinity setting
2222	07/07/2023	38.67
2222	17/01/2024	38.5
2222	09/05/2024	38.1
2222	09/11/2024	37.9
1111	23/01/2025	38

- **Location**

This section is described in Deliverable 7.1 section II.2.a.

- **Period of occurrence**

After a trial period in July 2023, from 11 September 2023 to 22 January 2025, CNR staff constantly monitored the functioning of the DO 2222 and Chl-*a* 8888 prototypes and the data

transmission. The annual trawl fishery closure occurred in this region from 31 July 2024 to 13 September 2024. The sensors DO 1111 and Chla-*a* 59dd were installed on board the same commercial trawler operating in the Adriatic Sea from 23 January to 27 February 2025. CNR and NKE were in constant contact.

- **Maintenance, events/issues occurred and actions taken**

Events occurred from July 2023 to January 2024 are described in Deliverable 7.1 section II.2.a. The CNR staff periodically monitored the battery level status of the DO 2222 and Chl-*a* 8888 sensors (see the CNR Results section), both through the NKE sensors web interface and the data arriving at the AdriFOOS server. When needed (Tab. 4), CNR staff removed and replaced the batteries following the instructions provided by NKE in the Sensor Quick Start Guide (see D7.1 for additional details).
On 12 March 2024 the WiHub stopped transmitting the data recorded by the sensors. The CNR staff tried to manually test the functioning of the WiHub both via Wifi and Ethernet connections, without success. Furthermore, the "start/stop measure" button of the WiHub web interface was stuck in the “OFF” position (Fig. 8a). When forcing the reactivation of the WiHub (Fig. 8b), the interface displayed an error message (Fig. 8c). In addition, the device’s LED started flashing at a rapid rate. The CNR staff contacted the NKE team for technical support, and an online meeting was held on 26 March 2024 to solve the problem. NKE operators carried out a remote inspection of the WiHub system (via TeamViewer[3]). The Linux system partition had to be repaired because inside there was a corrupted GPS file probably generated by a power cut. The corrupted GPS file was removed and the system returned to be operational.
On 21 March 2024, the DO 2222 sensor stopped recording data even if the battery level resulted to be at around 60%. On 11 April 2024, it was agreed among the partners to replace the battery. After the replacement, the sensor started working properly again. In order to understand the causes of the malfunctioning in the software, on 22 April 2024, CNR staff retrieved the log files from the sensor through a procedure provided by NKE and sent the code for inspection (Fig. 9). After examining the code, nothing notable was observed by NKE software experts. The issue was probably due to an underestimation of power consumption by the algorithm embedded in the sensor, in respect to the data transfer mode to the WiHub.

Table 4: Battery replacement dates for sensors DO2222 and Chl-a 8888.

Sensor	Date
8888	20/10/2023
2222-8888	17/01/2024
2222	11/04/2024
8888	09/05/2024
2222-8888	09/11/2024

[3] https://www.teamviewer.com/

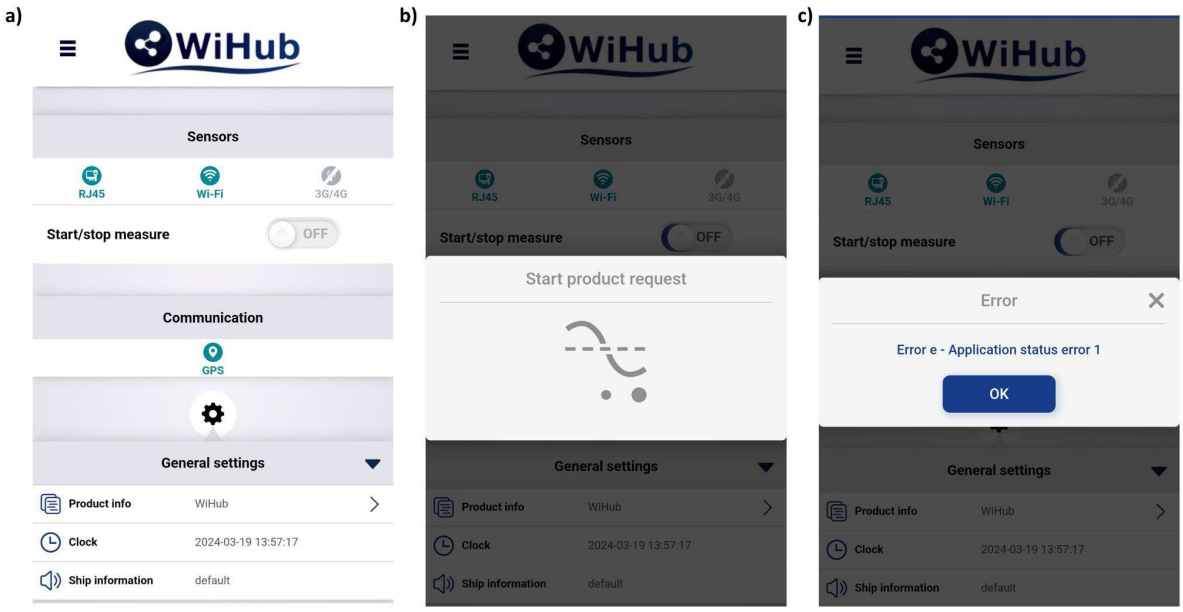


Figure 8: WiHub web interface showing a) the "start/stop measure" button stuck in the "OFF" position, b) the web interface loading screen, and c) the related error displayed afterwards.

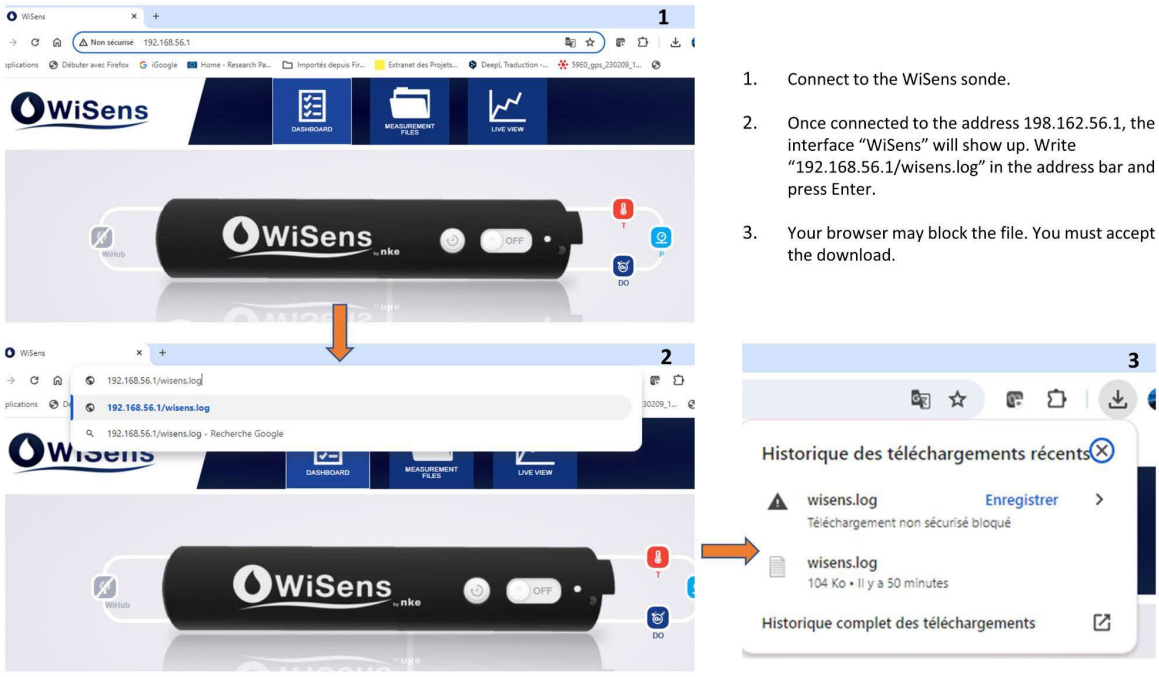
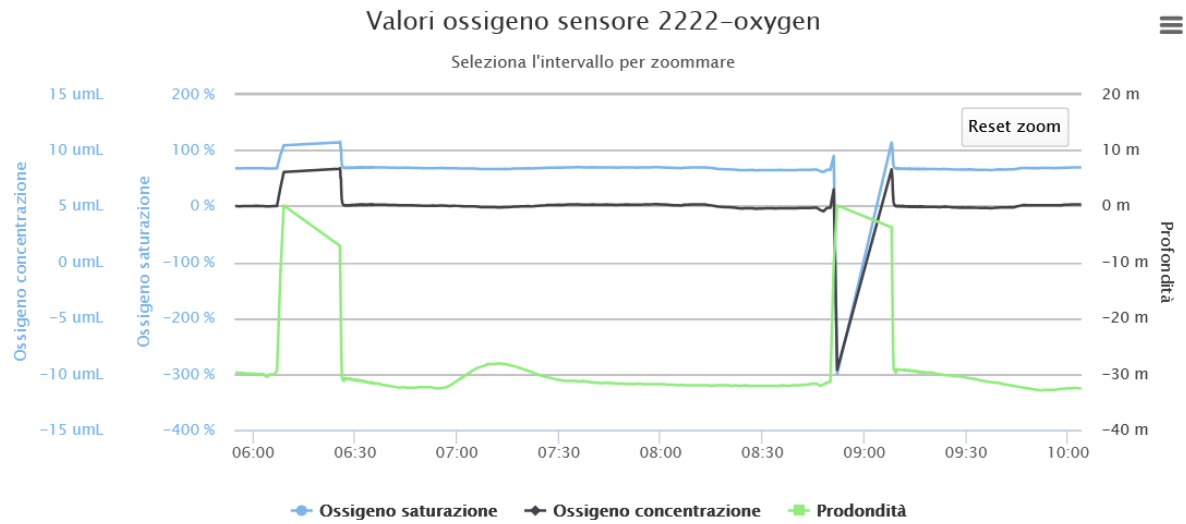


Figure 9: Wisense sensor log file recovery procedure.

Expected oxygen saturation values recorded by DO sensors out of the water should be close to 100%; however, on 15 October 2024, once out of the water after two normal fishing hauls, the DO 2222 prototype returned values of -300%, and a corresponding oxygen concentration values of -9.6 mg/l (Fig. 10a). After these two hauls the sensor continued to function normally. On 17 October 2024 the DO 2222 sensor stopped recording data, with a battery level of 17%. Once the battery was replaced, the sensor started to record again correct oxygen saturation data. On 25 November 2024, the same malfunctioning occurred again with an analogous

scheme, but from this day on, the oxygen saturation and concentration values constantly fell down respectively to -300% and -9.6 mg/l every time the sensor came out of the water (Fig. 10b). On 17 December 2024, the sensor permanently stopped recording correct dissolved oxygen data and remained stuck at -300% and -9.6 mg/l, despite it continued recording depth and temperature data.

a)



b)

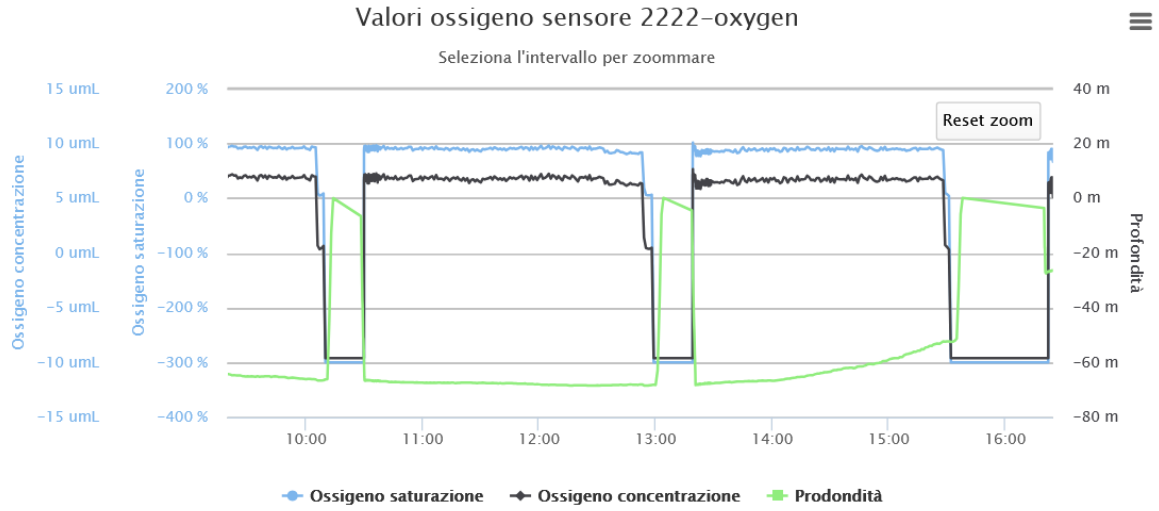


Figure 10: AdriFOOS web viewer shows the malfunctioning of the DO 2222 sensor occurred on 15 October 2024 (a), and on 25 November 2024 (b).

On 23 January 2025, prototypes DO 2222 and Chl-*a* 8888 were removed from the fishing gear and replaced by prototypes DO 1111 and Chl-*a* 59dd, respectively; the latter started to regularly record and send data to the AdriFOOS data center and subsequently to the NAUTILOS web services on 27 January 2025.

Subsequently, after the removal of the DO 2222 sensor from the fishing gear, on 27 January 2025, NKE team provided directions to CNR staff on how to carry out an inspection on the internal conditions of the sensor, checking for example whether the connector between the

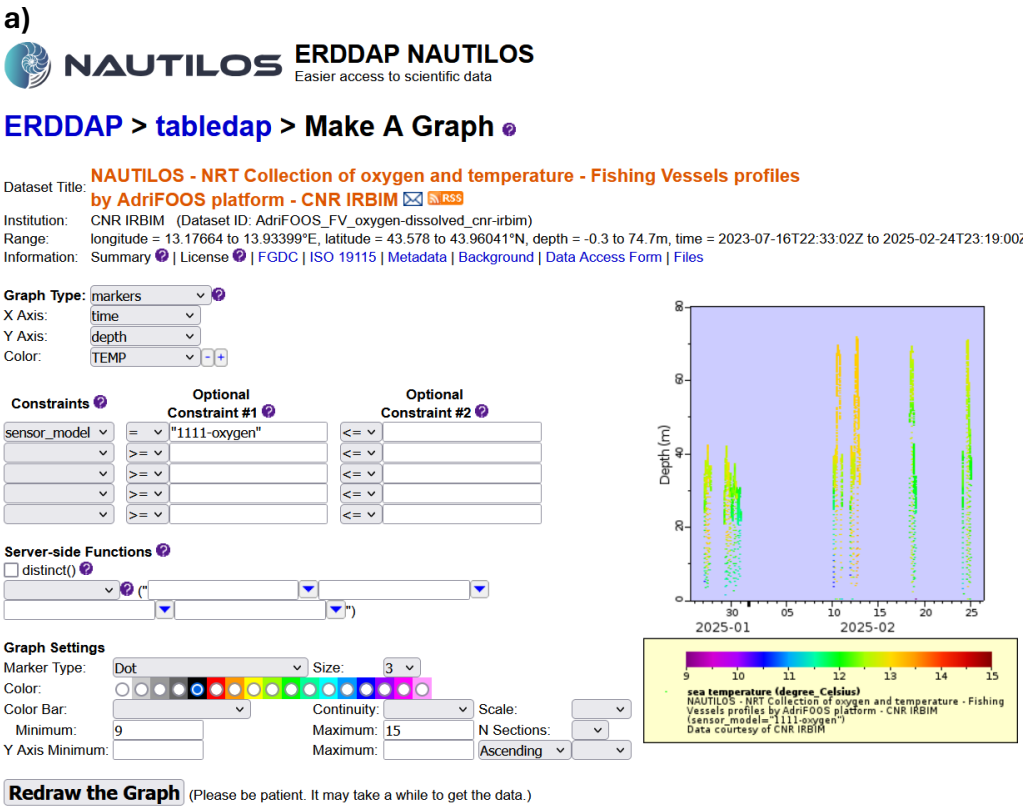
OEM module and the motherboard was disconnected as it happened for the DO 1111 during its use in the Bay of Biscay. The inspection revealed instead that the inner membrane had deteriorated, causing the dissolved oxygen data to fail to be recorded. In April 2025 the DO 2222 sensor was checked at the NKE facilities, the membrane was replaced and it was recalibrated, before being used again in ST7.1.2 activities (see Section III.2.a below).

- **Data recovery**

The data flow proceeded from Autumn 2023 to the end of February 2025 in Near Real Time (NRT) from the sensors installed on a fishing gear operating in the Adriatic Sea (firstly the prototypes 2222 and 8888 and then the 1111 and 59dd; Figs. 11 and 12), through the WiHub and the AdriFOOS server, up to the NAUTILOS web services. The full data stream from the fishing vessel toward the NAUTILOS ERDDAP™ is described in Deliverable 7.1 section II.2.a.
As described in Deliverable 7.1, a single dataset was created to collect data from the oxygen and chlorophyll sensors[4]. This dataset was then ingested into EMODnet, under the Physics theme. Subsequently, two separate datasets were created, one for the DO[5] and one for the Chl-*a*[6]. At the same time, the metadata was updated, specifically by adding information about the project, data creator and contributors, institution, and source.
Data with Quality Control (QC) flags set to 4 (=bad; see Deliverable 7.1 and L20 standard vocabulary in Seadatanet, 2022) were not sent by the AdriFOOS export script to the NAUTILOS ERRDAP™ (Simons and John 2022, see Deliverable 8.3).
In March 2023, the previously produced datasets were further verified and analyzed by CNR IRBIM specialized staff to ensure the quality of the records; a visual inspection was carried out by means of Ocean Data View (ODV; Schlitzer, 2021; Fig. 13) following the procedure described in Penna et al. 2023. The resulting validated dataset[7] was published on NAUTILOS ZENODO[8] collection and retransmitted to EMODnet.

[4] *https://data-nautilos-h2020.eu/erddap/tabledap/Adrifoos_FV.html*
[5] *https://data-nautilos-h2020.eu/erddap/tabledap/AdriFOOS_FV_oxygen-dissolved_cnr-irbim.html*
[6] *https://data-nautilos-h2020.eu/erddap/tabledap/AdriFOOS_FV_chlorophyll_cnr-irbim.html*
[7] *https://doi.org/10.5281/zenodo.15397170*
[8] *https://zenodo.org/communities/nautilos-h2020/about*

a)



b)

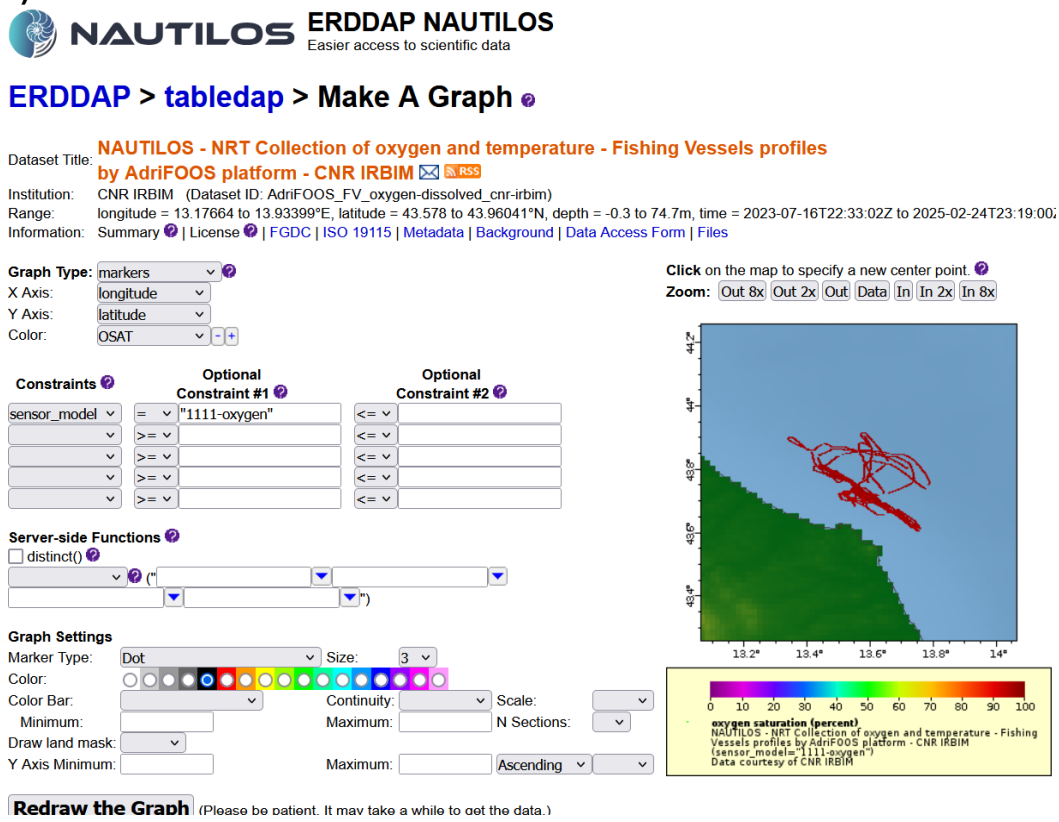


Figure 11: DO 1111 dataset recorded in the Adriatic Sea via AdriFOOS infrastructure and available through the NAUTILOS ERDDAP™: a) time, depth and temperature plot, b) map showing oxygen saturation values recorded.

a)

NAUTILOS ERDDAP NAUTILOS
Easier access to scientific data

ERDDAP > tabledap > Make A Graph

Dataset Title: NAUTILOS - NRT Collection of chlorophyll and temperature - Fishing Vessels profiles by AdriFOOS platform - CNR IRBIM
Institution: CNR IRBIM (Dataset ID: AdriFOOS_FV_chlorophyll_cnr-irbim)
Range: longitude = 13.1925 to 13.93399°E, latitude = 43.578 to 43.95581°N, depth = -0.1 to 75.1m, time = 2024-01-29T01:00:00Z to 2025-02-24T20:39:00Z
Information: Summary | License | FGDC | ISO 19115 | Metadata | Background | Data Access Form | Files

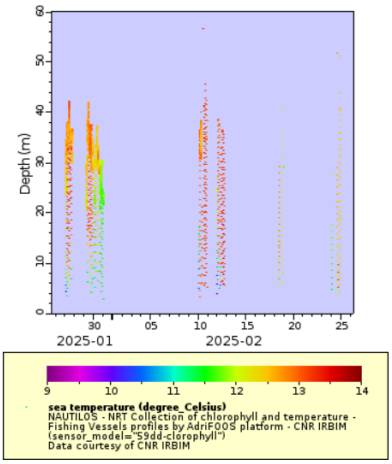
Graph Type: markers
X Axis: time
Y Axis: depth
Color: TEMP

Constraints	Optional Constraint #1	Optional Constraint #2
sensor_model	= "59dd-clorophyll"	<=
	>=	<=
	>=	<=
	>=	<=
	>=	<=

Server-side Functions
distinct()

Graph Settings
Marker Type: Dot Size: 4
Color:
Color Bar: Continuity: Scale:
Minimum: 9 Maximum: 14 N Sections:
Y Axis Minimum: Maximum: 60 Ascending

Redraw the Graph (Please be patient. It may take a while to get the data.)



b)

NAUTILOS ERDDAP NAUTILOS
Easier access to scientific data

ERDDAP > tabledap > Make A Graph

Dataset Title: NAUTILOS - NRT Collection of chlorophyll and temperature - Fishing Vessels profiles by AdriFOOS platform - CNR IRBIM
Institution: CNR IRBIM (Dataset ID: AdriFOOS_FV_chlorophyll_cnr-irbim)
Range: longitude = 13.1925 to 13.93399°E, latitude = 43.578 to 43.95581°N, depth = -0.1 to 75.1m, time = 2024-01-29T01:00:00Z to 2025-02-26T00:07:00Z
Information: Summary | License | FGDC | ISO 19115 | Metadata | Background | Data Access Form | Files

Graph Type: markers
X Axis: longitude
Y Axis: latitude
Color: CHLA

Constraints	Optional Constraint #1	Optional Constraint #2
sensor_model	= "59dd-clorophyll"	<=
longitude	>= 13.436	<= 13.764
latitude	>= 43.589	<= 43.8
	>=	<=
	>=	<=

Server-side Functions
distinct()

Graph Settings
Marker Type: Dot Size: 3
Color:
Color Bar: Continuity: Scale:
Minimum: 10 Maximum: 100 N Sections:
Draw land mask:
Y Axis Minimum: Maximum: Ascending

Redraw the Graph (Please be patient. It may take a while to get the data.)

Click on the map to specify a new center point.
Zoom: Out 8x Out 2x Out Data In In 2x In 8x

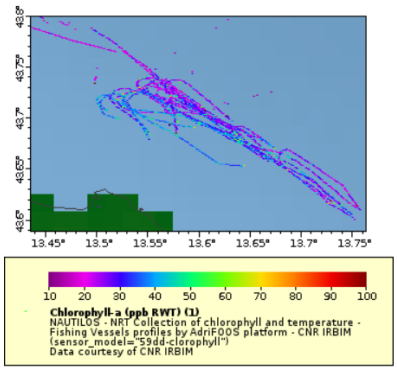


Figure 12: Chl-a 59dd dataset recorded in the Adriatic Sea via AdriFOOS infrastructure and available through the NAUTILOS ERDDAP™: a) time, depth and temperature plot, b) map showing oxygen saturation values recorded.

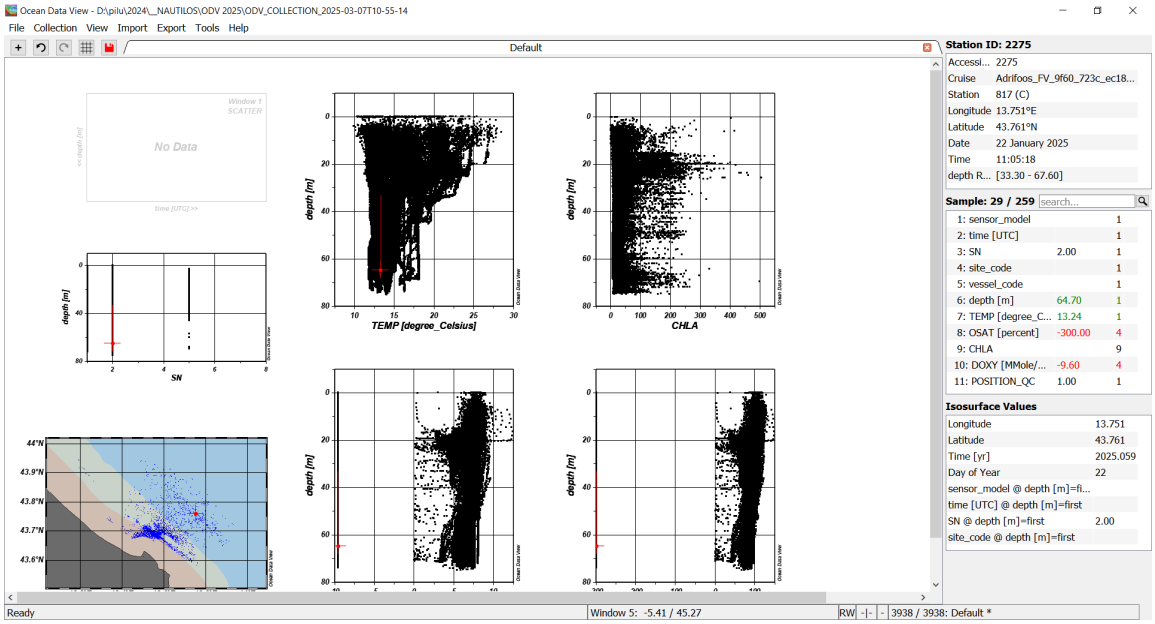


Figure 13: Data verification and validation process conducted through ODV by CNR IRBIM staff on the dataset produced in the Adriatic Sea.

- **Other Related Activities**

In March 2023, the prototypes 1111, 2222, 59dd and 8888 were used for the citizen science activity involving recreational scuba divers planned in WP10. Three divers from a local diving club were recruited to participate in a demonstration dive that occurred in the Adriatic Sea. They were first shown the pamphlet developed for the Ocean Literacy Campaign "NAUTILOS Quest"[9] and asked to sign the appropriate NAUTILOS consent form (Fig.14a; see Deliverable 13.7). Then, divers were instructed on how to mount the sensors on their buoyancy compensator device (BCDs; Fig. 14b) and correctly set the sensors through the user-friendly NKE web application, using the specific acquisition settings already described in Deliverable 10.9. The actual dive took place on 9 March 2025 in the Portonovo Bay (Ancona, Italy), from the shore to a maximum depth of approximately 4 m (Fig. 14c). Subsequently, the CNR staff downloaded the data from the instruments and sent them to ETT to be included in the NAUTILOS web services.

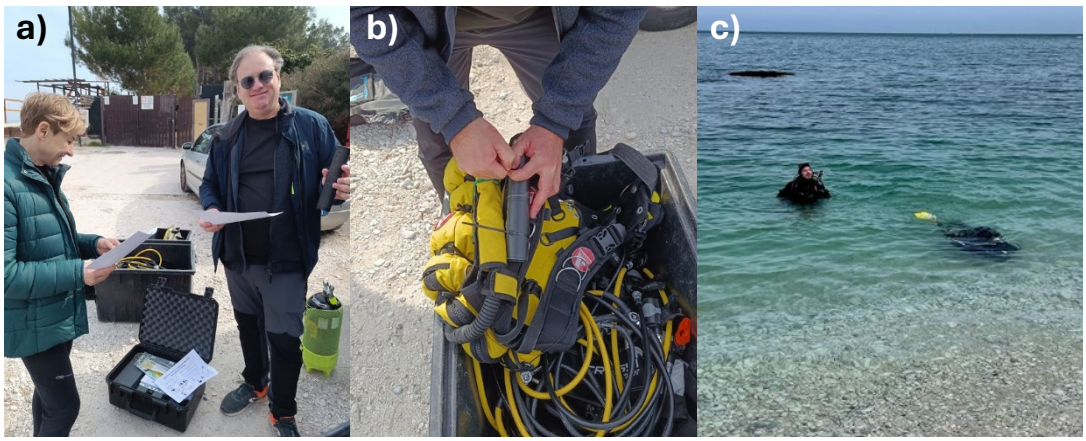


Figure 14: Citizen science activity carried out by CNR IRBIM with local scuba divers (a); DO and Chl-a sensors mounted on BCDs (b); end of the dive in Portonovo Bay, Adriatic Sea (c).

[9] https://nautilos-h2020.eu/wp-content/uploads/2025/02/ITALIAN_Nautilos-Comic-Strip-2.pdf

- **Ifremer Results**

Between June and July 2024, the sensors operated continuously for 1.5 months in the Bay of Biscay. This measurement campaign was used to validate the sensor-to-WiHub measurement chain, as well as to validate the measurement and pressure triggering frequencies in the field. Each fishing operation in the Iroise Sea can last a few days (setting-fishing-hauling). Even if no oxygen data was recorded (Table 5), before the battery stopped, between June and July 2024, the DO 1111 sensor registered 11905 records during 13 fishing operations. In fact the DO sensor still measured temperature and pressure, as shown in the data extracted from the NAUTILOS ERDDAP™ (Figure 15). The DO channel was not active, although it had been in the past on this same sensor as the connector was inadvertently disconnected. Probably due to the speed of the gear deployment, it was also observed that often the start and stop of the records occurred at 10 meters minimum, despite the configuration implemented (3 m).
Between June and July 2024, the Chl-*a* 59dd sensor registered 12018 measurements during 12 fishing operations, before the battery stopped. Over this period, time series of temperature, pressure, depth and Chlorophyll-*a* concentration (expressed in ppb Rhodamine WT -RWT) were recorded (Figure 16, Table 6).
Values between 100 and 1000 ppb Rhodamine WT (RWT) were measured for the Chl-*a* concentration (Fig 16a). According to the location of the fishing trap, variations in the concentration of Chl-*a* can be detected. Temperature data varied slightly around 14.2°C (Fig 16b).

Table 5: DO 1111 sensor data extracted from a file showing no Oxygen data and depth of the records start and stop.

Timestamp(Standard)	CH0:Pressure (bar)	CH1:Temperature (degC)	CH2:Oxygen (deg)	CH3:Depth (m)	CH4:Oxygen_ Concentration (mg/L)	CH5:Oxygen_ Saturation(%)
03/07/2024 08:30:02	1,14	14,372	0	11,2	0	**0**
03/07/2024 08:30:04	1,12	14,371	0	11,1	0	**0**
03/07/2024 08:30:06	1,11	14,371	0	11	0	**0**
03/07/2024 08:30:08	1,11	14,371	0	11	0	**0**
03/07/2024 08:30:10	1,12	14,371	0	11,1	0	**0**
03/07/2024 08:30:12	1,13	14,371	0	11,2	0	**0**
03/07/2024 08:30:14	1,13	14,371	0	11,2	0	**0**
03/07/2024 08:30:16	1,12	14,37	0	11	0	**0**
03/07/2024 08:30:18	1,11	14,371	0	11	0	**0**
03/07/2024 08:30:20	1,12	14,371	0	11,1	0	**0**
03/07/2024 08:30:22	1,13	14,371	0	11,2	0	**0**
03/07/2024 08:30:24	1,13	14,371	0	11,2	0	**0**
03/07/2024 08:30:26	1,1	14,371	0	10,9	0	**0**
03/07/2024 08:30:28	1,11	14,371	0	11	0	**0**
[...]						
08/07/2024 07:30:00	1,5	14,595	0	14,9	0	**0**
08/07/2024 07:40:00	1,52	14,586	0	15	0	**0**
08/07/2024 07:50:00	1,51	14,576	0	14,9	0	**0**
08/07/2024 08:00:00	1,5	14,568	0	14,9	0	**0**
08/07/2024 08:10:00	1,5	14,55	0	14,8	0	**0**
08/07/2024 08:20:00	1,49	14,524	0	14,8	0	**0**
08/07/2024 08:30:00	1,49	14,468	0	14,7	0	**0**
08/07/2024 08:40:00	1,48	14,453	0	14,6	0	**0**
08/07/2024 08:50:00	1,47	14,452	0	14,6	0	**0**
08/07/2024 09:00:00	1,46	14,439	0	14,4	0	**0**
08/07/2024 09:10:00	1,44	14,319	0	14,3	0	**0**
08/07/2024 09:20:00	1,44	14,187	0	14,2	0	**0**
08/07/2024 09:30:00	1,42	14,119	0	14,1	0	**0**
08/07/2024 09:40:00	-0,03	14,103	0	-0,3	0	**0**

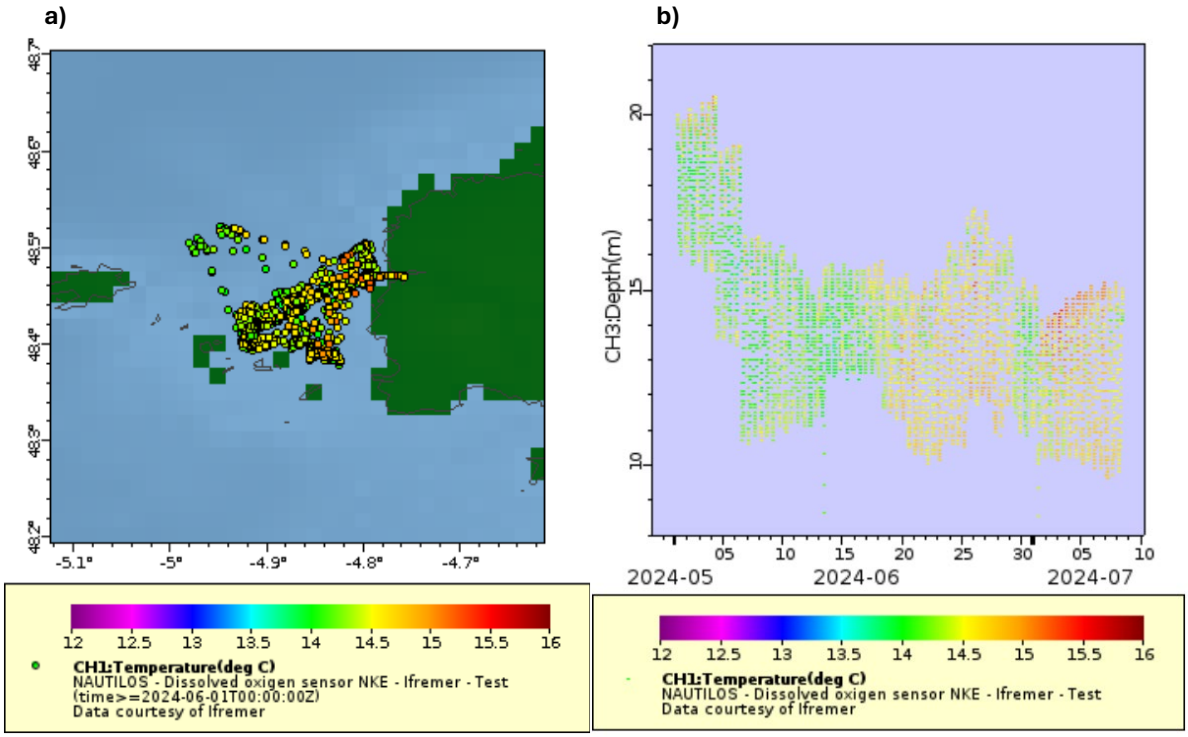


Figure 15: Map (a) and time series (b) of temperature data recorded between June and July by the DO prototype 1111 in the Bay of Biscay, as extracted from ERDDAP™ NAUTILOS.

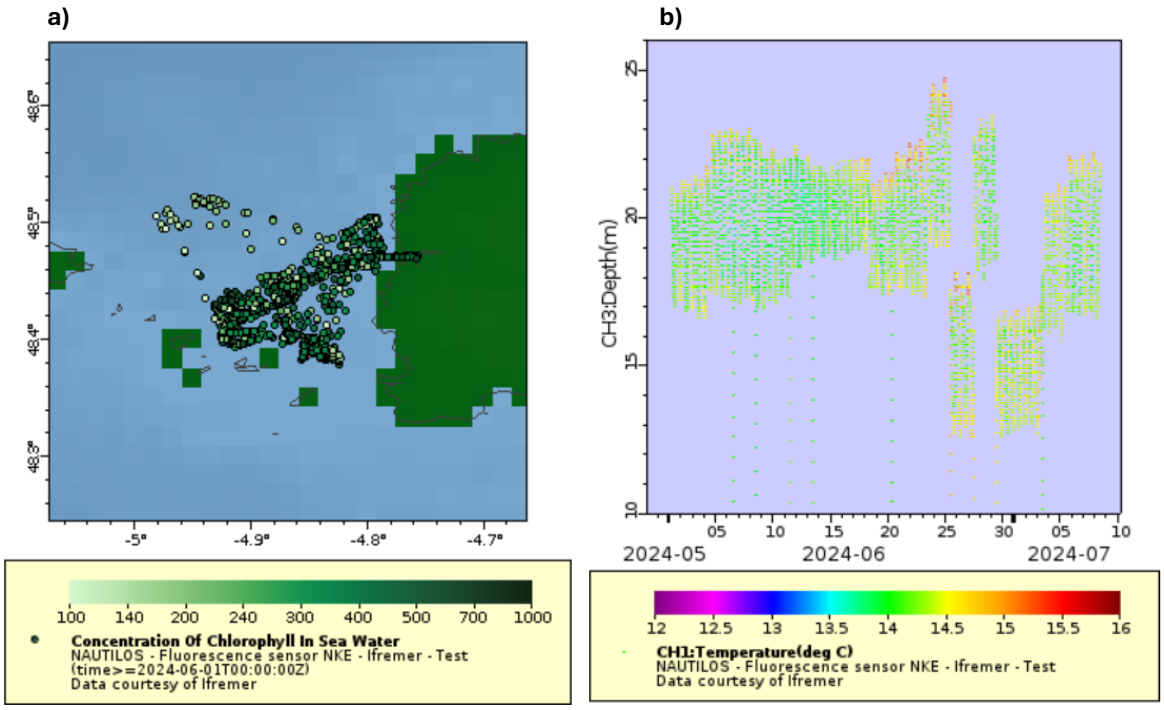


Figure 16: Chlorophyll-a geographical distribution (a) and depth-temperature time series (b) recorded between June and July by the Chl-a prototype 59dd in the Bay of Biscay, as extracted from ERDDAP™ NAUTILOS.

Table 6: Chl-a 59dd sensor data extracted from a file showing the depth of the records start and stop.

Timestamp(Standard)	CH0:Pressure (bar)	CH1:Temperature (degC)	CH2:Chlorophyll_a (ppb)	CH3:Depth (m)
03/07/2024 07:41:48	0.496	14.142	372.281	4.9
03/07/2024 07:41:50	0.562	14.142	277.729	5.6
03/07/2024 07:41:52	0.641	14.141	283.535	6.3
03/07/2024 07:41:54	0.705	14.141	328.625	7.0
03/07/2024 07:41:56	0.754	14.141	271.152	7.5
03/07/2024 07:41:58	0.820	14.142	296.373	8.1
03/07/2024 07:42:00	0.888	14.142	290.846	8.8
03/07/2024 07:42:02	0.960	14.142	289.867	9.5
03/07/2024 07:42:04	1.024	14.142	954.042	10.1
03/07/2024 07:42:06	1.071	14.142	285.879	10.6
03/07/2024 07:42:08	1.123	14.143	442.417	11.1
03/07/2024 07:42:10	1.196	14.143	251.633	11.8
03/07/2024 07:42:12	1.267	14.143	256.076	12.5
03/07/2024 07:42:14	1.338	14.143	257.335	13.3
[...]				
08/07/2024 06:50:00	2.173	14.459	617.599	21.5
08/07/2024 07:00:00	2.179	14.485	616.445	21.6
08/07/2024 07:10:00	2.194	14.503	618.474	21.7
08/07/2024 07:20:00	2.197	14.516	619.034	21.8
08/07/2024 07:30:00	2.199	14.540	630.682	21.8
08/07/2024 07:40:00	2.204	14.580	622.672	21.8
08/07/2024 07:50:00	2.205	14.558	629.038	21.8
08/07/2024 08:00:00	2.184	14.513	637.783	21.6
08/07/2024 08:10:00	2.197	14.493	622.776	21.8
08/07/2024 08:20:00	2.188	14.459	614.591	21.7
08/07/2024 08:30:00	2.179	14.401	618.964	21.6
08/07/2024 08:40:00	2.158	14.178	615.710	21.4
08/07/2024 08:50:00	2.110	14.019	637.433	20.9
08/07/2024 09:00:00	-0.006	14.030	202.451	-0.1

Ifremer DO sensor drift check n°2 and n°3

All the results for the tests performed at Ifremer laboratories are expressed in % of O_2 saturation (Table 7). Tap water was used to carry out the tests and internal salinity was set at 0. Drift measurements were carried out on the sensor without previously removing fouling.
The first and second drift tests for the O_2 saturation showed both a correction of +5% to be applied to the obtained measurements. It was not possible to carry out the third drift check on oxygen data at Ifremer's laboratories due to the above reported connector disconnection. However when the DO 1111 sensor was tested at NKE facilities after being cleaned by fouling and repaired, it showed a reading of 96% saturation, giving a residual error of 4%. The error measured is comparable with the drift values obtained during the two laboratory tests carried out at Ifremer. Considering the length of the sensor deployment the calculated drift seems to be quite small.
Furthermore, it should also be taken into account that correction factors on the O_2 saturation should be applied to correct field data recorded with salinity setting=0, while no correction is needed if the correct water salinity is used in the manual settings (with salinity H_20 =salinity setting or similar, average obtained offset with Winkler concentration in mg/l=-0.271 +-sd 0.349).

Table 7: DO 1111 sensor reference values (up), 1st, 2nd and 3rd drift checks results.

Wisens O2 SN 1111 01/2023 (calibration and validation references D6.1)

Winkler Reference				Temperature	Salinity	O2 sensor 1111									
[O2] (mg/L)		O2 % sat		°C	PSU	internal salinity setting	[O_2] en mg/L		Correction (mg/L)	[O_2] en % sat		Correction (%)	T en °C		Correction (°C)
Moyenne	Ecart-type						Moyenne	Ecart-type		Moyenne	Ecart-type		Moyenne	Ecart-type	
9,83	0,02	97,88	0,19	15,20	0,00	0	9,83	0,00	0,00	98,2	0,1	-0,3	15,20	0,02	0,00

Wisens O2 SN 1111 18/11/2023 (drift check n°1)

Winkler Reference				Temperature	Salinity	O2 sensor 1111									
[O2] (mg/L)		O2 % sat		°C	PSU	internal salinity setting	[O_2] en mg/L		Correction (mg/L)	[O_2] en % sat		Correction (%)	T en °C		Correction (°C)
Moyenne	Ecart-type						Moyenne	Ecart-type		Moyenne	Ecart-type		Moyenne	Ecart-type	
10,20	0,01	101,6	0,1	15,19	0,00	0	9,60	0,04	0,60	95,7	0,3	5,9	15,18	0,00	0,01

Wisens O2 SN 1111 21/02/2024 (drift check n°2)

Winkler Reference				Temperature	Salinity	O2 sensor 1111									
[O2] (mg/L)		O2 % sat		°C	PSU	internal salinity setting	[O_2] en mg/L		Correction (mg/L)	[O_2] en % sat		Correction (%)	T en °C		Correction (°C)
Moyenne	Ecart-type						Moyenne	Ecart-type		Moyenne	Ecart-type		Moyenne	Ecart-type	
9,07	0,02	99,8	0,2	20,00	0,00	0	8,60	0,01	0,47	94,7	0,1	5,1	19,98	0,07	0,02

Wisens O2 SN 1111 12/09/2024 (drift check n°3)

Winkler Reference				Temperature	Salinity	O2 sensor 1111									
[O2] (mg/L)		O2 % sat		°C	PSU	internal salinity setting	[O_2] en mg/L		Correction (mg/L)	[O_2] en % sat		Correction (%)	T en °C		Correction (°C)
Moyenne	Ecart-type						Moyenne	Ecart-type		Moyenne	Ecart-type		Moyenne	Ecart-type	
Drift check not possible: Oxygen sensor in ERROR															

Table 8 reports the suggested concentration and saturation offsets to adopt when the salinity setting is at 0 and water salinity at 35 or 38 as already reported in NAUTILOS Deliverable 6.1.

Table 8: Dissolved Oxygen Concentration offsets calculated for the DO 2222 sensor as function of salinity.

	mg/l		O_2 %
avg offset at H_2OS=35 and setting=0	-2.121		-4.458
avg offset at H_2OS=38 and setting=0	-2.538		-7.078

Ifremer Chl-*a* sensor drift check n°1 and n°2

For its 1st drift monitoring, the sensor 59dd battery level at 12% only allowed to see the data with the function "real live data" of the web application. The 1st and 2nd drift measurements were carried out on the sensor without previously removing fouling.
Figure 17 and Tables 9 and 10 show the results of the 1st and 2nd linearity tests of the Chl-*a* sensor with different fluorescein concentrations.
The fluorescence response was still linear for practical concentration ranges of fluorescein solutions at the first drift check performed on 20 February 2024, while it showed different results during the one occurred on 16 September 2024.
It can be assumed that attenuation of the sensor response could be due to the presence of fouling on the optical cell on the sensor after 5 months in situ (Fig. 6).
Therefore a further check of the sensor after cleaning the biofouling made it possible to evaluate the influence of this biofouling on the drift observed (Tab. 11).
After cleaning the biofouling, it was noticeable that the response of the sensor was identical to that before the in situ measurements. The sensor showed no drift and good stability (Figure 17, green line).

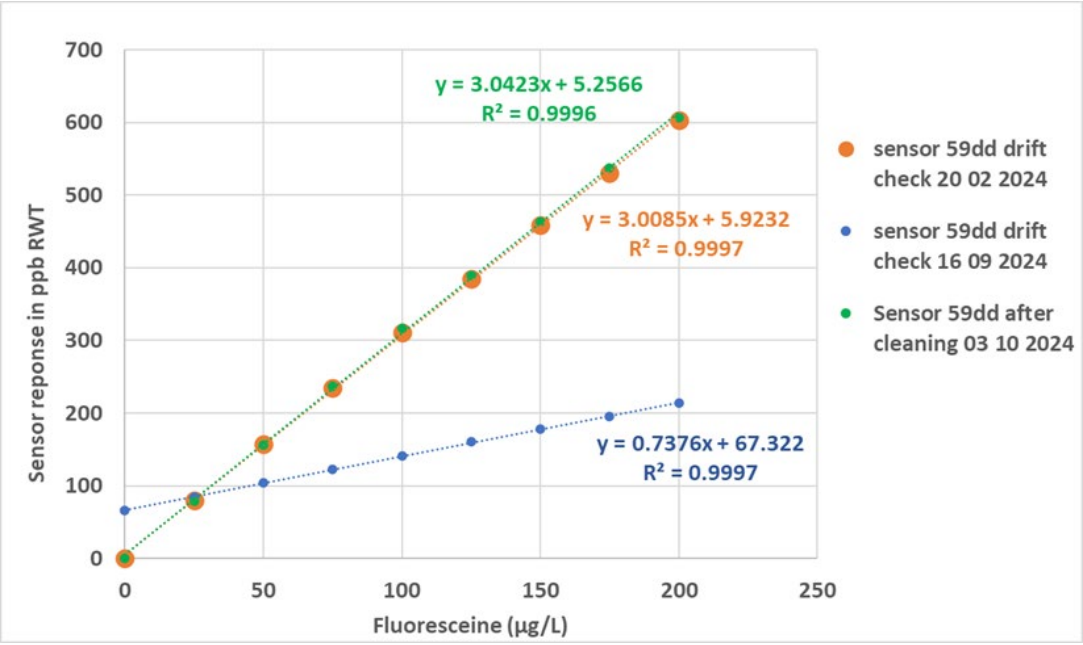


Figure 17: Response of the Chl-a 59dd sensor to fluorescein solutions during drift check n. 1 (orange line), n. 2 with biofouling (blue line) and last drift check carried out after cleaning (green line).

Table 9: Linearity results of the Chl-a 59dd sensor with different fluorescein concentrations during the drift check n°1 (20/02/24).

Fluorescein (µmol/L)	0	25	50	75	100	125	150	175	200
1	0.904	80.159	157.815	234.773	310.753	384.874	458.193	530.218	603.747
2	0.621	80.229	157.501	234.553	310.645	385.049	458.368	530.778	602.947
3	0.692	80.089	157.99	234.423	310.61	385.189	458.333	530.673	603.187
4	1.046	80.194	157.571	234.353	310.82	385.154	458.123	530.848	603.012
5	0.621	80.159	157.571	234.458	310.68	385.054	458.298	530.568	603.222
6	0.763	79.669	157.955	234.668	310.785	385.224	458.163	530.638	603.292
7	0.869	80.019	157.885	234.353	310.61	384.224	458.263	530.708	603.047
8	0.692	80.264	158.235	234.388	310.855	385.364	458.438	530.777	603.117
9	0.479	79.914	157.955	234.708	310.645	384.994	458.648	530.638	603.012
10	0.869	80.054	157.71	234.353	310.715	385.049	458.298	530.708	602.908
Averaged value	0.756	80.075	157.819	234.503	310.712	385.018	458.313	530.655	603.149
Standard deviation	0.168	0.177	0.231	0.161	0.088	0.310	0.152	0.174	0.243

Table 10: Linearity results of the Chl-a 59dd sensor with different fluorescein concentrations during the drift check n°2 (16/09/24).

Fluorescein (µmol/L)	0	25	50	75	100	125	150	175	200
1	66.8	84.81	104.48	123.12	141.69	160.89	178.56	196.52	213.95
2	66.89	84.52	103.95	122.99	141.55	160.99	178.47	195.44	212.99
3	66.75	84.61	104.39	123.25	141.65	160.75	178.65	195.66	214.01
4	66.66	84.89	104.55	123.45	141.79	160.56	178.61	195.49	213.89
5	66.49	85.11	104.51	123.02	141.43	161.12	178.54	195.51	213.85
6	66.55	84.95	104.47	123.13	141.82	161	178.59	195.4	213.99
7	66.95	84.8	104.45	123.25	141.49	160.99	178.48	195.69	213.92
8	66.81	84.83	104.65	123.02	141.58	160.66	178.39	195.55	213.9
9	66.75	85.01	104.53	123.33	141.65	160.88	178.35	195.62	213.89
10	66.85	85.21	104.65	123.09	141.73	160.85	178.04	195.55	213.92
Averaged value	66.750	84.874	104.463	123.165	141.638	160.869	178.468	195.643	213.831
Standard deviation	0.146	0.211	0.198	0.151	0.126	0.171	0.178	0.322	0.299

Table 11: Linearity results of the Chl-a 59dd sensor with different fluorescein concentrations during the drift check n°2 after cleaning (03/10/24).

Fluorescein (µmol/L)	0	25	50	75	100	125	150	175	200
1	0.372	79.72	156.21	237.011	316.219	388.757	462.811	536.21	606.615
2	0.692	78.445	157.1	237.431	315.368	389.456	462.915	536.284	606.641
3	0.443	79.529	156.41	237.396	315.927	389.596	463.23	537.689	605.951
4	0.337	79.774	156.031	237.956	316.347	389.806	463.195	537.109	606.021
5	0.195	80.054	155.482	237.886	316.347	389.351	463.055	536.739	607
6	0.408	79.599	156.008	237.991	316.452	389.806	463.125	536.159	606.751
7	0.372	79.564	156.311	237.641	316.417	389.561	463.265	536.229	607.77
8	0.727	79.55	156.836	238.166	316.172	389.666	463.405	536.654	607.07
9	0.195	78.724	157.081	237.131	316.277	389.946	463.545	536.039	606.371
10	0.231	78.899	155.082	231.787	316.627	389.666	463.23	536.829	607.49
Averaged value	0.397	79.386	156.255	237.040	316.215	389.561	463.178	536.594	606.768
Standard deviation	0.186	0.516	0.654	1.885	0.351	0.332	0.216	0.518	0.586

- **CNR Results**

The DO 2222 and Chl-*a* 8888 prototypes have been operational, sending data almost daily to NAUTILOS web services, for more than a year and a half, while installed on the otter door of a commercial bottom trawler belonging to the CNR AdriFOOS fleet. Figure 18 shows the battery consumption patterns detected for the 2 prototypes in 2024 according to the number of measurements recorded by each sensor. This type of deployment involves multiple hauls carried out during each fishing day with an average duration of about 2.5 hours. According to the set sampling regime, for each haul, 300 initial records are registered every 2 seconds, while in the second phase data are recorded every minute, thus the number of records depends on the actual haul duration. During the year 2024, 3 battery replacements occurred for each sensor (see Tab. 4).
Based on the entire period of use of the DO 2222 prototype, from the first testing phases in WPs 5 and 6 (see Deliverables 5.6 and 6.1) to its use in the demonstration activities, it can be estimated that the lifespan of the internal membrane of the DO sensors is of approximately 2 years. After the deployment in the Bay of Biscay and the subsequent testing carried out by NKE at its own facilities, the DO 1111 and Chl-*a* 59dd prototypes have proven to function correctly when installed on trawling vessels in the Adriatic Sea

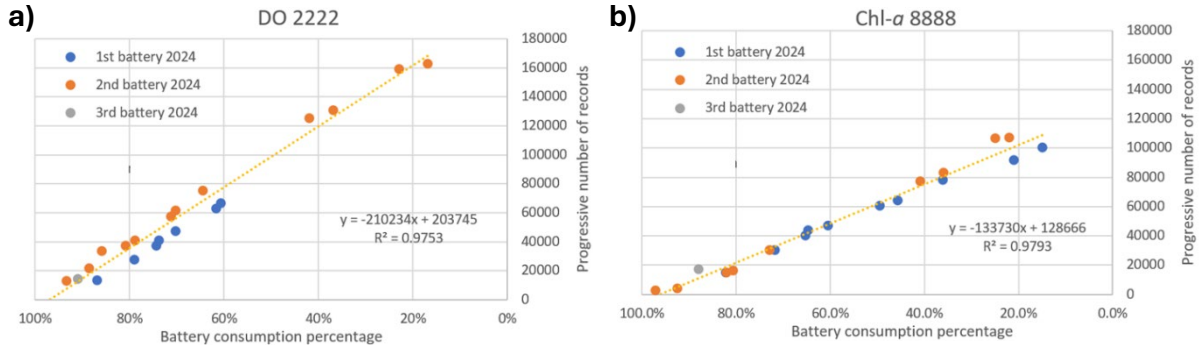


Figure 18: Battery consumption patterns detected in 2024 for sensors DO 2222 (a) and Chl-a 8888 (b) installed on a commercial bottom trawler operating daily in the Adriatic Sea.

The validated dataset (see Data recovery section) relating to the measurements recorded by the DO 2222 and Chl-*a* 8888 sensors in the Adriatic Sea consists of 4274 hauls, corresponding to 504190 measurement points in total (Fig. 19). The acquisition of oceanographic data during fishing operations generates data when the fishing gear is deployed into the water (down-cast), during the fishing phase either on the bottom or at the depth at which the fishing gear operates (horizontal profile), and when the gear is retrieved, depending on the combination of the sensor settings and the ascent rate (up-cast; Penna et al. 2023).
As an example of oceanographic data products that may be obtained by means of fisheries observing systems, isosurface (parameters at fixed depth) maps, related to the fishing area exploited by the vessel monitored through CNR AdriFOOS and the NKE DO and Chl-*a* sensors (Fig. 20), were generated using the ODV embedded data-interpolating variational analysis interpolation algorithm (Troupin et al., 2019). Seasonal maps (Summer: July to September, Autumn: October to December, Winter: January to March, Spring: April to June) of temperature (°C), oxygen saturation (%), and chlorophyll concentration (ppb RWT) at 5, 10, 20, 30, 50 and 70 m depth were produced for the period Summer 2023 to Autumn 2024 and are available in Appendix 2.

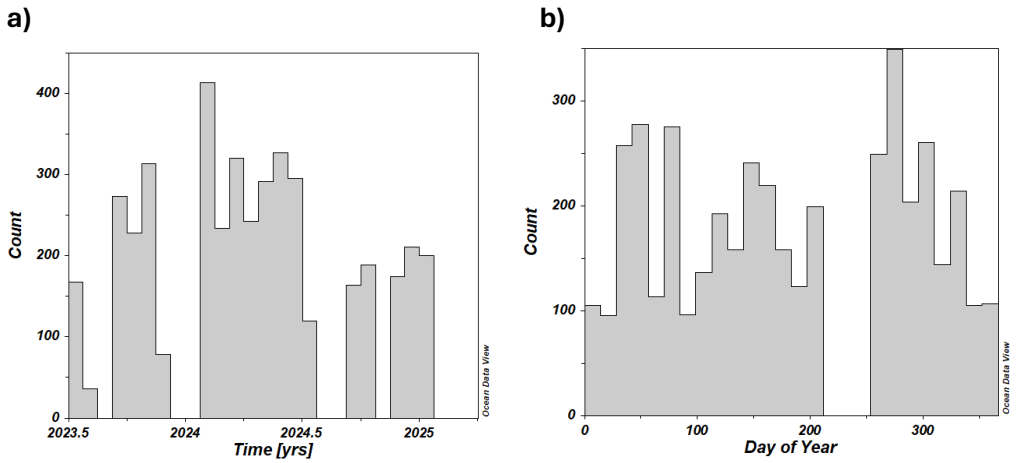


Figure 19. Count of validated profiles measured over years (a) and day of the year (b) by the DO 2222 and Chl-a 8888 sensors in the Adriatic Sea from Summer 2023 to Autumn 2024. Graphs generated by means of ODV.

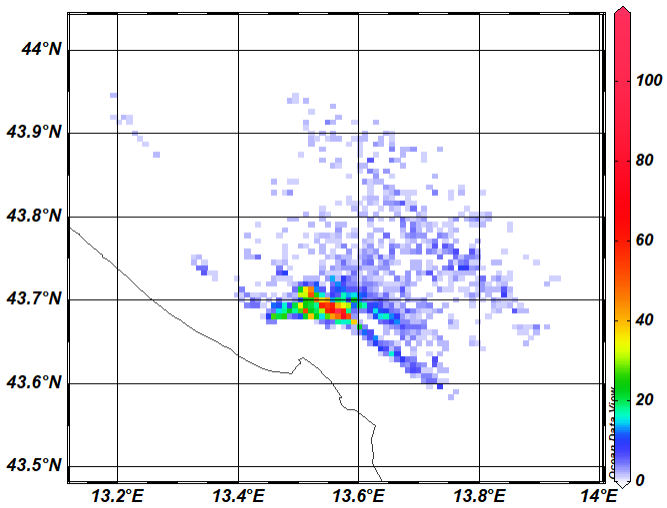


Figure 20. Quantitative spatial distribution (number of hauls per cell) of the DO and Chl-a profile dataset recorded by the DO 2222 and Chl-a 8888 sensors in the Adriatic Sea from Summer 2023 to Autumn 2024 mapped by means of ODV.

In July 2024, the CNR IRBIM oceanographic beacon[10] positioned within the same coastal monitored area, recorded a sea surface temperature of 29.5 °C. This measurement represents a record-breaking value, exceeding all previously observed summer temperatures in the area, including the previous peak recorded in August 2023 (Penna, pers. comm.[11]). Temperature values above 28 °C at a depth between 0 and 10 meters were also detected by the sensors installed on the fishing vessel in Summer 2023 and 2024 (Fig. 21). This convergence of observations underscores the growing utility of fisheries-based observing systems in climate-related oceanographic research. Thanks to their ability to collect near real-time and spatially extensive datasets, these systems provide crucial information not only for scientific studies on climate variability, but also for operational ocean forecasting models and practical applications involving sectors such as fisheries management, public health, and coastal economic activities (Van Vranken et al. 2020, 2023; Penna et al. 2023).

[10] https://www.irbim.cnr.it/en/sitoss-dettagli/senigallia/

[11] https://www.centropagina.it/attualita/ancona-caldo-mare-adriatico-penna-cnr-irbim-record/

An additional noteworthy phenomenon observed during Summer 2024 was a significant mucilage event[12] occurred in the same area (Fig. 22a). This type of events occasionally occur along the Adriatic coast during late spring and summer, significantly impacting tourism, fisheries, aquaculture, and benthic organisms; however the episode recorded in 2024 appeared particularly intense (Vilibić et al. 2025). The drop in dissolved oxygen levels observed near the seafloor in spring/summer 2024 is probably related to this event (Fig. 22b). For example, between 24 and 27 June, dissolved oxygen at the bottom dropped to 40% of saturation, both at 20 and 70 m depth. Oxygen depletions near the sea bottom may have important implications for habitat quality, species distribution, and availability of fishery resources (Chiarini et al. 2022).

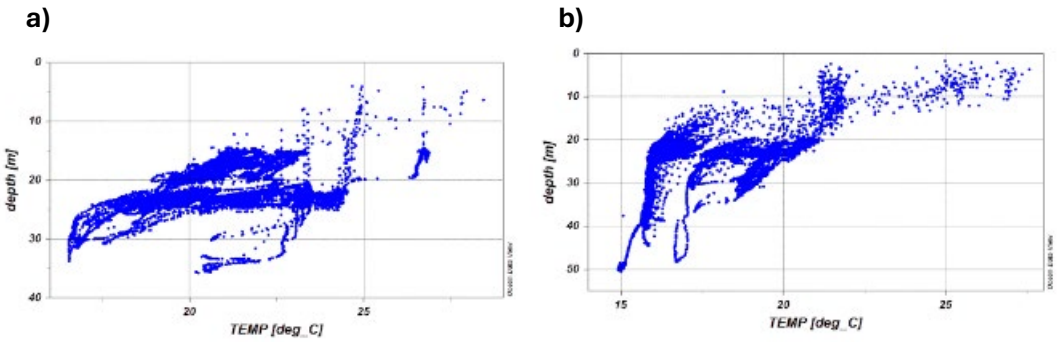


Figure 21: Scatter plot of temperature (°C) at depth (m) data recorded by the NKE DO 2222 and Chl-a 8888 sensors in the fishing area exploited by the vessel monitored through CNR AdriFOOS for the periods July to September 2023 (a) and July to September 2024 (b); graphs were generated by means ODV using the validated dataset.

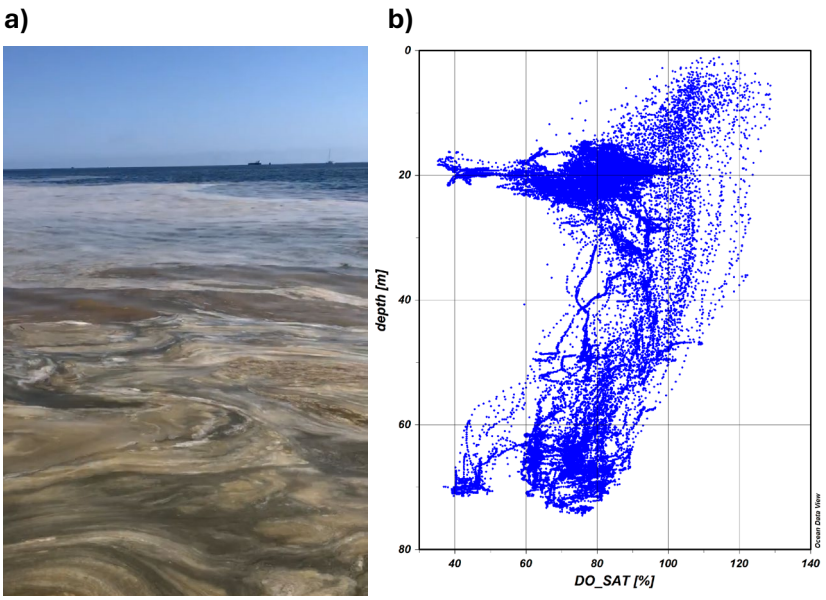


Figure 22: Mucilage event documented in the monitored area, picture taken on 21 July 2024 (a); Scatter plot of dissolved oxygen saturation (%) at depth (m) data recorded by the NKE DO 2222 sensor in the fishing area exploited by the vessel monitored through CNR AdriFOOS for the period May to July 2024 (b).

[12] https://www.arpa.marche.it/notizie-2024/1545-22-06-2024-mucillagini-in-adriatico-centro-settentrionale

- **TRL achievement level**

Based on the technical issues encountered during the first part of the demonstration phase, the sensors' battery housing has been redesigned, the sensor firmware has been upgraded as well as the quick start guides related to the sensor use (see D7.1).
A software update occurred in the WiHub to allow the port for the FTP server to support the mobile operator selected by Ifremer. Due to these improvements the Technology Readiness Levels (TRL) declared in D7.1 was 7.
During the period of activity described in the present document, further upgrades were made to the sensors (i.e. NKE made the fixing of internal connectors stronger against vibrations), the manufacturer consolidated its ability to offer remote technical support for data transmission via WiHub and the optimal operating conditions for fisheries monitoring and the recalibration interval were better defined. Furthermore, the same sensors were used in aquaculture plants and for citizen science activities involving divers.
Therefore, after more than another year of demonstration activities, taking into account also what is reported in Section III.3 below, the current TRL of the Chl-*a* sensor can be increased to 7; instead, given the results discussed above and the fact that it has already been commercialized before the end of the project (see Deliverable 11.7), the current TRL of the DO sensor can be declared 9.

- **Recommendations**

In general, the WiSens Dissolved Oxygen and Chlorophyll-*a* sensors demonstrated good performance in measuring for both depth and temperature, comparable to those of traditional oceanographic instruments (see also Deliverable 5.6). To acquire reliable data sets it is recommended to use the DO sensor together with a salinity sensor and to change its internal salinity settings accordingly and regularly (or at least to post-process data taking real salinity into account). The acquired Chl-*a* trends could be considered reliable, however when accurate measurements are required, the dataset should be post-processed (as it is normally done with other commercial products). Furthermore, the Chl-*a* sensor could be directly calibrated with other standard substances in the future depending on the required use. The sensors showed no or small measurement drifts and good stability over the measurement period. It is recommended that the membrane of the DO sensors is replaced and the probes are recalibrated by the manufacturer at least every 2 years.
The first field validation tests reported in Deliverable 5.6 suggested that, based on their acquisition speeds, the DO and Chl-*a* prototypes were suitable for use in relatively stable conditions and for prolonged deployments at fixed depths. However, the measurement campaigns carried out at sea by Ifremer and CNR enabled the sensors to be tested under real conditions with different configurations and prolonged operating modalities. In general, due also to possible problems with biofouling, unless the fisherman is required to maintain and clean the sensors, they have been shown to be more suitable for monitoring fishing activities with towed gears rather than long-term use on fixed gears.
Furthermore, the acquisition settings, the fishing operation duration and the communication rate with the WiHub influence the battery consumption. Based on the results above reported, it is possible to schedule battery replacements for these sensors. For example, with the configuration used for the sensors mounted on the pot fishing gear deployed in the Bay of Biscay over several months, batteries should be changed more frequently.

III. Novel approach to Aquaculture Observing Systems Demonstration Report

1. Background

This section is described in Deliverable 7.1 section III.1.

2. Demonstration Plan

a. Demonstration on Aquaculture Observing Systems in Coastal Norway (NIVA)

- **Specific Objectives**

Salmon aquaculture is a major industry in Norway, producing over 1 million metric tons annually, valued at more than 11 billion Euros[13]. Coastal ocean processes, such as harmful algal blooms (HABs), can severely impact fish health. For instance, a 2019 bloom of *Chrysochromulina leadbeateri* (John et al., 2022) killed 8 million salmon in a week, causing ~50 million Euros in losses. Low-cost sensors for DO, Chl-*a*, pH, and pCO_2 (partial pressure of carbon dioxide) can help detect bloom events or other negatively associated water conditions, allowing operators to take preventive measures like relocation or early harvesting. High pCO_2 and low pH can also harm salmon, but affordable, reliable sensors for these parameters remain scarce in aquaculture.

- **Location and period of occurrence**

Due to unavailability of the BLUE Campus, the activities could no longer be carried out at their site as described in D7.1. Therefore another aquaculture site situated in Herdelfjord, 25 km northwest of Bergen (Norway) was selected for the demonstration which took place from 14 May 2025 to 17 June 2025 (coordinates of the farm: 60°32'35.6"N 5°02'06.0"E). The farm hosts approximately 800 tonnes of salmon and trout and is operated by Blom Fiskeoppdrett AS, a family-owned company that has been in operation for more than 50 years, which owns a total of roughly 6000 tonnes of fish throughout all its farms. The farm is located only 250m from the route of the coastal line sailing between Bergen and Kirkesnes operated by Hurtigruten (Fig. 23 and 24), which is covered by ocean observations made by NIVA with FerryBox systems on three vessels sailing this route (Fig. 25): the MS (Motor Ship) Trollfjord, the MS Vesterålen and the MS Richard With. MS Vesterålen's FerryBox is a cooperation between NIVA and the Norwegian Institute for Marine Research (IMR). The MS Vesterålen has been rerouted and no longer sails the coastline but the two other ships, MS Trollfjord and MS Richard With are still operating on the same route and are each revisiting Herdelfjord where the demonstration is located twice a month on average. However, during the demonstration period the ships also transected adjacent fjords (~6 km to the east and west of the farm location). All the ships are equipped with temperature, salinity, turbidity, dissolved oxygen, fDOM (fluorescent Dissolved Organic Matter) and Chl-*a* fluorescence sensors, and MS Richard With also has carbonate system sensors in operation. For the demonstration, the dissolved oxygen, pH, and pCO_2 observations made by the FerryBoxes were used to complement the sensor observations from the fish farm.

[13] https://en.seafood.no/news-and-media/news-archive/record-exports-of-norwegian-seafood-in-2023-due-to-price-growth-and-weak-krone/



Figure 23: The demonstration site at a fish aquaculture farm in Herdelfjord near Bergen, Norway (~25 km away); within the region marked with a red square.

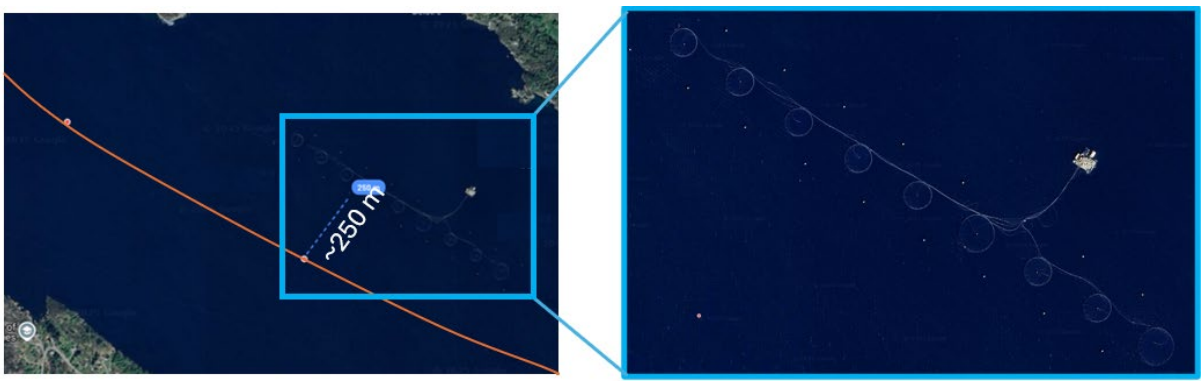


Figure 24: Fish aquaculture farm demonstration site near Bergen, Norway. The left panel shows a fjord-level view with the light blue box outlining the fish farm location and the orange transect representing the Hurtigruten FerryBox route for MS Richard With and MS Trollfjord. The right panel shows a zoomed-in view of the fish farm with nine enclosed floating cages (circular-shaped objects) and feeding barge (light coloured object to the northeast of the floating cages.



Figure 25: *NAUTILOS sensors installed at the fish farm and FerryBox measuring simultaneously.*

- **Equipment involved**

NAUTILOS DO, Chl-*a*, pH and pCO_2 low-cost sensors demonstrated at the aquaculture site. See also Deliverable 7.1 section III.2.a.

- **Deployment configuration**

The sensors were deployed from one of the fish cages within the infrastructure (Fig. 26). A 220V AC power supply was available on the cage and used to power sensors that did not have battery packs (e.g., carbonate system sensors). The loggers were housed in a waterproof plastic case, securely attached to the cage structure (black Pelicase-type waterproof case attached to the railing to the right of the operator in Fig. 26). The sensors were attached to a deployment frame and submerged off the side of the fish cage at ~2 m depth and secured to the fish cage platform.



Figure 26: Installation of the sensors at the aquaculture facility.

- **Maintenance, events/issues occurred and actions taken**

The DO, Chl-*a* and the pCO_2 sensors were damaged during the initial deployment. The DO and Chl-*a* were deployed without their rugged protection and did not withstand mechanical stress of the attachment to a custom-fabricated deployment frame. During an initial deployment in March 2025, the pCO_2 cable was also damaged. The Wisens sensors were subsequently replaced with a new set of sensors (namely sensors 2222 and 8888 already used in the Adriatic Sea for demonstration on fishing vessels) and the cable of the pCO_2 sensor was repaired on 14 May 2025. The pCO_2 and new DO sensor functioned well until the end of the demonstration on 17 June 2025, however the Chl-*a* sensor experienced water leakage and data was not recoverable. The pH sensor experienced a grounding issue due to the deployment configuration and possibly related to the power supply at the fish farm, and the pH data were unfortunately not usable after a quality control check with pCO_2 data from the fish farm and FerryBox pCO_2. As a result, pCO_2 and DO data collected from 14/05 to 17/06 will be presented. Chl-*a* and pH data were not available, however, pH was calculated using the R script seacarb (Gattuso et al., 2024) with inputs of salinity from the FerryBox, and temperature and pCO_2 from the fish farm.

- **Data recovery/ Analysis**

The DO data were post-processed after recovery to correct for salinity effect according to Aminot and Kérouel (2004), as the sensor itself is not measuring conductivity (see section II for more details on sensor settings). Salinity measured by the nearby FerryBox route was used to correct the sensor data (S=~15). The pH instrument was calibrated with pH buffers to ensure a Nernstian-response, and it was also calibrated before and after recovery with a water bath and reference thermometer for its temperature sensor and with a Tris seawater buffer solution set at a pH=8.094 at 25 °C and a salinity of 35, with its temperature controlled by the bath, following the calibration protocol described in Deliverable 4.1. Based on the calibration coefficients, an additional short demonstration in a different coastal fjord in Bergen, Norway (Puddefjord), and assessment of consistency of carbonate system variables, the grounding issue that is described in the previous section was discovered. The system was also configured with a 4G modem, enabling real-time transmission of data from the pH and pCO_2 sensor. Data from the NKE sensors were stored locally and retrieved after the equipment was recovered. FerryBox sensor data with vessel navigation data are automatically transferred over the vessel's satellite communication link to NIVA's onshore FTP server, and data are stored on NIVA's cloud database for automated quality control and interactive Grafana[14]-based visualisation.

- **Other Relative Activities**

In March 2025, the data of the three FerryBoxes have been annotated by NIVA's experts for phytoplankton blooms for the 2023-2025 time period through NIVA's Grafana interface (Fig. 27) and the annotated dataset has been transferred to DFKI for the algorithm training. It contains 51 distinct events.

[14] https://grafana.com/



Figure 27: *NIVA's Grafana interface for visualisation and annotation of FerryBox data.*

The methods used by DFKI for the event detection in this case are the same as described in NAUTILOS Deliverable 7.3 section VII, except for the following changes. Other than stated in D7.1 it turned out that because of the fact that there was just one specific event type (algal bloom) annotated, the concept drift and anomaly detection approach became unusable. Therefore, only the classification approaches described in D7.3 section VII were used to distinguish time windows of measurements being either from the type "bloom" or not. In comparison to the data streams from the FerryBoxes used in D7.3, the dataset used for Subtask 7.1.2 only contains segments of time series of the relevant environment around the area of Bergen. Also for this dataset the times where the ship stayed in the harbor of Bergen needed to be removed. This results in a further segmentation in most of the time two parts, the part entering the area and sailing towards Bergen, and the one from Bergen to the outer boundary of the area. Since most of the time these segments are entirely annotated as containing an algal bloom or not, the transition patterns occurring when entering or leaving these zones were not included or at least could not be compared to data before or after them, which is a limitation for this dataset compared to the one used in D7.3. Furthermore, the data is split into training and validation by ship: Training data consists of data from vessels MS Richard With and MS Trollfjord while data from the MS Vesterålen is used for validation. pH and pCO2 are only available from one vessel, so they cannot be used in this demonstration. As the data set is smaller, the optimizer may use data from D7.3 for training as well.

b. Demonstration on Aquaculture Observing Systems in Coastal Greece (HCMR)

Aquaculture is a key sector of the blue economy in the Eastern Mediterranean Sea. Within the framework of the European Union Strategy for the Adriatic and Ionian Region (EUSAIR), aquaculture is recognized as one of the most promising economic activities across all coastal countries in the region. Greece emerged as the largest producer in 2020, overtaking Italy, which had previously led the sector until 2019[15]. Greece's aquaculture industry is well-developed, contributing significantly to national seafood production, with finfish and mussels representing the primary cultivated species. However, in recent decades, extreme environmental events—particularly marine heatwaves (MHWs)—have severely impacted marine ecosystems and seafood industries in the Mediterranean. These MHWs have caused mass mortality events across various species, resulting in substantial economic losses (Lattos et al., 2022). Projections indicate that MHWs will continue to increase in intensity, duration, and frequency due to anthropogenic climate change (Darmaraki et al., 2019). Despite the critical importance of accurate environmental data for aquaculture, significant gaps remain in coastal monitoring across the Mediterranean, particularly in hard-to-access or under-monitored areas. These data deficiencies hinder our understanding of essential coastal processes such as temperature fluctuations, currents, pollution levels, and ecosystem responses. Addressing these gaps is vital for enabling timely and informed decision-making in aquaculture, ensuring optimal growth conditions, minimizing disease risks, and reducing environmental impacts. Enhancing coastal data collection is therefore fundamental to the long-term sustainability and resilience of the aquaculture sector in the region.

[15] https://ec.europa.eu/eurostat/databrowser/view/fish_aq2a/default/bar?lang=en&category=fish.fish_aq

- **Specific Objectives**

The objective of this demonstration is to evaluate the performance of sea surface temperature (SST) data collected by means of an infrared (IR) Calex PyroMini Bus sensor[16] deployed from the HCMR Research Vessel (R/V) Philia (see also Deliverable 7.3) as part of ongoing efforts to monitor marine parameters that affect the aquaculture industry in coastal areas. The results will support the development of a cost effective sampling scheme aimed at enhancing data quality and spatiotemporal resolution. This refined data collection approach will contribute to the generation of short-term regional forecasts of Essential Ocean Variables (EOVs) and other parameters relevant to the Marine Strategy Framework Directive (MSFD), ultimately supporting better-informed management practices and fostering sustainable aquaculture.

- **Platform/equipment involved**

The R/V Philia and the onboard SeaBird CTD (Conductivity, Temperature, Depth profiler) instrumentation was involved in this demonstration. The R/V Philia is a coastal research vessel operated by HCMR. More details can be found in Deliverable 7.3 section III.

- **Deployment configuration**

The deployment configuration and the technical integration are described in Deliverable 7.3 section III.

- **Location and period of occurrence**

Aquaculture in Greece is concentrated in specific coastal regions and gulfs, reflecting the morphology of the coastline[17]. As of 2020, there were 899 aquaculture farms in Greece, 82% of which (740 sites) were located in marine waters and were used for fish and shellfish farming. The remaining sites were distributed across freshwater and brackish environments (10%) and lagoons (8%). Marine fish production is carried out by 67 companies operating 280 sites. Notably, 78% of these sites are concentrated in three decentralised administrative regions, which together account for 82% of total marine fish production. The majority of marine aquaculture activity, particularly fish farming, is concentrated in areas offering sheltered waters, optimal water quality and proximity to mainland transport networks and processing facilities (Fig. 28).
Data for this task were collected during an infrared (IR) temperature sensor demonstration conducted onboard the R/V Philia from 06/09/2024 to 13/10/2024 (see D7.3). During this period, the vessel carried out daily surveys in the coastal waters of Western Greece and the Ionian Islands —areas characterized by a high concentration of aquaculture facilities (Fig. 29). The IR temperature sensor operated continuously throughout the surveys, enabling the acquisition of uninterrupted sea surface temperature data.

- **Maintenance, events/issues occurred and actions taken**

The maintenance and technical aspects are described in Deliverable 7.3 section III.

[16] *https://www.calex.co.uk/product/temperature-measurement/infrared-temperature-sensors/pyrominibus/*

[17] *https://fishfromgreece.com/en/annual-report-2024/*

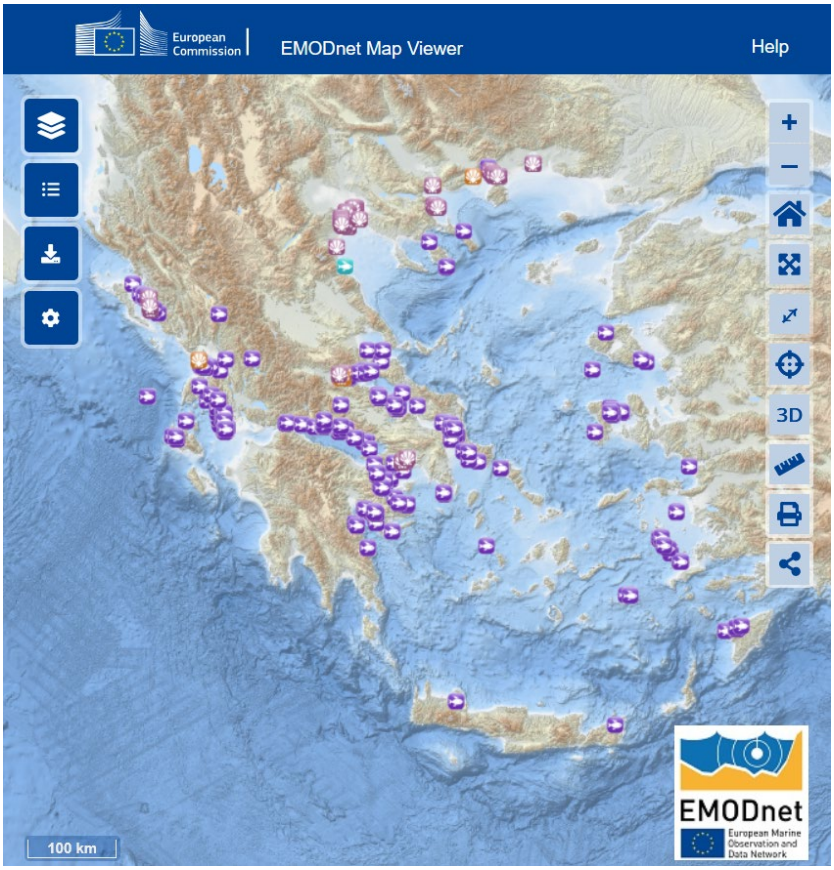


Figure 28: The aquaculture facilities distribution in Greece (source: EMODnet[18]).

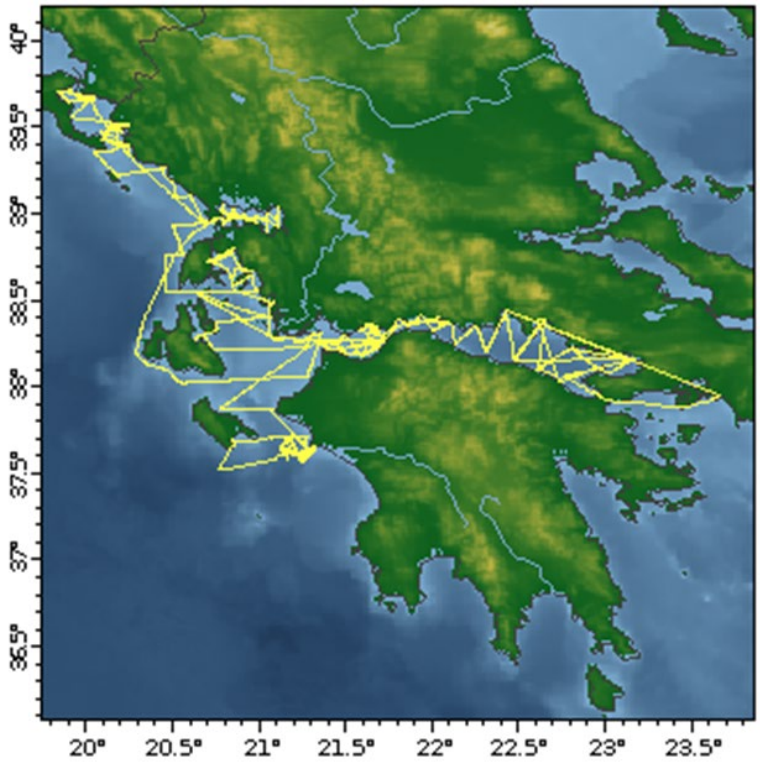


Figure 29: The R/V Philia tracks from 06/09/2024 to 13/10/2024.

[18] https://emodnet.ec.europa.eu/geoviewer/

- **Data recovery/ Analysis**

The data collected by the Calex PyroMini Bus sensor were stored locally on a system computer (Raspberry Pi), which continuously logged measurements every 10 seconds to a file corresponding to a 24-hour period. A new file was automatically created each day to organise the data chronologically and facilitate later analysis.

- **Other Related Activities**

This activity is also linked with Task 7.2. The objective of Task 7.2 (Demonstration on platforms of opportunity) was to provide field demonstration of NAUTILOS-developed sensors, samplers and systems in a range of different marine conditions, utilising the existing fleet of platforms of opportunity.

3. RESULTS – COMMENTS – CONCLUSIONS

NIVA and DFKI Results

A time series of the data collected from the aquaculture fish farm at Herdelfjord and the FerryBox passing nearby is shown in Fig. 30. In the 33 day time series, DO, pH, and pCO_2 measured at the fish farm were very highly variable, likely due to currents and water mass movement as well as activities at the fish farm including feed addition and the high biomass of fish present. DO varied between 235-329 µmol/L (mean: 296 µmol/L) and 76-104% DO saturation (mean: 95%), pH (total scale; calculated) ranged between 7.7-8.0-11 (mean: 7.9), and pCO_2 ranged between 452-1088 ppm (mean: 641 ppm). Complementary FerryBox observations in the vicinity of the fish farm were made on six transects in the 33 day time period. One pass was made on 15 May 4:20 UTC at <1 km from the fish farm by MS Trollfjord, which only had a DO sensor operational. A second pass at <1 km from the fish farm was made on 8 June 11:38 UTC by MS Richard With, which had sensors for DO, pH, and pCO_2 (the measurements acquired during these passes are represented with triangles in Fig. 30.) Four other passes were made during the time series, but in fjords ~6-7 km east or west of Herdelfjord. These include 20 May 13:30 UTC by MS Richard With ~7 km east of the fish farm, 28 May 11:40 UTC by MS Richard With ~6 km west of the fish farm, 28 May 19:40 UTC by MS Trollfjord ~6 km west of the fish farm, and 8 June 19:40 UTC by MS Richard With ~6 km west of the fish farm (the measurements collected at the eastern and western fjords are represented with square and circles, respectively, in Fig. 30). DO measured at the fish farm was on average ~30-40 µmol/L lower than that observed by the FerryBoxes, while pCO_2 was ~250-450 ppm higher at the fish farm compared to that observed by the FerryBoxes. In agreement with higher pCO_2 observations at the fish farm, pH at the fish farm was, on average, ~0.1-0.2- pH units lower compared to FerryBox measurements. However, nighttime pH at the fish farm was ~0.2-0.4 pH units lower compared to daytime pH at the fish farm.

The fish farm observations also exhibited a strong diel cycle as evidenced by periods of higher pCO_2 observations, lower pH, and lower DO, generally during the daytime. The observed directional changes in DO (decrease) and pCO_2 (increase) were inline with oxygen consumption and CO_2 production associated with presumably higher activity and thus respiration during the daytime when feeding occurred. Assuming a molar ratio of 1.3 mol O_2: 1 mol CO_2, the observed decreases in DO relative to FerryBox-measured DO were used to estimate the production of ~30-55 µmol/L CO_2 which is equivalent to ~+300-550 ppm pCO_2 at the in situ temperature and salinity regime. This approximately accounts for the observed

+~250-450 ppm pCO_2 at the fish farms compared to FerryBox measurements. Based on the FerryBox observations that were made concurrently close to the fish farm and nearby fjords, it was clear that the extreme variability at the fish farm did not significantly influence the nearby water mass. This indicates that either the low DO and high pCO_2 fish farm water masses were far enough away to impact FerryBox observations (<1 km away) or that circulation in the region diluted the low DO/high pCO_2 waters and the impact was only at a local level. On the other hand, FerryBox observations made close to the fish farm and nearby fjords can provide real-time observations to complement measurements made at the fish farms - i.e., fjord- or regional-scale events that could lead to low DO and high pCO_2 conditions like upwelling or overturning - that can assist in determining mitigative actions at the fish farm. The combination of sensors on traditional ocean observing platforms, such as FerryBoxes, in combination with aquaculture-based sensor systems equipped with sensors demonstrated here, can provide fish farm companies real-time local observations for a better understanding and management of their operations as well as larger scale "weather" observations that can have potential negative impacts on fish welfare and production.

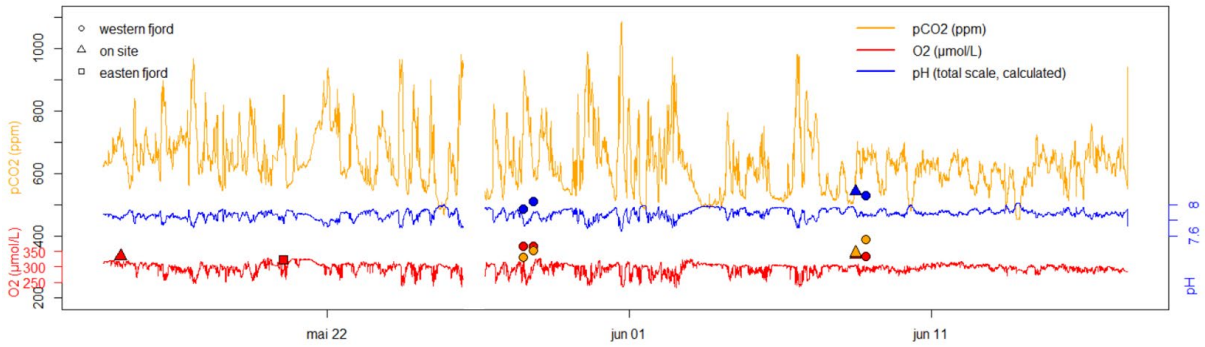


Figure 30: Time series of pCO_2 and DO sensor data, and calculated pH from their deployment at the fish farm (lines). Discrete measurements are averaged FerryBox data when passing the demo site or the two neighbouring fjords.

Event detection of algal blooms, which can include some nuisance or toxic species for fish, in the same region was carried out in the vicinity of the fish farm where sensors were demonstrated. Figure 31 shows a Pareto front plot of models trained and evaluated using the optional setup described in D7.3 section VII. It uses a Pareto front to identify the best models according to Precision and Recall, two metrics which often oppose each other. Because no target performance levels have been set for this task beforehand, the Pareto front provides an overview to identify trade-offs in individual models. The best models for the event detection are highlighted in red and achieve Precision-Recall scores of (0.72, 0.4), (0.64, 0.62), (0.6, 0.75) and (0.5, 0.88). These results are skewed towards models with a higher recall but lower precision, meaning that they predict more false positives. Overall, based on these results the models are expected to predict more often than those in D7.3, which means they might not be good enough for operational use yet. Two causes might be responsible for these results. Firstly, the data set is a lot smaller than the data set used in D7.3. However, few trials along the Pareto front used data from D7.3 as well, which indicates that a transfer from the D7.3 data set to this data set is not simple. Secondly, the fANOVA analysis in D7.3 showed that pCO2 is an important parameter, however it was not available here. Nevertheless, first results seem promising and the performance on D7.3 indicates that improvements are possible.

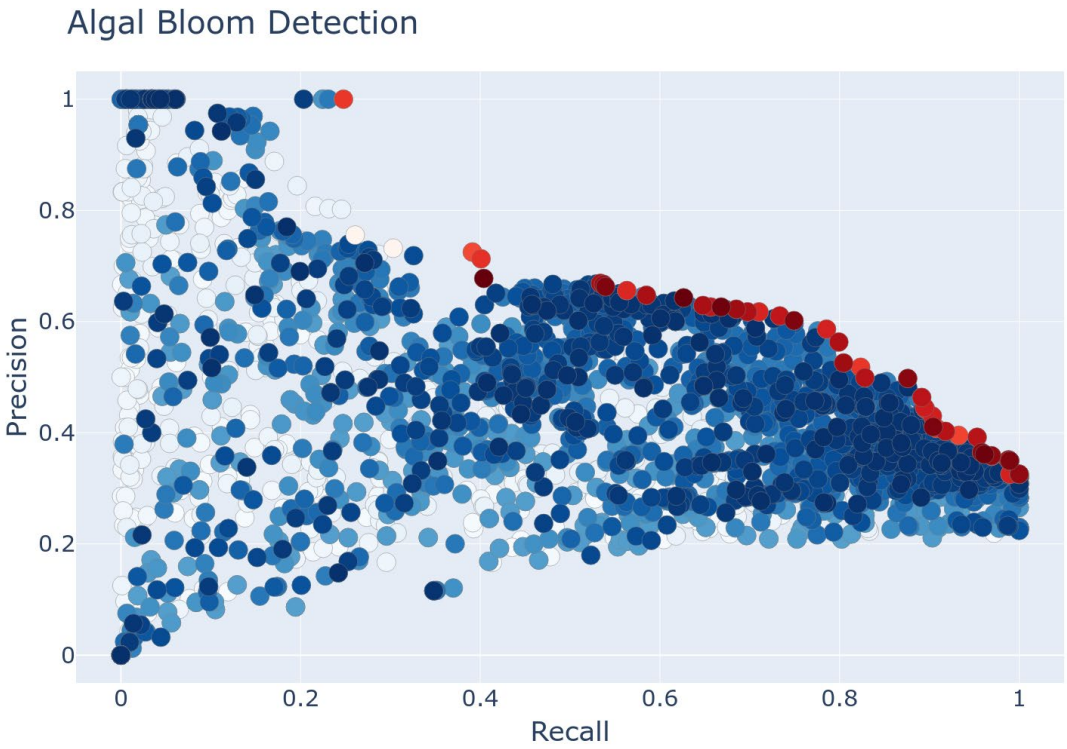


Figure 31: Pareto front of the fitted models. Best trials highlighted in red. Color saturation indicates number of the trial.

HCMR Results

The retrieved dataset from the IR sensor deployed on the HCMR R/V Philia underwent a two-level QC process, as detailed in Section 3 of Deliverable D7.3. The first level of QC focused on assessing the internal consistency and integrity of the raw data. This included checks for time-series continuity, range validation, detection of missing or outlier values, and verification of sensor performance based on expected operational parameters. These preliminary steps ensured that the dataset was free from non-valid data related to sensor malfunction or data transmission errors. The second level of QC involved a comparative validation process, in which the cleaned dataset was cross-checked against an independent and reliable external data source. This step aimed to confirm the accuracy and environmental representativeness of the IR sensor measurements. The final QC data set of the IR sensor demonstration was uploaded to the NAUTILOS data portal (Fig. 32).

The temperature measurements obtained from the Calex PyroMini Bus infrared sensor were generally in good agreement with those recorded by the in situ CTD sensor. This alignment is considered satisfactory given the specified performance characteristics of the Calex IR sensor, which has a stated accuracy of ±1 °C and a repeatability of ±0.5 °C, as provided by the manufacturer. The statistics of the comparison of the IR data and CTD casts performed in the area is highlighted in Figure 33.

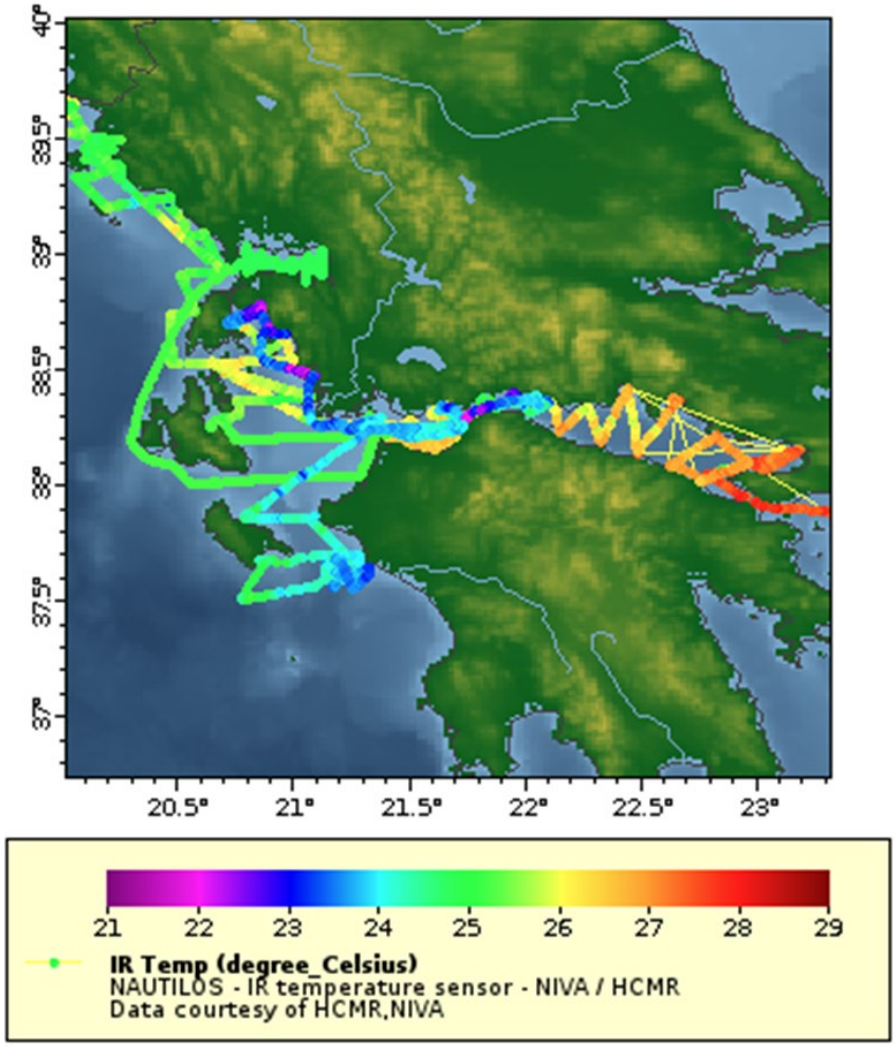


Figure 32: The IR temperature sensor dataset in the Ionian Sea and internal gulfs of West Greece.

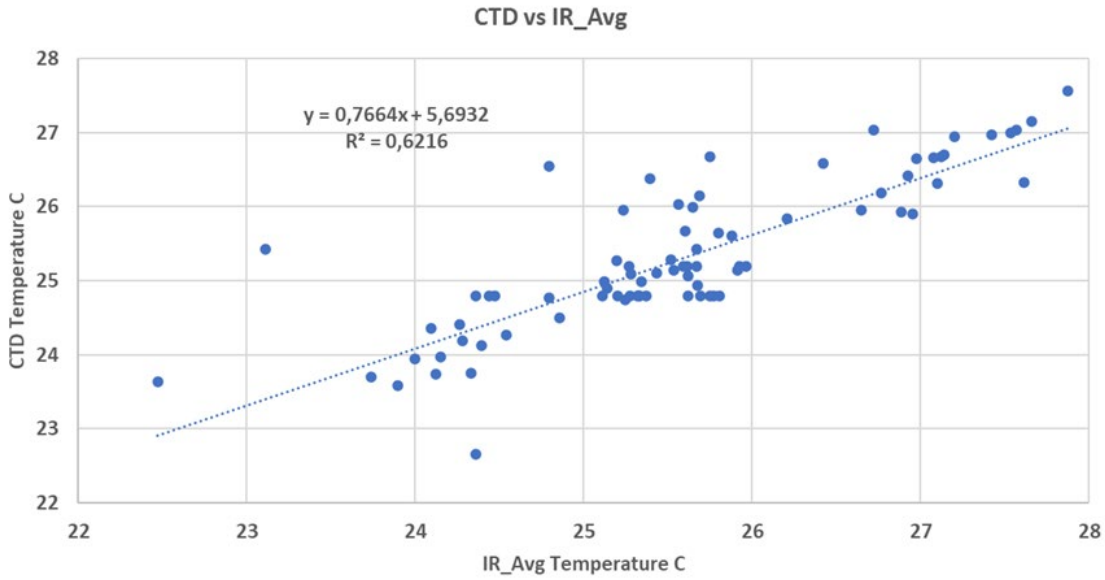


Figure 33: Comparison statistics for IR and CTD temperature.

To evaluate the IR sensor data product as a complementary tool for monitoring marine parameters relevant to the aquaculture industry in coastal areas, two case study areas were selected. The selection of these sites was guided by multiple criteria to ensure both scientific relevance and practical impact. Specifically, priority was given to regions with limited observational coverage from satellites and oceanographic models, where in situ data could provide critical added value. Additionally, areas with intensive aquaculture activity were targeted to ensure that the results would directly support operational needs and inform sustainable management practices. Finally, the spatial coverage of the coastal data product generated from the IR sensor demonstration was also taken into account, ensuring that the selected areas fell within the range of reliable sensor performance.
The two areas (Fig. 34) fulfilling the criteria and selected as case studies to propose the operational use of the IR sensor are:

- Amvrakikos Gulf (Western Greece)
  An enclosed gulf with significant aquaculture, especially seabream and seabass farming. It is underrepresented in high-resolution ocean models and often experiences reduced satellite clarity due to land proximity and river inflow.

- Korinthiakos Gulf (Gulf of Corinth)
  The gulf supports intensive aquaculture, primarily seabass and seabream farming in floating cages, with several well-established operations along its northern and southern coasts. The narrow, semi-enclosed nature of the gulf, combined with mountainous terrain, affects satellite SST accuracy due to frequent mixed pixels, land contamination, and cloud cover. In addition, many operational ocean models have low resolution in this area, making it harder to resolve fine-scale variability.

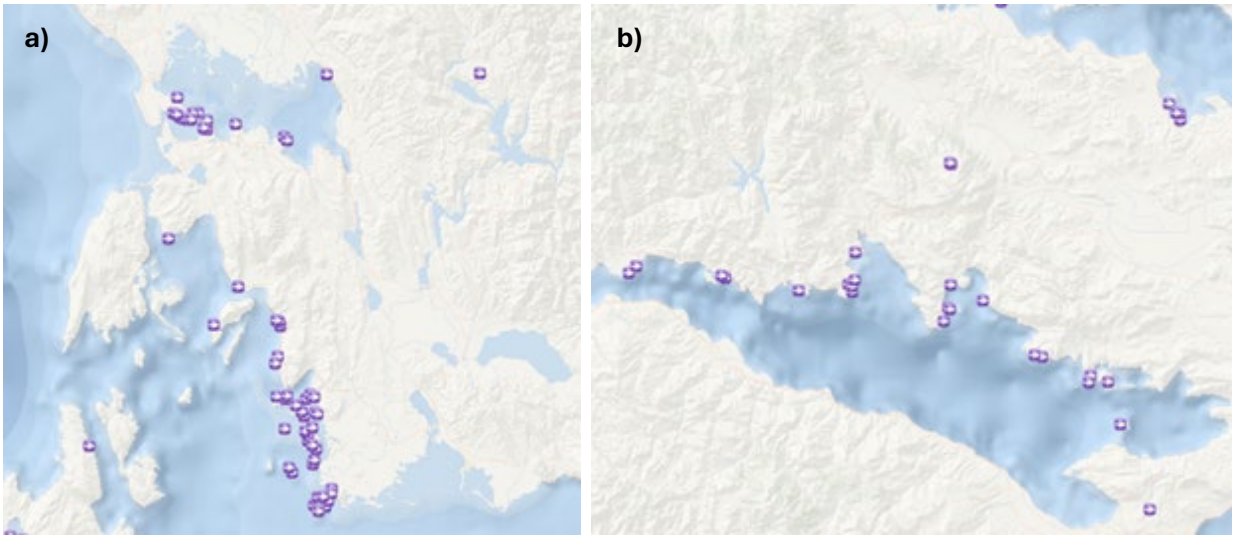


Figure 34: The aquaculture facilities distribution in the selected areas: a) Amvrakikos and Ionian coast, b) Gulf of Corinth (source: EMODnet).

To assess the feasibility of using low-cost SST measurement from ships of opportunity for aquaculture purposes, ship density maps of the study area were analysed, as provided by the Marine Traffic website[19] (Fig. 35). A ship density map visualizes the spatial distribution of vessel traffic within a defined area and time frame. These maps are typically generated from Automatic Identification System (AIS) data and illustrate how frequently ships transit through specific grid cells, helping to identify marine traffic hotspots.

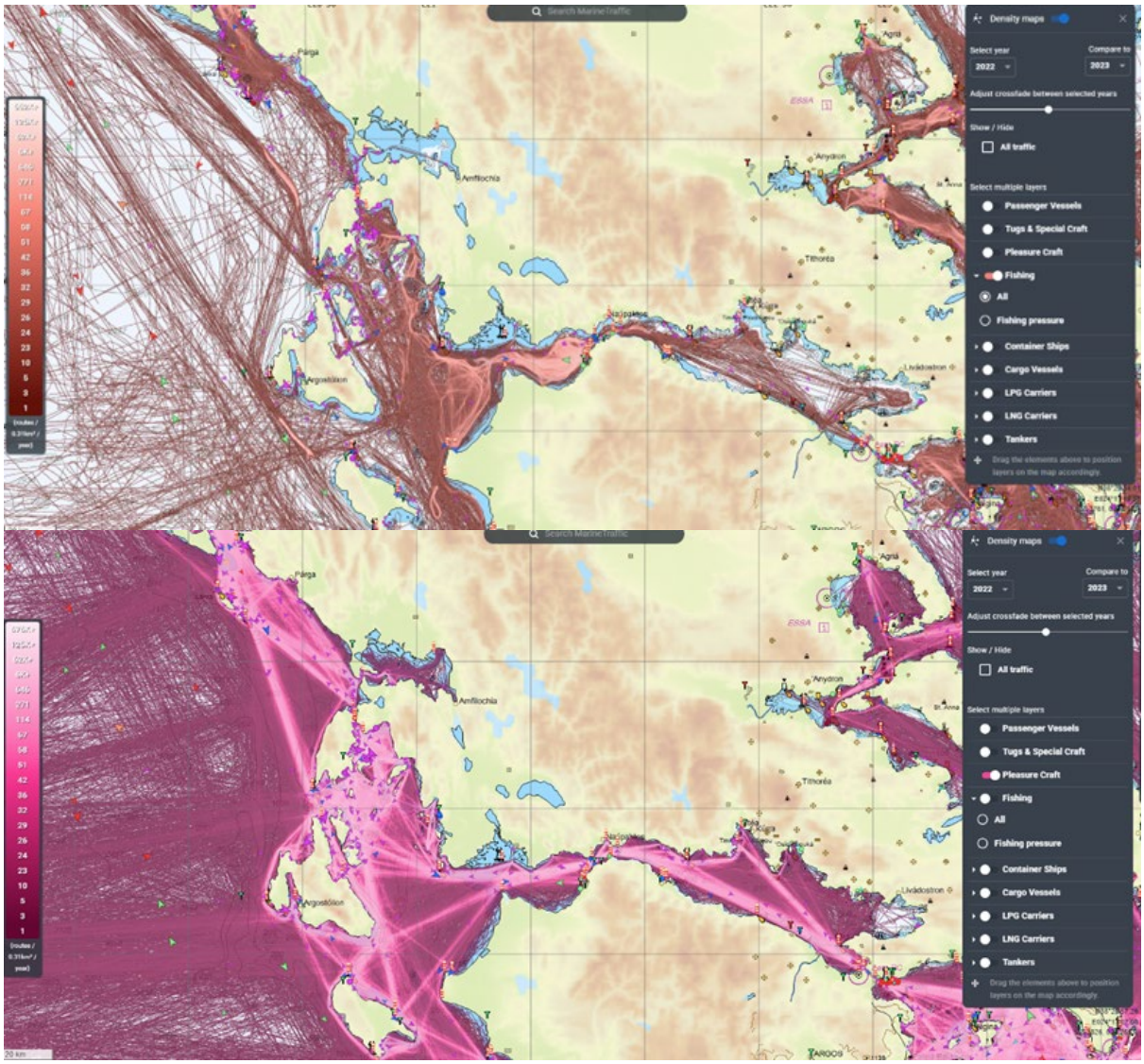


Figure 35: The ship density map in the selected areas. Upper panel corresponds to the fishing vessels density and the lower panel corresponds to leisure vessels.

The analysis of ship density data revealed distinct patterns based on vessel type. Cargo ships and ferries were excluded from this analysis, as they generally do not operate within nearshore coastal zones, which are the primary focus for environmental monitoring in aquaculture. Leisure boats, including sailing yachts and motor yachts, provide higher spatial resolution, as they frequently navigate close to the coastline. However, their operations are highly seasonal, with most activity occurring during the tourist season. On the other hand,

[19] https://www.marinetraffic.com/en/ais/home/

fishing vessels offer better temporal resolution, as they typically operate throughout the year. While their spatial coverage is more localized compared to leisure boats, their consistent year-round activity makes them valuable platforms for long-term environmental data collection in coastal waters.
Monitoring SST and other marine parameters is essential for the sustainable development of aquaculture, particularly in sensitive and data-scarce coastal areas of east Mediterranean sea. This task aimed to assess the accuracy of a low-cost IR SST sensor and to explore its potential for integration into future sampling strategies, including deployment on ships of opportunity, in the context of sustainable aquaculture. The development of this approach could for example help in an early way to address situations arising from the occurrence of marine heatwaves.

TRL achievement level

For the TRL of sensors deployed in the aquaculture site and installed on the R/V Philia refer to the previous chapter of this deliverable and to Deliverable 7.3.
As well for the TRL of the event detection tool developed by DFKI check Deliverable 7.3.

Future plans and Recommendations

For the NKE DO and Chl-*a* sensors, the use of the plastic protections provided by the producers for use on fishing gears (see D7.1) is recommended also in aquaculture applications. It is also recommended to check the watertightness of the sensors before each use. Furthermore, in order to be really useful to the owners of the fish farm to periodically check the sensors by removing them from the water, download the data with the app on their phone and putting them back in the water. In addition to having data available in near real time, this would also give them the possibility to verify daily that the sensors are working correctly. In general wired DO and Chl-a sensors would probably fit better for this type of application.
Event detection systems can be improved most easily by providing larger data sets from multiple locations to improve generalization capabilities and transfer learning options. The development of dedicated sampling strategies to obtain water samples during events can enable analysis in the lab for improved warning capabilities. Results might be further improved by using a larger wealth of methods, e.g., physics-informed machine learning. Finally, once better detection models are available, explainable artificial intelligence methods could be used to compare the most important parameters to identify each event to the feedback of domain experts.
A cost-effective network of infrared temperature sensors can be installed on small commercial vessels to measure sea surface temperature in specific areas of the Mediterranean Sea. Adopting the suggestions and technical improvements of D7.3, these SST IR sensor modules will be compact, easy to install and relatively low-cost, making them well-suited for use on a variety of coastal vessel types, including leisure boats and fishing boats. Planning sensor placement using ship density maps allows us to focus on high-traffic maritime routes, ensuring frequent and widespread data collection across. This strategic deployment provides the kind of spatial and temporal coverage that would otherwise be difficult and expensive to achieve using traditional research vessels or fixed monitoring stations.

IV. ACOUSTIC MARINE MAMMAL MONITORING SYSTEM DEMONSTRATION REPORT

1. BACKGROUND

This section is described in Deliverable 7.1 section IV.1**.**

2. DEMONSTRATION PLAN

a. Demonstration on Passive Acoustic Marine Mammal Monitoring System in Swedish waters (Aquatec)

- **Specific Objectives**

This activity aims to demonstrate the efficiency and effectiveness of the AQUAclick Sound in detecting and identifying marine mammals in their natural habitats. It showcases the enhanced Acoustic Marine Mammal Monitoring System developed under ST 3.3.2, focusing on deployment, underwater measurements as a standalone device with an internal battery, and post-analysis of recorded audio data. Additionally, the demonstration assesses battery performance, firmware and software updates, and overall sensor functionality.
Specifically, multiple sensor deployments at the Kolmården Dolphinarium were conducted to optimize the sensor's ability to record broadband audio triggered by dolphin echolocation clicks, in preparation for its later use in open-water conditions. The subsequent deployment in Swedish waters is intended to demonstrate the sensor's effectiveness in a natural marine environment, where marine mammal populations are not managed by humans and their presence must be detected passively.
The open-water demonstration in Swedish waters is of particular interest to fishermen as it showcases the sensor's ability to passively detect marine mammals in natural environments. This technology can help reduce bycatch, support sustainable fishing practices and enhance operational efficiency by providing early warnings of nearby marine mammals. Ultimately, it offers a practical tool for minimizing environmental impact while supporting responsible fisheries management.

- **Platform/equipment involved**

This section is described in Deliverable 7.1 section IV.2

- **Deployment configuration**

During the deployments at the Kolmården Dolphinarium, the sensor was configured in various setups to update the firmware and prepare the unit for different scenarios anticipated in the subsequent open-water demonstration. Aside from a few isolated tests using a 130 kHz click pinger, the sensor was primarily set to detect 60 kHz echolocation clicks (dolphin range) and record less than 5 seconds of audio following the first detected click. This configuration aimed to capture click trains, which were expected to last no longer than 2 seconds.
For the subsequent deployment in open Swedish waters, the sensor was similarly configured for 130 kHz click detection but set to record up to 3 seconds of audio after the initial click.

- **Location**

This section is described in Deliverable 7.1 section IV.2

- **Period of occurrence**

From April 2024 to April 2025, a series of tests and firmware updates were carried out to evaluate and enhance the performance of the Passive Acoustic Sensors. In April 2024, 2 sensor units were shipped to Sweden with the latest hardware update, followed by an additional 4 units in September 2024. These units underwent extensive testing and deployments at the Kolmården Wildlife Park dolphinarium, where controlled conditions allowed for detailed assessment of the sensor's response to dolphin echolocation clicks. Based on the insights gained and sensor results feedback during the project extension time, several firmware updates were implemented to improve detection accuracy and audio recording performance, specifically tailoring the system for upcoming open-water deployment.

In mid-June 2025, when weather and logistical conditions allowed, an open-water deployment was successfully conducted in the Lysekil area of Swedish waters by researchers from the Institute of Marine Research at the Department of Aquatic Resources (SLU Aqua). This field test showcased the sensor's performance in a natural marine environment and demonstrated its potential relevance for fisheries, particularly for detecting the presence of marine mammals to support sustainable fishing practices.

- **Maintenance, events/issues occurred and actions taken**

Between April 2024 and April 2025, extensive testing was conducted at the Kolmården Wildlife Park dolphinarium in Sweden, where a significant amount of valuable data was collected. During this period, the sensor's firmware was updated several times to include a new feature, "Audio Recording Triggered by Echo-location Click". This enhancement allows the sensor to only record audio when it detects an echo-location click from a marine mammal, making it suitable for deployment in areas with lower mammal populations, thereby optimizing data collection efficiency.

Although the amended Grant Agreement scheduled the demonstration with fishermen for autumn 2024 or spring 2025, this was ultimately not feasible due to a combination of technical and logistical challenges. In autumn 2024, sensor testing and firmware development were still in progress, based on ongoing trials at the Kolmården Wildlife Park dolphinarium. At that stage, the sensor was not yet fully optimized for open-water deployment, and proceeding with a demonstration would have risked showcasing an underperforming system incapable of reliably recording audio triggered by echolocation clicks.

By spring 2025, thanks to the project extension, the sensor had reached the necessary level of technical readiness. Extensive efforts were made to coordinate with local fishermen and plan a deployment in operational fisheries. However, practical constraints (including vessel unavailability, scheduling conflicts, and unfavourable weather conditions in the target deployment area) prevented successful alignment between the Kolmården's team and fishing operations.

Despite these challenges, an open-water deployment was successfully conducted in June 2025 in the Lysekil area, made possible through collaboration with the Institute of Marine Research at SLU Aqua. This demonstration provided a valuable demonstration of the sensor's performance in a real-world marine environment.

- **Data recovery/ Analysis**

The data, once analysed and validated by Aquatec, were sent to ETT by uploading it in WAV format via FTP to the NAUTILOS server. The audio files were then gathered into a single dataset on the NAUTILOS ERDDAP™ managed by ETT[20].

A service was implemented to automatically upload new files to the ERDDAP™ dataset. To achieve this, a standard was defined for naming the files in a way that allowed the deployment identification (sample_ID) and release date (time) to be extracted automatically. In parallel with the data, work was done on the metadata by inserting all the mandatory information (e.g., geographical and temporal information, project, institution, keywords).

Since ERDDAP™ is not designed to analyse and visualise acoustic data, ETT developed a comprehensive Google Colab notebook for all data collected by the AQUAclick Sound Passive Acoustic sensor[21]. Colab facilitates data discovery and harvesting, utilising datasets from the ERDDAP™ server. This Colab allows both sound playback and visualisation through graphs (Fig. 36): waveform representation (sound amplitude over time) and spectral representation, which provides a clear view of how the audio signal's energy (amplitude) is distributed across different frequency components. To access Colab, a Google account including the Google Colaboratory application extension installed is needed to visualize the document. It is possible to make changes to the Colab code on a copy that is automatically saved to the personal Google Drive.

For the data portal an *ad hoc* Colab for each deployment was made.

[20] *https://data-nautilos-h2020.eu/erddap/tabledap/passive_acoustic_sensor_aquatec_test.html*

[21] *https://drive.google.com/file/d/1AbFsGa3VbBeEn_4xd-Nm9TUm_o-HH7V2/view*

NAUTILOS

ANALYSIS of DATA from PASSIVE SENSORS

This notebook analyzes acoustic data sampled with passive sensors.
The analyzed data refers to the datasets present on ERDDAP of the NAUTILOS project: https://data-nautilos-h2020.eu/erddap/tabledap/passive_acoustic_sensor_aquatec_test.html

By running the code cell below with its Play button , all the necessary libraries will be installed and imported.

[2] Show code

By running this code cell below a list of available wav files from https://data-nautilos-h2020.eu/erddap/tabledap/passive_acoustic_sensor_aquatec_test.html will be downloaded and a dropdown to select the desired sound created.

[3] Show code

File name: DM_test_sound_passivacoustics

After selecting the sound from the dropdown above, running the code cell below will download the sound and create a player to hear it. Each time a new sound is selected from the dropdown this cell has to be played again.

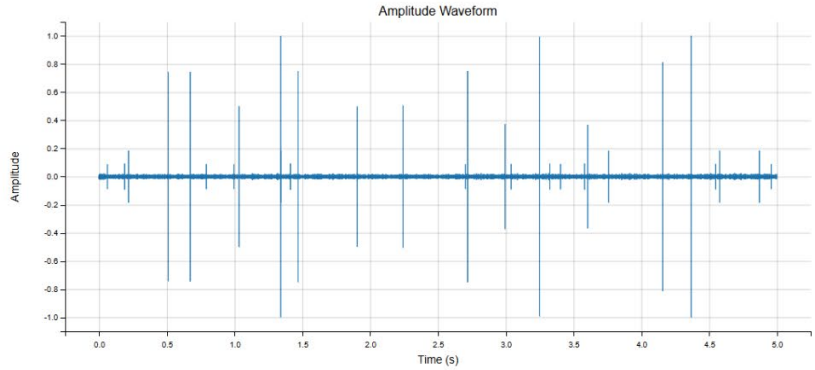
[4] Show code

0:00 / 0:05

Once the WAV file has been downloaded and loaded into the code, the visualizations can start.
The first type of visualization, the waveform, will display the data as a plot with amplitude on the y-axis and time on the x-axis.

To generate this plot with the previously selected file, run the code cell below.

[5] Show code



Another type of visualization commonly used in the analysis of an audio file is the spectrum. In this type of visualization, the amplitude of the audio signal, converted to decibels, is displayed on the y-axis, while the frequencies are displayed on the x-axis. This provides a clear view of how the energy of the audio signal is distributed across different frequency components.

Show code

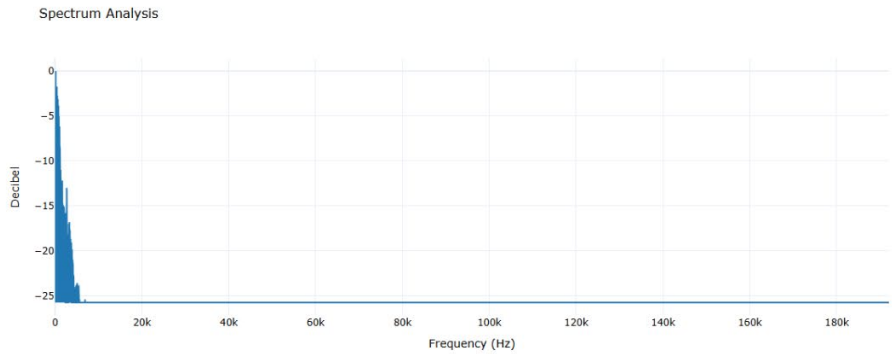


Figure 36: NAUTILOS Google Colab notebook to visualise AQUAclick Sound Passive Acoustic Sensor (Swedish waters).

b. Demonstration on Passive Acoustic Marine Mammal Monitoring System in Portofino MPA cetaceans sanctuary (ETT)

- **Specific Objectives**

The demonstration aims to further evaluate the efficiency and effectiveness of the AQUAclick Sound in detecting and identifying marine mammals in the field, in a protected marine area specifically designated for the conservation of cetaceans, where it should therefore be easy to find them.

- **Platform/equipment involved**

The demonstrations were conducted by ETT, which, with the support of the University of Genoa, installed AQUAclick Sound on a fixed pylon managed by the University. The pylon is located approximately 500 meters from the Portofino Promontory (Italy), within the Pelagos Sanctuary for Mediterranean Marine Mammals. The sensor was installed at 2.2 meters depth.

- **Deployment configuration**

For the Portofino deployment, the sensor was configured to record audio based on a scheduled alarm. It captured 3 seconds of audio data every 20 minutes at a sampling rate of 384 kHz. This setup enabled broadband underwater sound recording with frequency coverage up to 150 kHz.

- **Location**

This section is described in Deliverable 7.1 section IV.2

- **Period of occurrence**

In August 2024, a first demonstration was conducted by ETT at the Pelagos Sanctuary near Portofino. During this deployment, an issue with data download was encountered, likely caused by the displacement of the battery pack due to external vibrations. The sensor was returned to Aquatec for repairs, after which it was sent back to ETT. A second deployment was carried out in Portofino from May 15th to June 26th 2025 with an operational unit.

- **Maintenance, events/issues occurred and actions taken**

To address the issue encountered in August 2024, the unit was repaired, reinforced, updated, and subjected to functional testing. After these improvements, the unit was sent back to Italy in October 2024, ready for the next deployment. The second demonstration was planned for late winter or early spring. However, it could not be carried out between February and April due to two unrelated but interconnected issues: adverse marine weather conditions and the University of Genoa's new requirement to rely on certified divers following changes to its internal regulations. Following this, the demonstration took place in Portofino from mid-May to end-June successfully.

- **Data recovery/ Analysis**

Data, analysed and validated by Aquatec, was sent to ETT via FTP and then automatically uploaded to the ERDDAP™ dataset and added to Colab, following the same procedure outlined for the demonstration in Swedish. Test data from the unsuccessful demonstration carried out in August 2024 were manually excluded.

- **Other Related Activities**

Due to difficulties in deploying the sensor and resulting delays, it was not possible to sample water and phytoplankton as stated in Deliverable 7.1 section IV.2.

3. Results – Comments – Conclusions

- **Aquatec Results**

Pre-deployment tests conducted in the controlled environment of the Kolmården Wildlife Park dolphinarium played a crucial role in refining the sensor firmware and optimizing data collection. Specifically, these tests led to significant improvements in the "Audio Recording Triggered by Echo-location Click" feature.

Previously, the sensor could only be configured to record audio based on a time trigger or to log clicks in a CSV file. The new functionality combines both approaches, enabling the sensor to record broadband audio (5Hz to 150kHz) only when it detects a mammal's echo-location click.

At the dolphinarium, a controlled setting with a limited dolphin population (Fig. 37), multiple audio recordings were collected during various deployments in March 2025, providing valuable data for further optimization (Fig. 38).

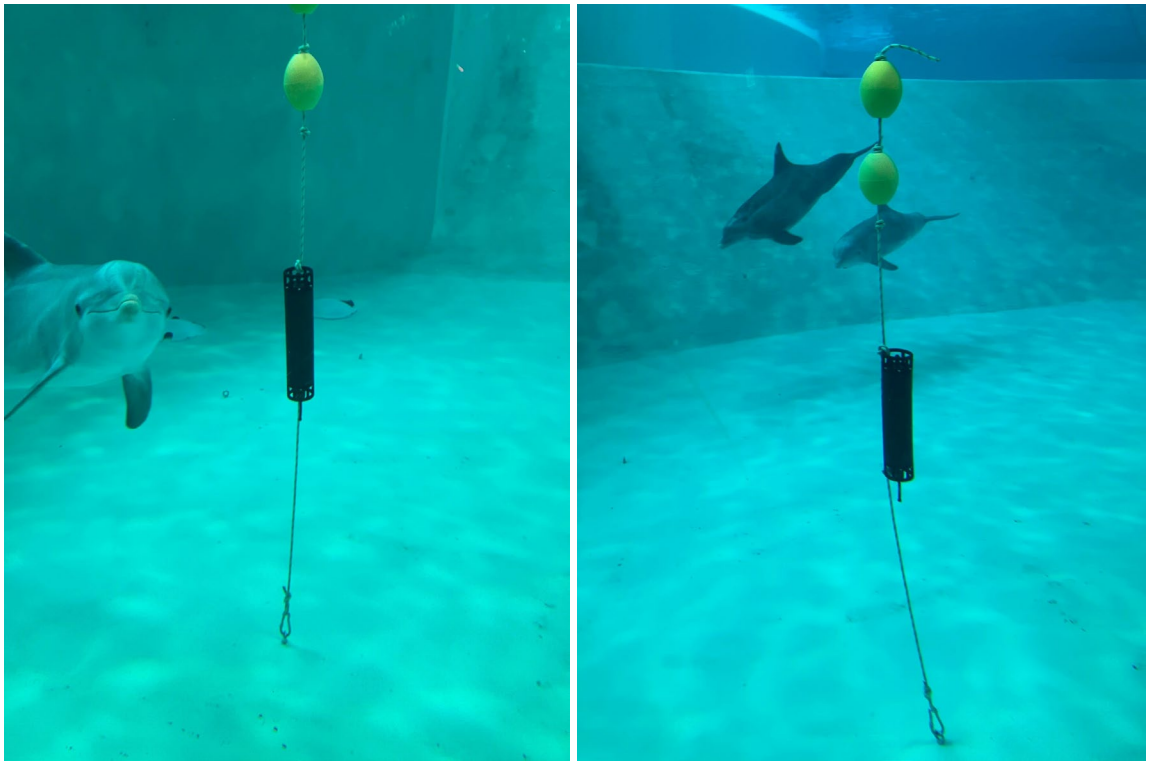


Figure 37: Deployment of the Passive Acoustic Sensor at the Kolmården Wildlife Park Dolphinarium, Sweden.

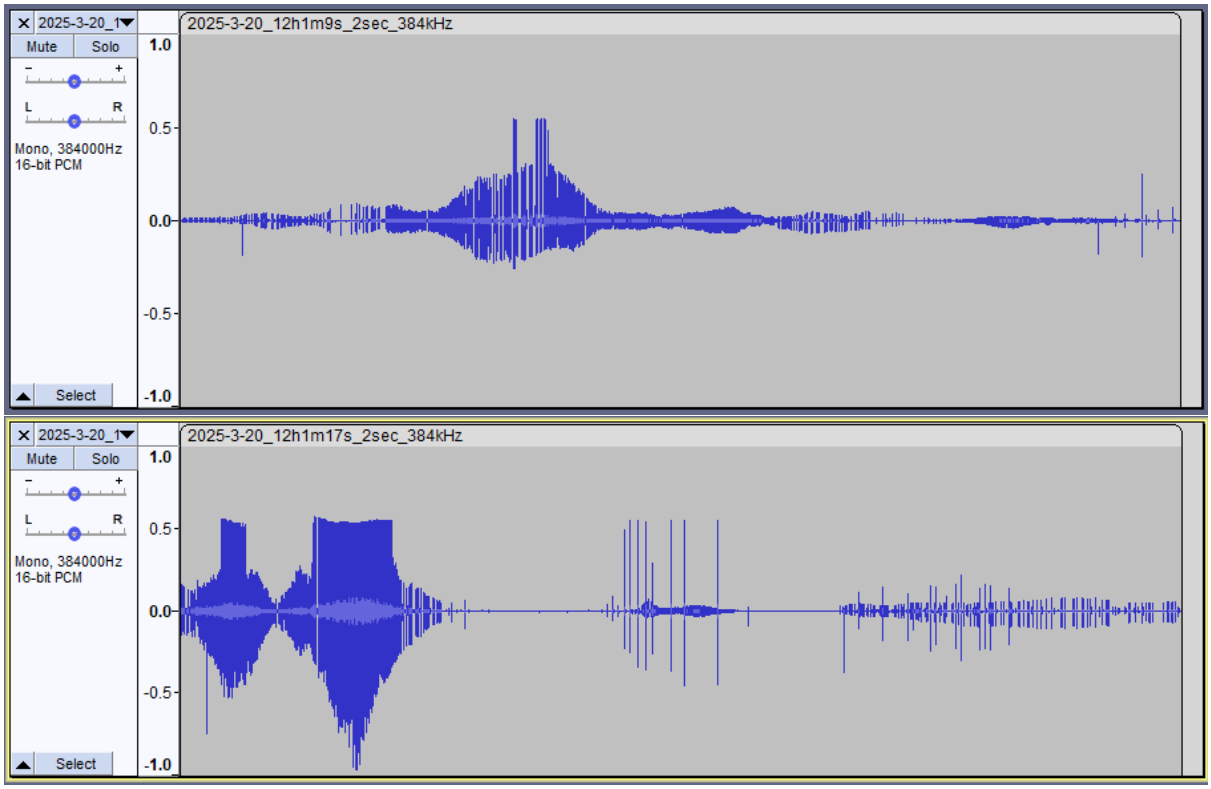


Figure 38: Broadband sound recordings of dolphin echo-location click train.

During the week of June 9th 2024, coastal fishermen in the Lysekil area (Swedish waters) assisted in deploying 2 sensor units (Fig. 39). The deployment included the Passive Acoustic Sensor configured to record audio upon detecting signals around 130 kHz—frequencies typically associated with porpoise echolocation.



Figure 39: Swedish coastal fishermen involved in the PAS deployment. (Left picture: Bobbo Roysson / Right picture: Karl Åke Wallin).

Unfortunately, no porpoise activity was detected during this deployment. However, the Passive Acoustic Sensor was triggered multiple times, likely due to industrial activity in the area—specifically, the presence of echo-sounders operating near the 130 kHz range, which activated the sensor.
Although no dolphin clicks were recorded, the deployment successfully demonstrated the functionality of the sensor's new trigger feature in open sea conditions. The sensor effectively recorded audio whenever signals within the preset frequency range were detected.
The image below (Fig. 40) includes a 3-second recording captured when the sensor was triggered by an industrial signal. The recording shows the ambient noise floor, with noticeable peaks indicating high background noise levels, especially in the presence of nearby vessels.

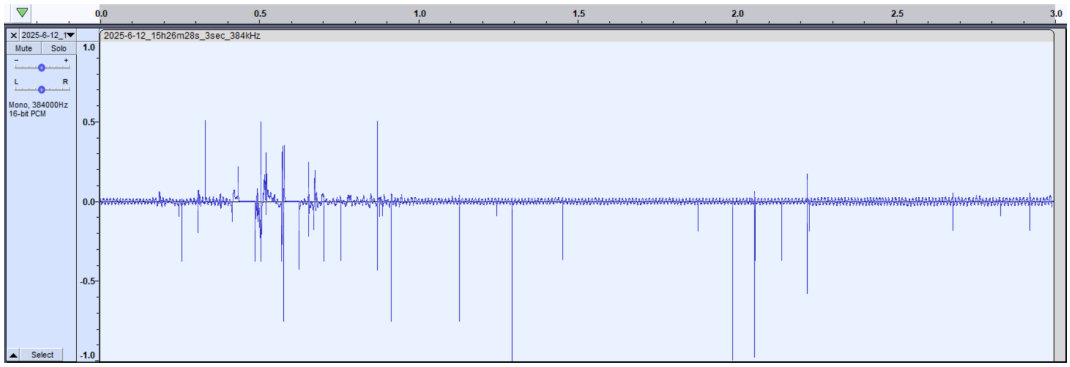


Figure 40: Broadband sound recording of Lysekil area triggered by a 130kHz signal (probably from industrial activity in the area).

- **ETT Results**

The Passive Acoustic Sensor deployed within the Pelagos Sanctuary for Mediterranean Marine Mammals successfully operated from mid-May until its recovery on June 26th (Fig. 41). Over this period, the sensor adhered to its programmed schedule (Alarm mode), recording 3-second audio segments every 20 minutes at a high sampling rate of 384 kHz, allowing for broadband sound acquisition up to approximately 150 kHz.

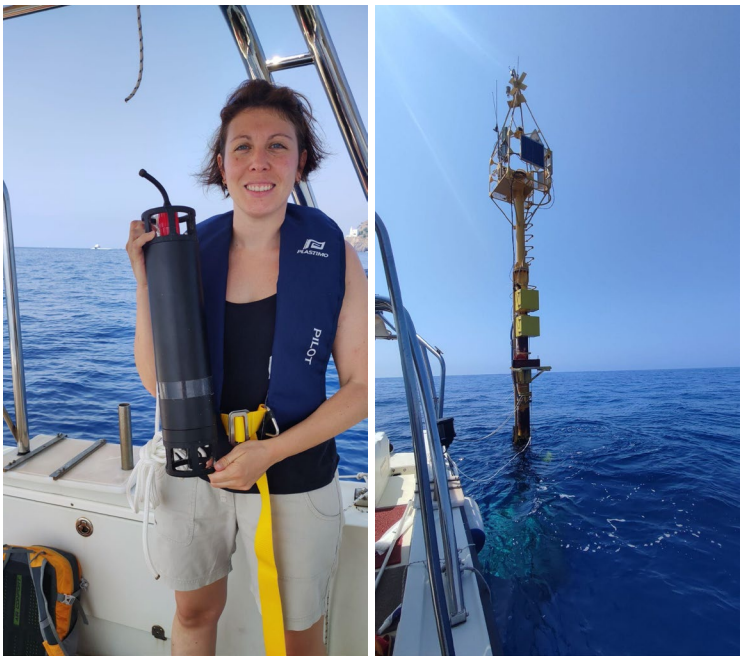


Figure 41: Deployment of the Passive Acoustic Sensor by Giulia Dapueto in Portofino (May 2025).

Upon recovery, a substantial dataset of acoustic recordings was collected. Initial screening of the audio files revealed that the majority of recordings were dominated by low-level background noise, indicative of the natural underwater ambient soundscape. This baseline noise is likely influenced by wind and wave motion.
However, a number of recordings contained transient high-amplitude acoustic events (Fig. 42). These brief signal spikes were broadband in nature and appeared sporadically throughout the dataset. These events are most likely generated by the passage of nearby recreational vessels, which are commonly active in this coastal area during the spring and early summer months.
Although no evident marine mammal sounds were identified during the preliminary analysis, the deployment successfully demonstrated the feasibility of long-term passive acoustic monitoring in this region. The sensor proved capable of capturing both ambient and episodic acoustic phenomena within a marine protected area.
Fig. 43 shows an example of Colab for the Portofino demonstration.

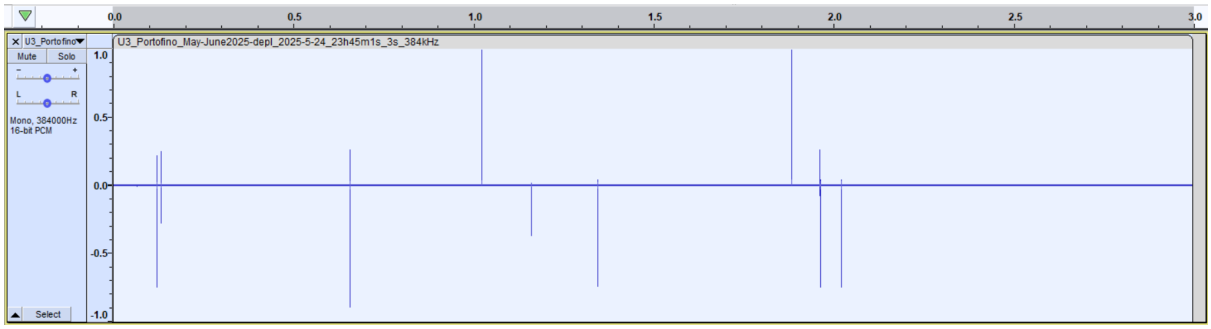


Figure 42: Audio file containing some transient high-amplitude acoustic events.

NAUTILOS

ANALYSIS of DATA from PASSIVE SENSORS

This notebook analyzes the wav file U3_Portofino_May-June2025-depl_2025-5-24_23h45m1s_3s_384kHz_Portofino_20250524234501
The file will be downloaded from the dataset on NAUTILOS' ERDDAP:
https://data-nautilos-h2020.eu/erddap/tabledap/passive_acoustic_sensor_aquatec_test.html

By running the code cell below with its Play button, all the necessary libraries will be installed and imported.

Mostra codice

Running the code cell below will download the sound and create a player to hear it. Each time a new sound is selected from the dropdown this cell has to be played again.

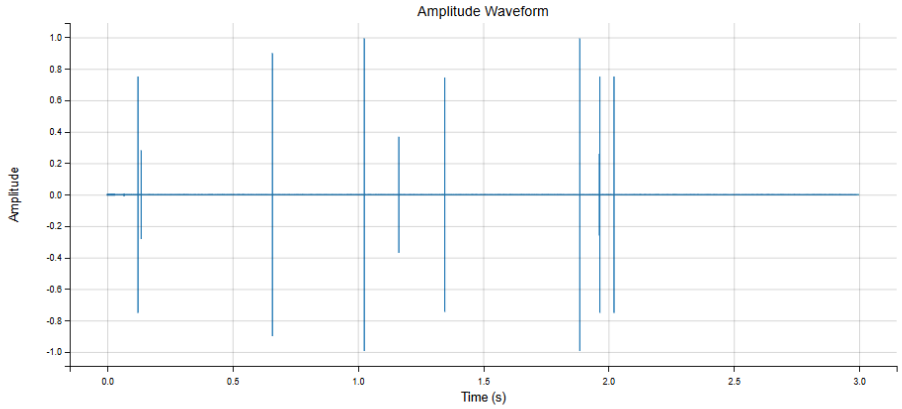
Mostra codice

0:00 / 0:03

Once the WAV file has been downloaded, the visualizations can start.
The first type of visualization, the waveform, will display the data as a plot with amplitude on the y-axis and time on the x-axis.

To generate this plot with the wav file, run the code cell below.

Mostra codice



Another type of visualization commonly used in the analysis of an audio file is the spectrum. In this type of visualization, the amplitude of the audio signal, converted to decibels, is displayed on the y-axis, while the frequencies are displayed on the x-axis. This provides a clear view of how the energy of the audio signal is distributed across different frequency components.

Mostra codice

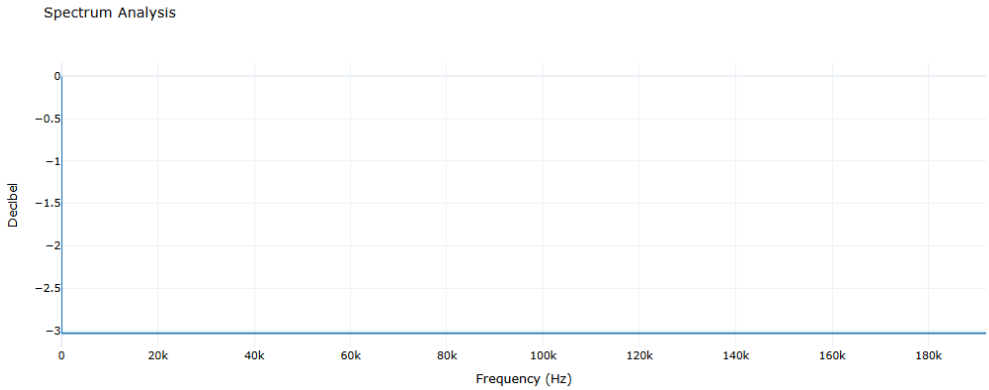


Figure 43: NAUTILOS Google Colab notebook to visualise AQUAclick Sound Passive Acoustic Sensor (Portofino).

TRL achievement level

Based on feedback from the dolphinarium data, the sensor firmware underwent multiple updates, resulting in significantly improved data collection performance and enhanced battery efficiency. These updates optimized the sensor's functionality, ensuring more reliable and accurate recordings during deployments in areas where there are mammal populations.
This enhancement increased the hydrophone signal gain, leading to better detection and recording of underwater acoustic signals. During the period of activity described in this document, further upgrades were also made to the sensor's user interface (PC software). These improvements streamlined the sensor configuration process, making it easier for users to set up deployments and download collected data efficiently. The improved user experience ensures smoother operations and reduces the risk of errors during field use.
As a result of these advancements, the TRL 7 has been achieved.

Future plans and Recommendations

Looking ahead, the focus will be on expanding the use of the AQUAclick Sound recorder for more marine monitoring projects. Additional deployments in different environments will help confirm how well the sensor performs over time and in various conditions. This will also provide valuable feedback for further improvements and TRL increase
It's recommended to continue testing the sensor in areas with fewer marine mammals to assess how effectively the "Audio Recording Triggered by Echo-location Click" feature works. Collaborating with marine researchers and conservation groups could also help gather useful data and refine the technology.
Improving the user experience (PC software) will remain a priority. Gathering feedback from users during deployments can help make the sensor's setup and data management even more user-friendly. Enhancing compatibility with other data analysis tools will also make it easier to interpret the results.
Lastly, further efforts to increase battery life and reinforce the sensor's durability are suggested. Learning from past challenges, like the battery displacement issue in Portofino, will ensure the sensor is more resilient in harsh marine conditions where the sensor is exposed to vibrations.
With these steps, the AQUAclick Sound recorder will continue to grow as a reliable tool for marine research, supporting efforts to better understand and protect marine life.

V. ETHICAL CONSIDERATIONS

Ethical considerations involved in the above reported demonstration activities are broadly described in Deliverable 7.1 section V.
Furthermore for what may concern Data Protection, the consent forms described in Deliverable 13.7 (Pieri et al. 2022), and already used in ST7.1.1, were made available and signed by the aquaculture plant owners and commercial fishermen, respectively involved in ST7.1.2 and ST7.1.3, before sensor installations and are stored in the archives of the partners who lead each demonstration.

VI. SUMMARY

Demonstrations carried out in Task 7.1 contributed mainly to NAUTILOS Specific Objectives SO1 (Develop and demonstrate improved observing systems in coastal and shelf-sea environments) and SO4 (Develop and demonstrate improved observing systems in commercial operations, i.e. fishing vessels, aquaculture facilities, ships of opportunity).
The ST7.1.1 demonstrations on Fisheries Observing Systems, involving the DO and Chl-*a* prototypes developed by NKE in ST3.1.2, were carried out, from summer 2023 to winter 2025, in the Adriatic Sea and the Bay of Biscay, by CNR-IRBIM and Ifremer, respectively. The sensors were installed on fishing gear (bottom trawler and pots) and were supported by the WiHub devices enabling data transfer. The aim of the demonstrations was to evaluate the performance, reliability of the sensor systems in real fishing conditions and data quality. The technical challenges encountered allowed to derive recommendations for sensor maintenance, battery management and preferred operating conditions. Overall, the systems demonstrated stability and resilience and, thanks to the improvements made during the demonstration phase, the technology readiness level of the systems increased to 8. Near real-time data transmission from fishing vessels to central repositories was achieved. Furthermore, the sensors were also tested in a citizen science context, confirming their versatility. In the Adriatic Sea, the system allowed the observation of exceptional events that occurred during the summer, confirming that fisheries-based observation systems can serve as cost-effective and wide-coverage tools to support marine observations and climate related research.

In ST7.1.2, two different approaches were demonstrated, based on the locality of the phenomena in the two sites of Norway and Greece, focusing on providing useful information to support sustainable aquaculture management.
In Norway, the DO and Chl-*a* prototypes developed by NKE in ST3.1.2 and pH and pCO_2 sensors developed in ST4.1 were deployed in May-June 2025 at an aquaculture fish farm in Herdlefjord, Norway which is 25 km northwest of Bergen, Norway. Complementary data was also collected from the nearby FerryBoxes MS Trollfjord, MS Richard With, and MS Vesterålen that pass by ~250 m from the fish farm. Time series data of DO, pCO_2, and pH from the fish farm and nearby FerryBoxes showed that local-level impacts at a scale of <~500 m) were observed at the fish farm, especially lower DO and elevated pCO_2 during day time when feeding and fish activity (respiration) presumably influenced conditions, while nearby water masses observed by the FerryBox were not influenced. An event detection concept developed by DFKI was tested on a new aquaculture dataset provided and also annotated by NIVA in May 2025. Machine learning models were trained on a dataset provided and annotated by NIVA in 2024 that was part of Task 7.2 (Demonstration on platforms of opportunity). Methods needed to be adapted/selected based on different characteristics of the aquaculture dataset. In this new dataset segments were extracted from a larger dataset only containing the relevant environment. Final evaluations on these data was done in June 2025 and are presented in this deliverable. The demonstration of NAUTILOS sensors at an operational fish farm, in combination with FerryBox observations made by ships passing nearby, formed the basis of an observing system that can be used to support aquaculture operations with near real-time in situ data for decision-making dependent on current conditions as well as utilise event detection machine learning models to forecast potentially negative conditions in the local area.

In Greece, this sub-task aimed to evaluate the performance of low-cost infrared sensor data collected aboard the HCMR R/V Philia as part of efforts to enhance coastal marine monitoring for sustainable aquaculture. Two case study areas—Amvrakikos Gulf and Korinthiakos Gulf—were selected based on criteria including limited satellite/model coverage, high aquaculture activity, and compatibility with the IR sensor's spatial footprint. The objective was to support the development of a cost-effective sampling strategy to improve data quality and spatiotemporal resolution for short-term regional forecasts of Essential Ocean Variables (EOVs) and Marine Strategy Framework Directive (MSFD)-related parameters. The IR sensor data, collected during a month-long survey in September–October 2024, demonstrated good agreement with in situ CTD measurements, confirming its operational reliability. Additionally, ship density maps were analyzed to assess the feasibility of using vessels of opportunity for expanding the spatial coverage of SST monitoring. Cargo ships and ferries were excluded due to their limited presence in nearshore zones. The analysis highlighted that leisure boats, though offering high spatial resolution along the coast, operate primarily during the tourist season, limiting year-round monitoring potential. In contrast, fishing vessels showed consistent year-round activity and are therefore promising candidates for supporting continuous SST data collection. These findings underscore the potential of integrating low-cost sensors on small vessels to enhance environmental monitoring capacity in aquaculture-intensive coastal areas.

Subtask 7.1.3 involved demonstrating the Passive Acoustic Sensor to evaluate its effectiveness in detecting and identifying marine mammals in their natural habitats. The sensor was tested in different environments: the Kolmården Wildlife Park dolphinarium in Sweden, including a deployment at Lysekil area; and the Pelagos Sanctuary near Portofino, Italy. These demonstrations assessed the sensor's functionality, focusing on its battery life, firmware performance, and audio data analysis capabilities. In Sweden, from April 2024 to April 2025, the controlled dolphinarium environment provided valuable insights that led to significant firmware updates. A key enhancement was the implementation of the "Audio Recording Triggered by Echo-location Click" feature, optimizing data collection in areas with lower marine mammal populations, preparing the sensor for the subsequent open-water deployment. In June 2025, the sensor was successfully deployed in Swedish waters, allowing further real-world testing in an open-water scenario. In Italy, an initial deployment in August 2024 faced challenges due to battery displacement caused by external vibrations. The sensor was returned to Aquatec for repairs and reinforcement. After resolving these issues, a second deployment was conducted in May 2025. Future plans include further expanding the sensor's applications across diverse environments, improving battery resilience, and enhancing the user interface for a more user friendly experience.

APPENDIX 1: REFERENCES AND RELATED DOCUMENTS

ID	Reference or Related Document	Source or Link/Location
1	Martinelli, M., Duchene, J., King, A., Marty, S., Ntoumas, M., Berghöfer, E., Alonso, I., Penna, P., Moro, F., Zacchetti, L., Cecapolli, E., Domenichetti, F., Le Gall, C., Malardé, D., Misurale, F., & Smerdon, A. NAUTILOS D7.1 - Fisheries and Aquaculture Observing Systems demonstration mid-term. Zenodo, 2024.	*https://doi.org/10.5281/zenodo.14260995*
2	Malardé D., David A.., Paillot A., Schaeffer C. Benoît Jugeau D 3.2 Report on the development of Dissolved Oxygen and chlorophyll-a sensors for fishery vessels, WP3 "Biogeochemical and Biological Instrument Development" H2020 NAUTILOS project "New Approach to Underwater Technologies for Innovative, Low-cost Ocean observation", 31/03/2022.	NAUTILOS Team Drive
3	Chatzinikolaou E., Rallis I., Sarafidou G., Digenis M., Keklikoglou N., Chatzigeorgiou G., Grigoriou P., Novellino A., Dapueto G., Martinelli M., Bartolomeu T., Martins F., Janeiro J., Mills L., Smerdon A., Alonso I., Malardé D., Nautilos D10.9 - Report on Citizen Science Campaigns. Zenodo, 2024	*https://doi.org/10.5281/zenodo.14856149*
4	Simons, R.A., and Chris John. ERDDAP. 2022, Monterey, CA: NOAA/NMFS/SWFSC/ERD.	*https://coastwatch.pfeg.noaa.gov/erddap*
5	Novellino A., Colombo F., Gianvincenzi A. D8.3 Data Management Workflow. WP8 "Data Management", H2020 NAUTILOS project "New Approach to Underwater Technologies for Innovative, Low-cost Ocean observation", 14/09/2021.	*https://doi.org/10.5281/zenodo.7211798*
6	Schlitzer, Reiner, Ocean Data View, 2021	*https://odv.awi.de*
7	Penna, P., Domenichetti, F., Belardinelli, A., and Martinelli, M. Dataset of depth and temperature profiles obtained from 2012 to 2020 using commercial fishing vessels of the AdriFOOS fleet in the Adriatic Sea, Earth Syst. Sci. Data, 15, 3513–3527, 2023.	*https://doi.org/10.5194/essd-15-3513-2023*
8	Pieri G., Zugic N., Ntoumas M., Martinelli M., Chatzinikolaou E. D13.7 GEN - Requirement No. 10. WP13 "Ethics" H2020 NAUTILOS project "New Approach to	NAUTILOS Team Drive

	Underwater Technologies for Innovative, Low-cost Ocean observation", 04/04/2022 .	
9	Martinelli M., Penna P., Guicciardi S., Duchene J., Haavisto N., Marty S., King A., Van Bavel B., Ødegaard Ø., Ntoumas M., Campanelli A., David A., Domenichetti F., Le Gall C., Lescroart E., Malardé D., Moro F., Kielosto S., Seppälä J., Sparnocchia S., Zacchetti L. D5.6 Validation and integration report on ships of opportunity, WP5 "Integration" H2020 NAUTILOS project "New Approach to Underwater Technologies for Innovative, Low-cost Ocean observation", 03/11/2023.	*https://doi.org/10.5281/zenodo.10665503*
10	Ntoumas M., Le Gall C., Seppälä J., Martinelli M., Marty S., King A., Alonso I., Smerdon A., Ødegaard Ø., Duchene J., Colin N., Campanelli A., Haavisto N., Lescroart E., Malardé D., Engesmo A., Sørensen K., Egge E., Garett J., Ghareeb M., Rijo C., Bartolomeu T., Vasconcelos F., Lemos C, Macedo T. D6.1 Report on results and methodology of calibration / validation experiments performed in T6.1, WP6 "Calibration, Validation and Scenario Testing" H2020 NAUTILOS project "New Approach to Underwater Technologies for Innovative, Low-cost Ocean observation", 5/12/2023.	NAUTILOS Team Drive
11	Troupin, C., Watelet, S., Ouberdous, M., Sirjacobs, D., Alvera-Azcárate, A., Barth, A., Toussaint, M. E., and Beckers, J. M. Data Interpolating Variational Analysis User Guide, Zenodo, 2019.	*https://doi.org/10.5281/zenodo.836723*
12	Van Vranken, C.H., Vastenhoud, B.M., Manning, J.P., Plet-Hansen, K.S., Jakoboski, J., Gorringe, P., Martinelli, M., Fishing 585 Gear as a Data Collection Platform: Opportunities to Fill Spatial and Temporal Gaps in Operational Sub-Surface Observation, Front. Mar. Sci., 7: Article 485512, 2020.	*https://doi.org/10.3389/fmars.2020.485512*
13	Van Vranken C., Jakoboski J., Carroll J.W., Cusack C., Gorringe P., Hirose N., Manning J.P., Martinelli M., Penna P., Pickering M., Santos A.P.M., Roughan M., Correia De Souza J. A., Moustahfid H.A. Towards a global Fishing Vessel Ocean Observing	*https://doi.org/10.3389/fmars.2023.1176814*

	Network (FVON): State of the art and future directions. Front. Mar. Sci. Sec. Ocean Observation Vol.10, 2023.	
14	Vilibić I., Terzić E., Vrdoljak I., Dominović Novković I., Vodopivec M., Ciglenečki I., Djakovac T., Hamer B., Extraordinary mucilage event in the northern Adriatic in 2024—a glimpse into the future climate?, Estuarine, Coastal and Shelf Science, 317, 109222, 2025.	https://doi.org/10.1016/j.ecss.2025.109222
15	Chiarini M., Guicciardi S., Angelini S., Tuck I.D., Grilli F., Penna P., Domenichetti F., Canduci G., Belardinelli A., Santojanni A., Arneri E., Milone N., Medvešek D., Isajlović I., Vrgoč N., Martinelli M. Accounting for environmental and fishery management factors when standardizing CPUE data from a scientific survey: A case study for Nephrops norvegicus in the Pomo Pits area (Central Adriatic Sea). PLoS ONE 17(7): e0270703, 2022.	https://doi.org/10.1371/journal.pone.0270703
16	Pieri G., Zugic N., Ntoumas M., Martinelli M., Chatzinikolaou E. D13.7 GEN - Requirement No. 10. WP13 "Ethics" H2020 NAUTILOS project "New Approach to Underwater Technologies for Innovative, Low-cost Ocean observation", 04/04/2022 .	NAUTILOS Team Drive
17	Lemos et al. NAUTILOS D11.7 NAUTILOS Exploitation Strategy - final, 2025.	NAUTILOS Team Drive
18	John U., Šupraha L., Gran-Stadniczeñko S., Bunse C., Cembella A., Eikrem W., Janouškovec J., Klemm K., Kühne N., Naustvoll L., Voss D., Wohlrab S., Edvardsen B. Spatial and biological oceanographic insights into the massive fish-killing bloom of the haptophyte *Chrysochromulina leadbeateri* in northern Norway. Harmful Algae 118:102287. 2022.	https://doi.org/10.1016/j.hal.2022.102287
19	Gattuso J, Epitalon J, Lavigne H, Orr J (2024). seacarb: Seawater Carbonate Chemistry. R package version 3.3.	https://CRAN.R-project.org/package=seacarb
20	Aminot, A. and Kérouel, R. Hydrologie des écosystèmes marins: Paramètres et analyses, Ifremer, 2004.	https://books.google.es/books?id=dd7qZIWQGb8C&printsec=frontcover&hl=it&source=gbs_ge_summary_r&cad=0
21	Marty S., Roden N., King A., Jaccard P., Fahning J., Ntoumas M., Sørensen K. NAUTILOS Deliverable 4.1 - Development	NAUTILOS Team Drive

	of carbonate chemistry/ocean acidification sensors, 2022.	
22	Seppälä et al. NAUTILOS D7.3. Platforms of Opportunity and Ferryboxes demonstration final report, 2025.	NAUTILOS Team Drive
23	Lattos, A.; Papadopoulos, D.K.; Feidantsis, K.; Karagiannis, D.; Giantsis, I.A.; Michaelidis, B. Are Marine Heatwaves Responsible for Mortalities of Farmed Mytilus galloprovincialis? A Pathophysiological Analysis of Marteilia Infected Mussels from Thermaikos Gulf, Greece. Animals, 12, 2805. 2022.	*https://doi.org/10.3390/ani12202805*
24	Darmaraki, S., Somot, S., Sevault, F. et al. Future evolution of Marine Heatwaves in the Mediterranean Sea. Clim Dyn 53, 1371–1392. 2019.	*https://doi.org/10.1007/s00382-019-04661-z*

APPENDIX 2: ADRIATIC SEA TEMPERATURE, DO AND CHL-*A* SEASONAL MAPS

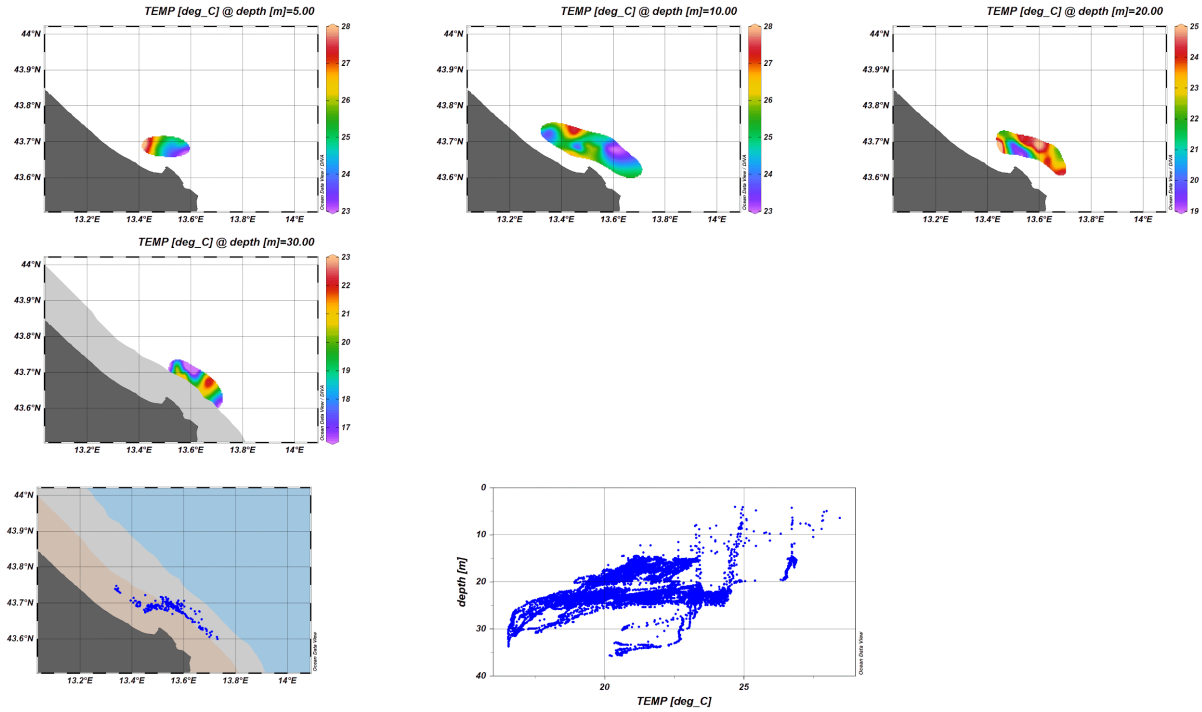


Figure 1A2: Temperature (°C) maps at depths of 5, 10, 20, 30, 50 and 70 m, related to the fishing area exploited by the vessel monitored through CNR AdriFOOS and the NKE DO and Chl-a sensors, generated from the validated dataset for the period from July to September 2023.

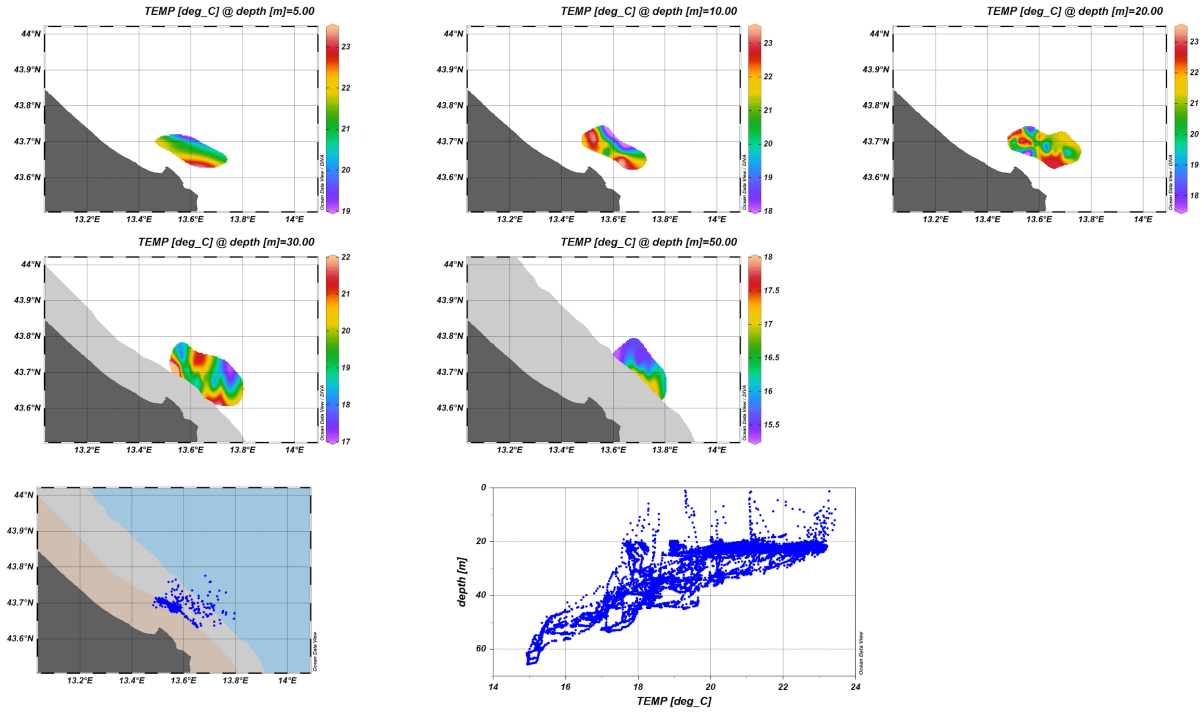


Figure 2A2: Temperature (°C) maps at depths of 5, 10, 20, 30, 50 and 70 m, related to the fishing area exploited by the vessel monitored through CNR AdriFOOS and the NKE DO and Chl-a sensors, generated from the validated dataset for the period from October to December 2023.

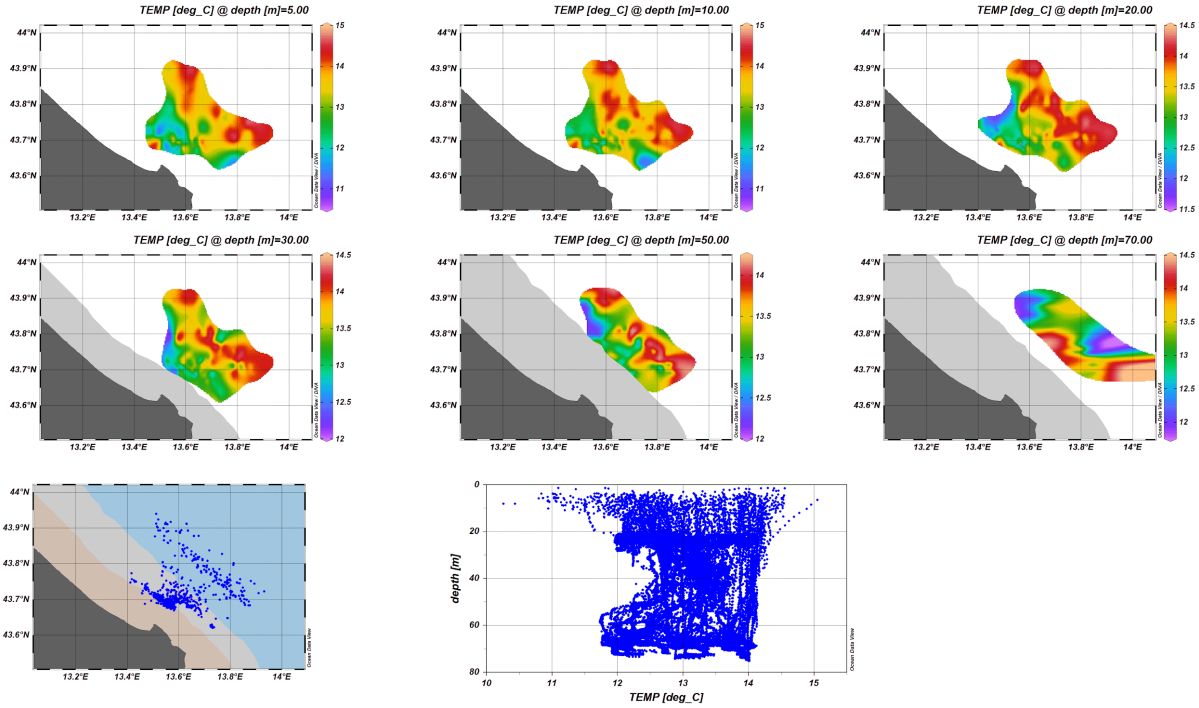


Figure 3A2: Temperature (°C) maps at depths of 5, 10, 20, 30, 50 and 70 m, related to the fishing area exploited by the vessel monitored through CNR AdriFOOS and the NKE DO and Chl-a sensors, generated from the validated dataset for the period from January to March 2024.

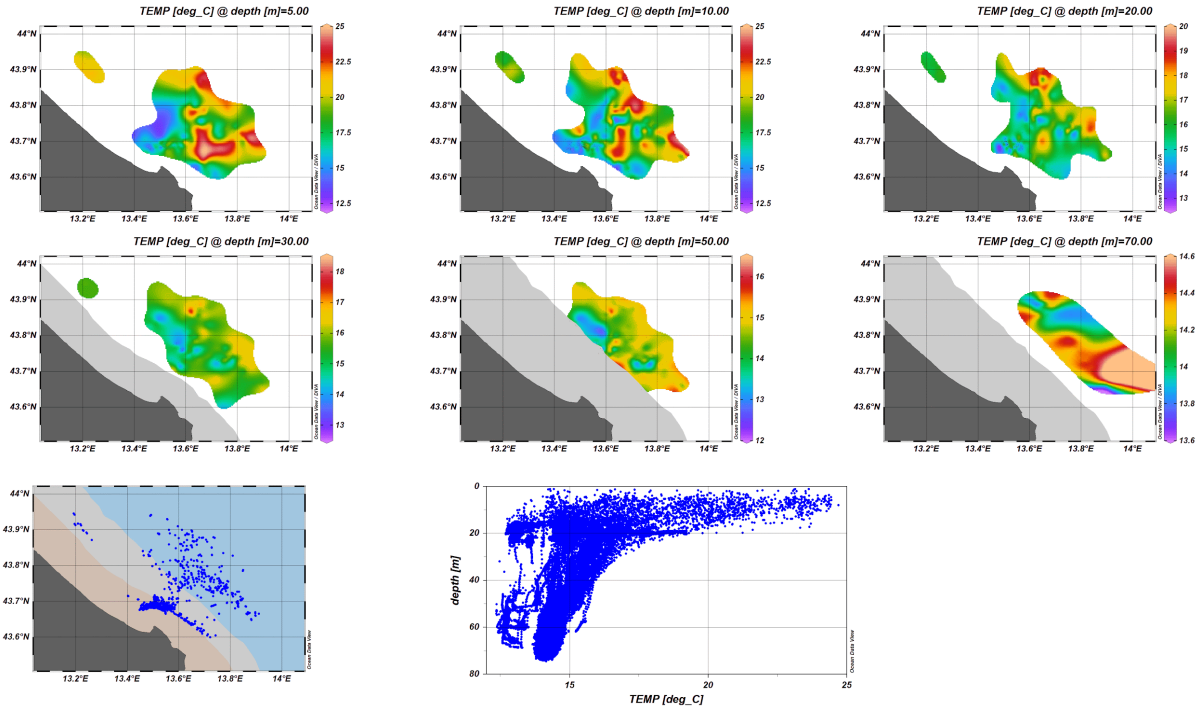


Figure 4A2: Temperature (°C) maps at depths of 5, 10, 20, 30, 50 and 70 m, related to the fishing area exploited by the vessel monitored through CNR AdriFOOS and the NKE DO and Chl-a sensors, generated from the validated dataset for the period from April to June 2024.

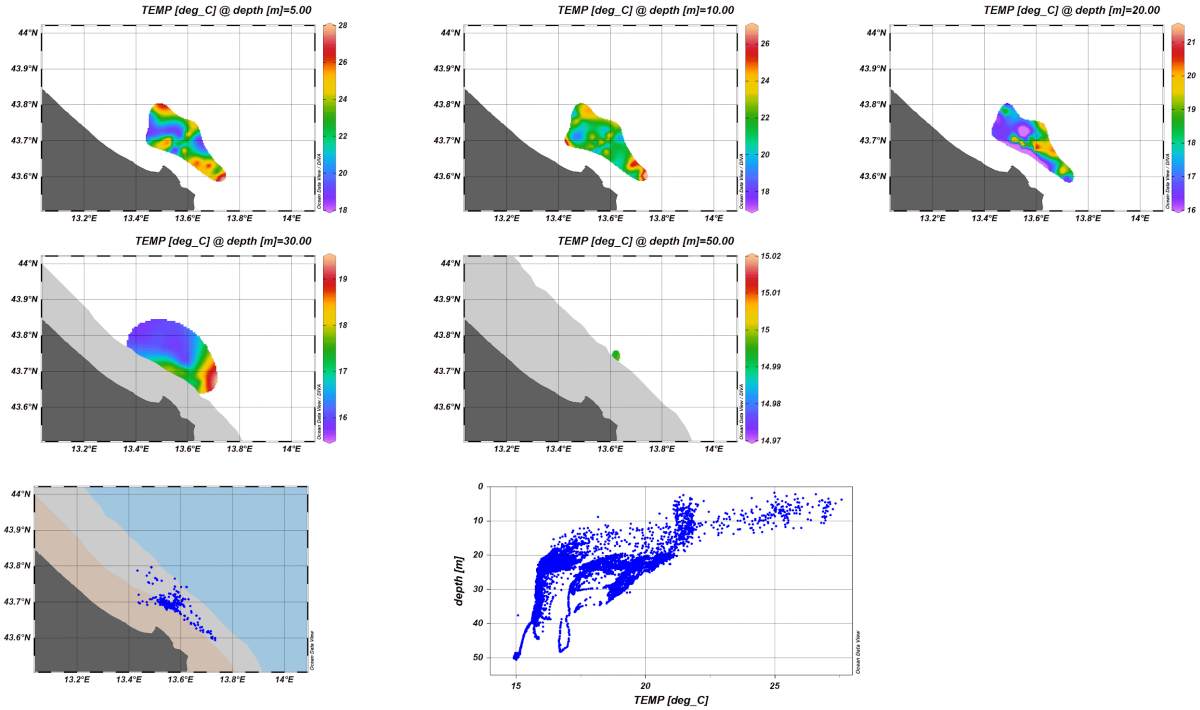


Figure 5A2: Temperature (°C) maps at depths of 5, 10, 20, 30, 50 and 70 m, related to the fishing area exploited by the vessel monitored through CNR AdriFOOS and the NKE DO and Chl-a sensors, generated from the validated dataset for the period from July to September 2024.

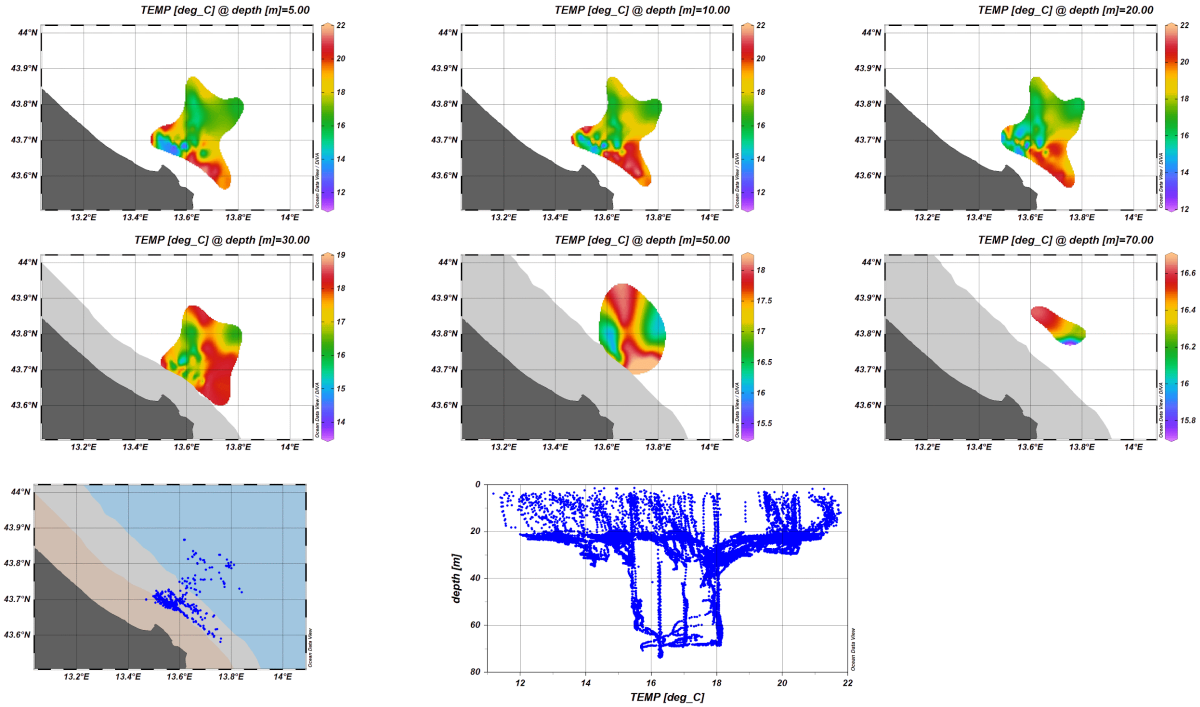


Figure 6A2: Temperature (°C) maps at depths of 5, 10, 20, 30, 50 and 70 m, related to the fishing area exploited by the vessel monitored through CNR AdriFOOS and the NKE DO and Chl-a sensors, generated from the validated dataset for the period from October to December 2024.

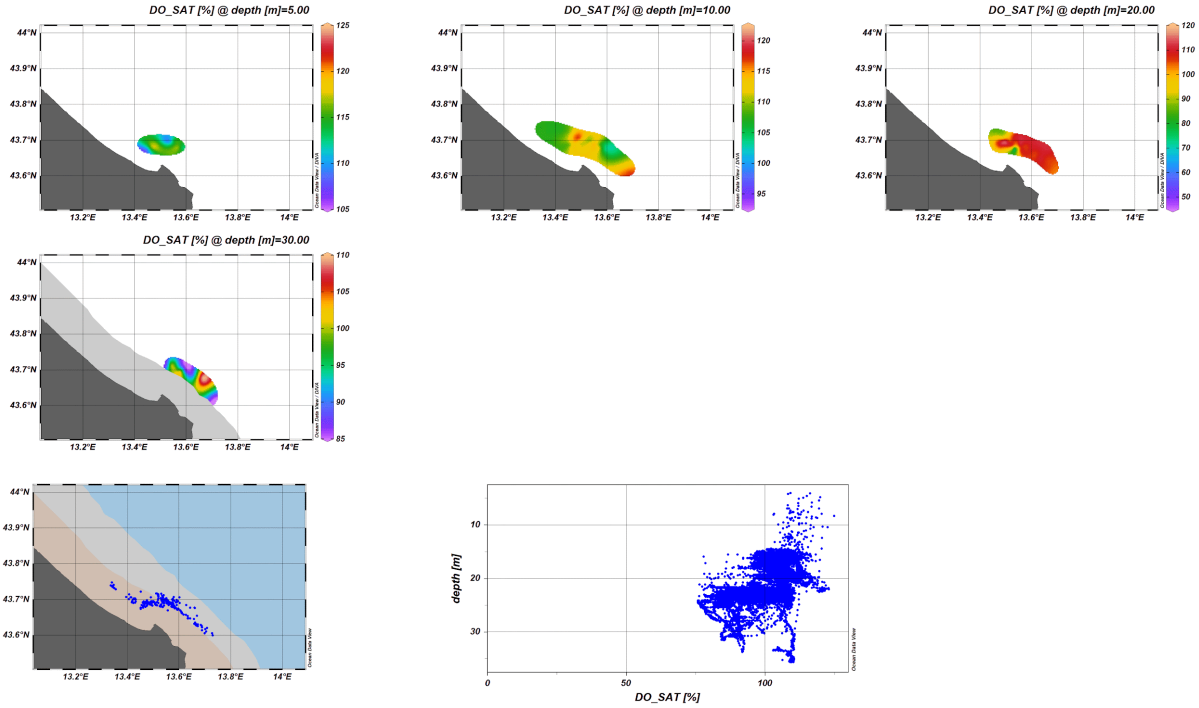


Figure 7A2: Dissolved oxygen saturation (%) maps at depths of 5, 10, 20, 30, 50 and 70 m, related to the fishing area exploited by the vessel monitored through CNR AdriFOOS and the NKE DO sensor, generated from the validated dataset for the period from July to September 2023.

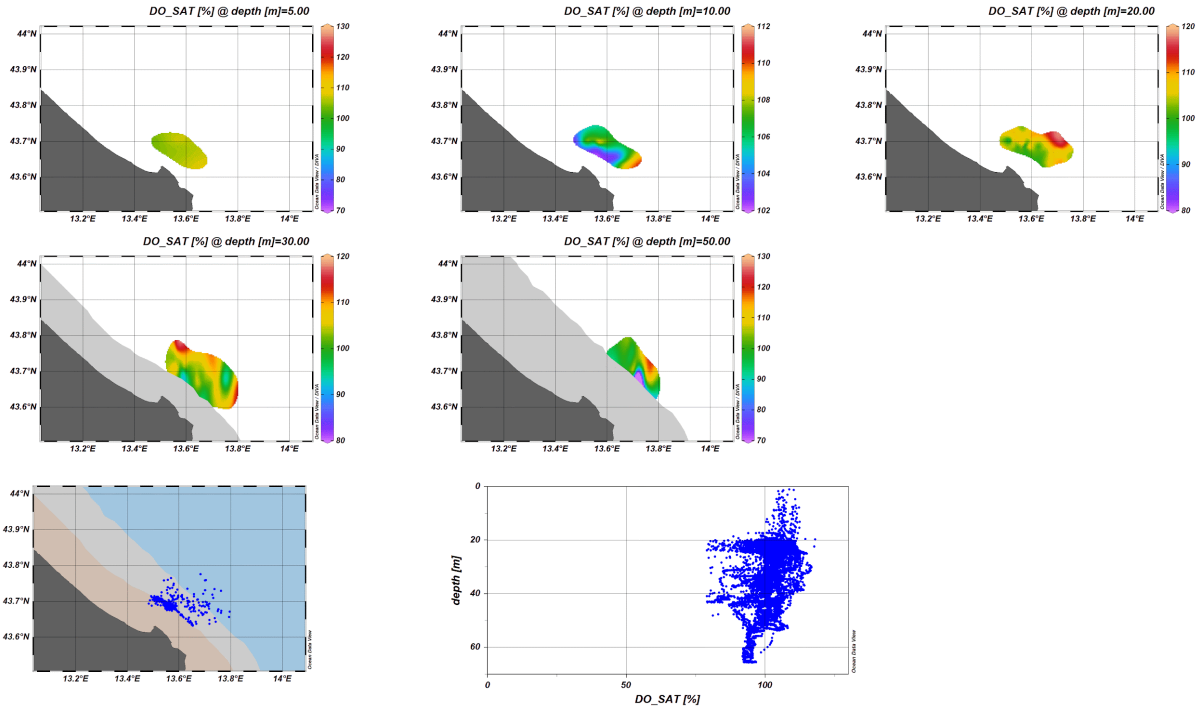


Figure 8A2: Dissolved oxygen saturation (%) maps at depths of 5, 10, 20, 30, 50 and 70 m, related to the fishing area exploited by the vessel monitored through CNR AdriFOOS and the NKE DO sensor, generated from the validated dataset for the period from October to December 2023.

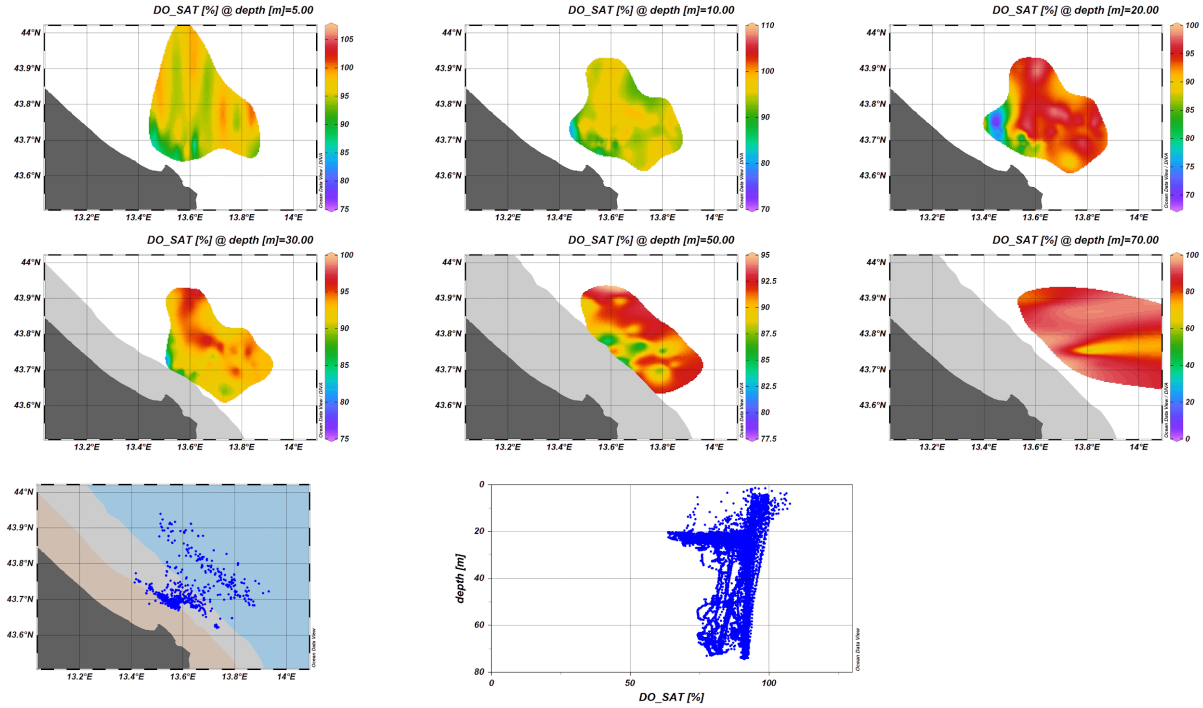


Figure 9A2: Dissolved oxygen saturation (%) maps at depths of 5, 10, 20, 30, 50 and 70 m, related to the fishing area exploited by the vessel monitored through CNR AdriFOOS and the NKE DO sensor, generated from the validated dataset for the period from January to March 2024.

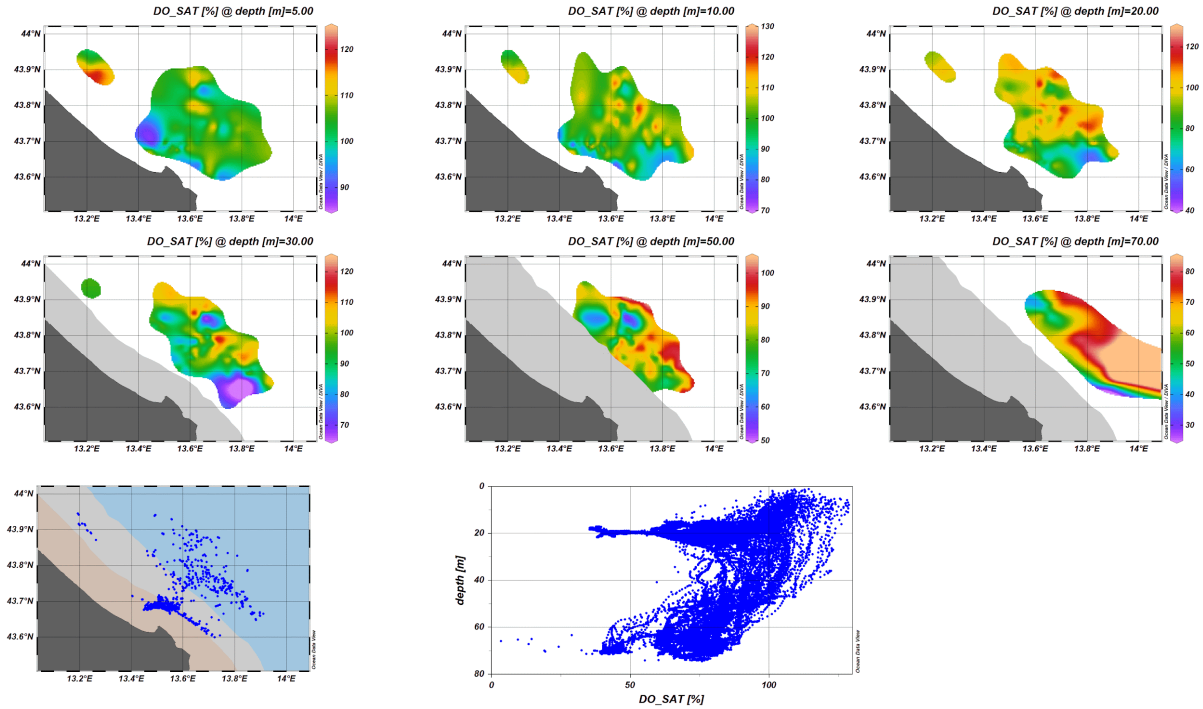


Figure 10A2: Dissolved oxygen saturation (%) maps at depths of 5, 10, 20, 30, 50 and 70 m, related to the fishing area exploited by the vessel monitored through CNR AdriFOOS and the NKE DO sensor, generated from the validated dataset for the period from April to June 2024.

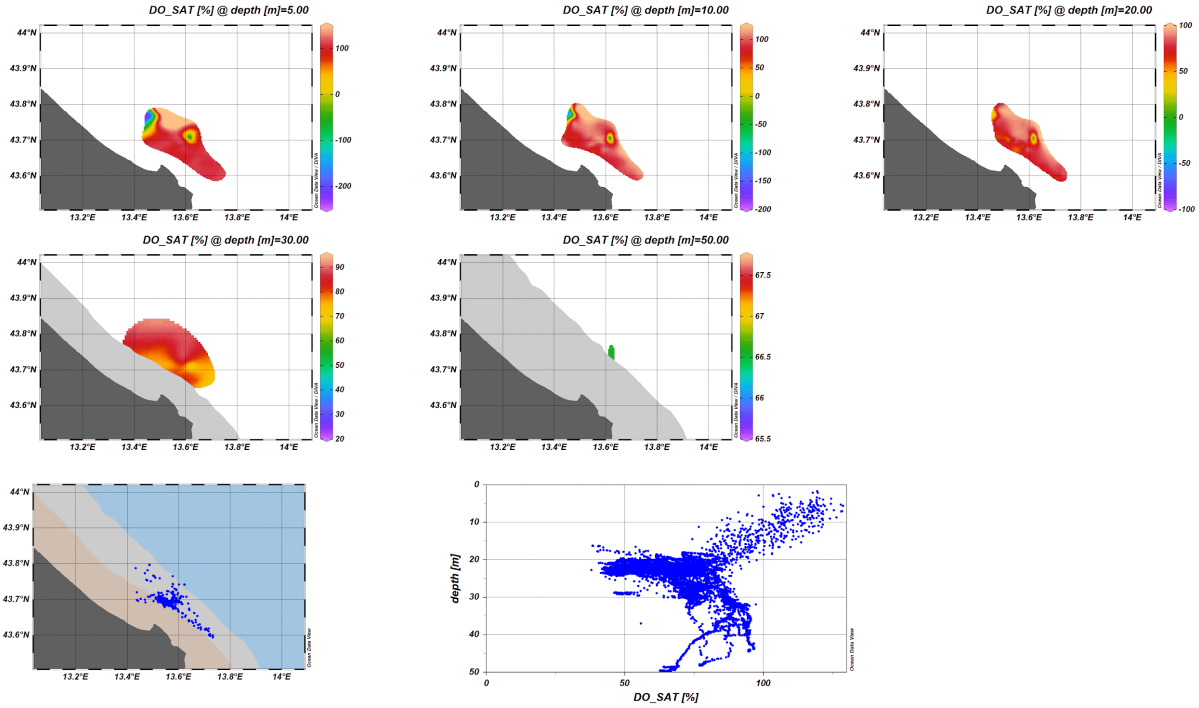


Figure 11A2: Dissolved oxygen saturation (%) maps at depths of 5, 10, 20, 30, 50 and 70 m, related to the fishing area exploited by the vessel monitored through CNR AdriFOOS and the NKE DO sensor, generated from the validated dataset for the period from July to September 2024.

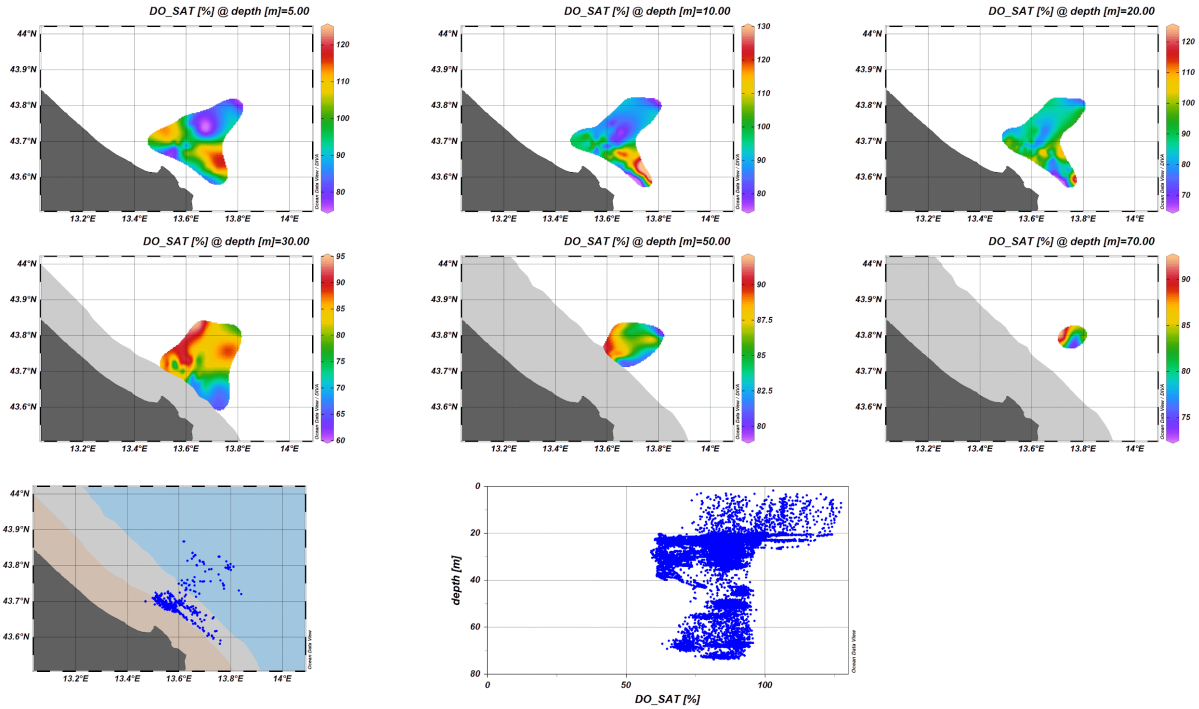


Figure 12A2: Dissolved oxygen saturation (%) maps at depths of 5, 10, 20, 30, 50 and 70 m, related to the fishing area exploited by the vessel monitored through CNR AdriFOOS and the NKE DO sensor, generated from the validated dataset for the period from October to December 2024.

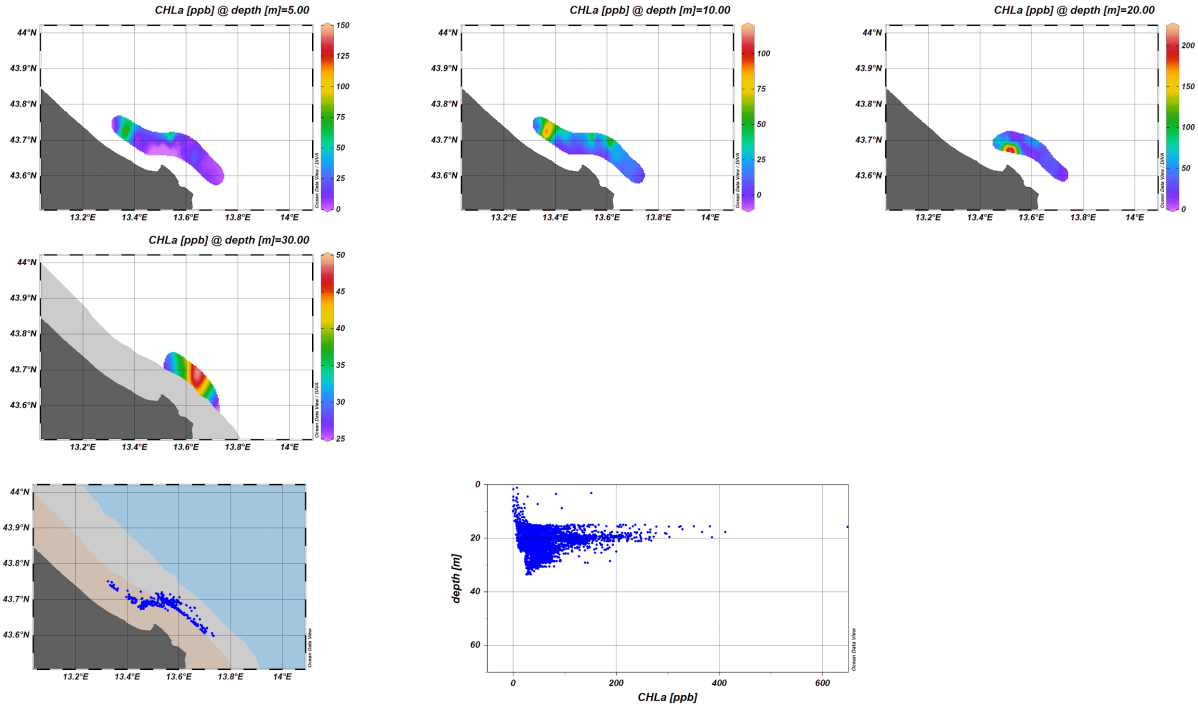


Figure 13A2: Chlorophyll concentration (RWT) maps at depths of 5, 10, 20, 30, 50 and 70 m, related to the fishing area exploited by the vessel monitored through CNR AdriFOOS and the NKE Chl-a sensor, generated from the validated dataset for the period from July to September 2023.

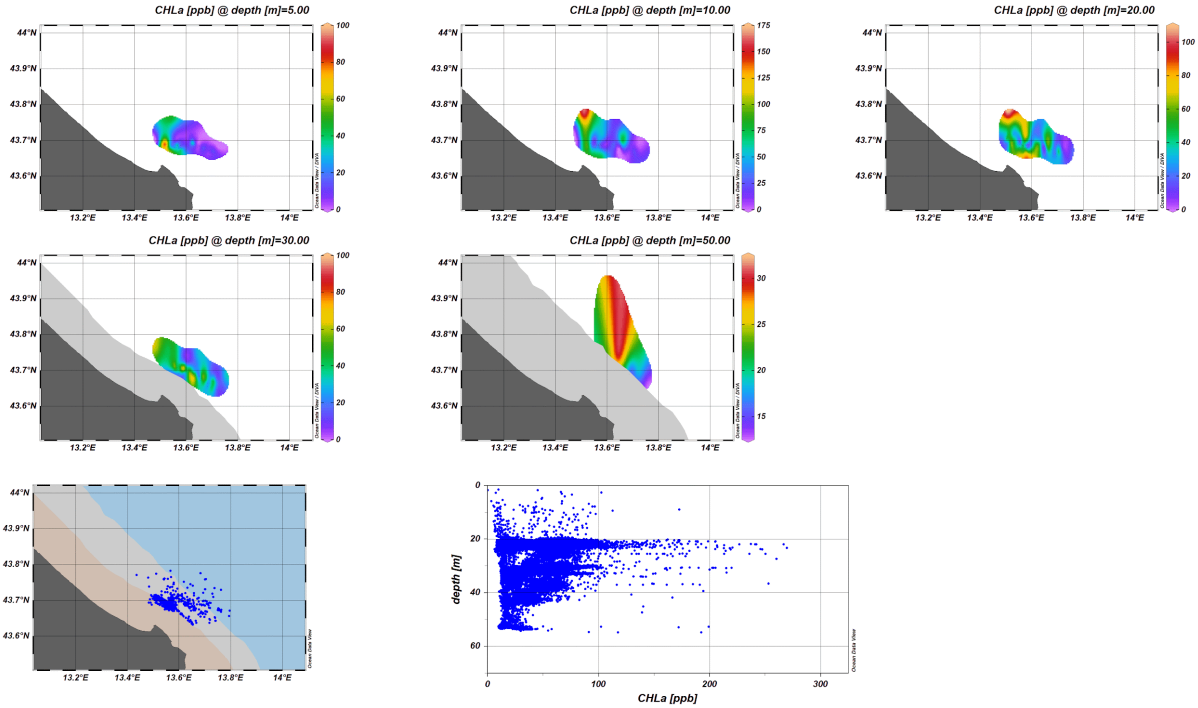


Figure 14A2: Chlorophyll concentration (RWT) maps at depths of 5, 10, 20, 30, 50 and 70 m, related to the fishing area exploited by the vessel monitored through CNR AdriFOOS and the NKE Chl-a sensor, generated from the validated dataset for the period from October to December 2023.

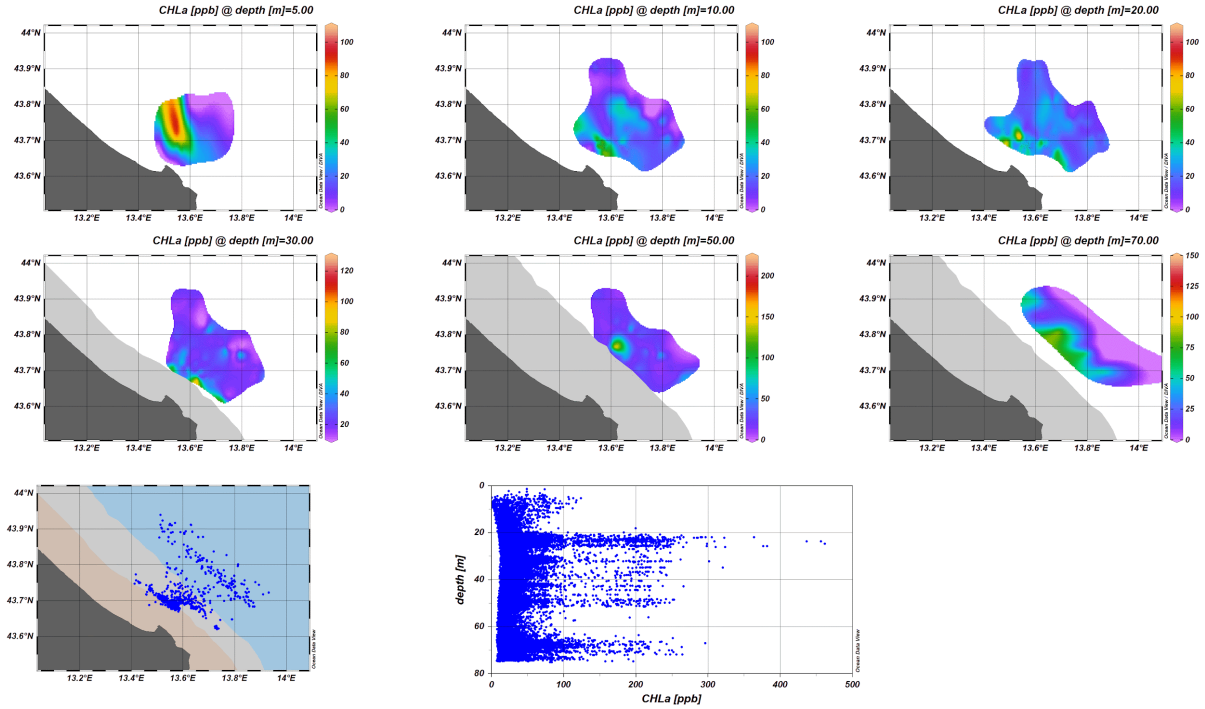


Figure 15A2: Chlorophyll concentration (RWT) maps at depths of 5, 10, 20, 30, 50 and 70 m, related to the fishing area exploited by the vessel monitored through CNR AdriFOOS and the NKE Chl-a sensor, generated from the validated dataset for the period from January to March 2024.

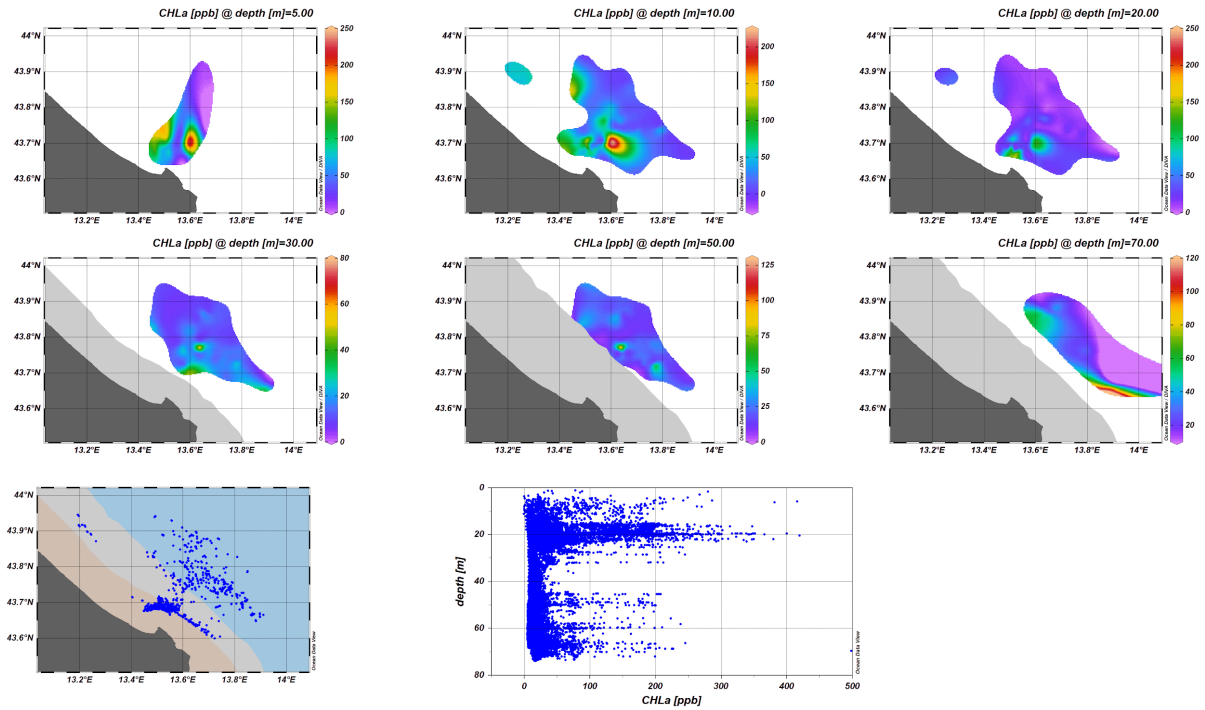


Figure 16A2: Chlorophyll concentration (RWT) maps at depths of 5, 10, 20, 30, 50 and 70 m, related to the fishing area exploited by the vessel monitored through CNR AdriFOOS and the NKE Chl-a sensor, generated from the validated dataset for the period from April to June 2024.

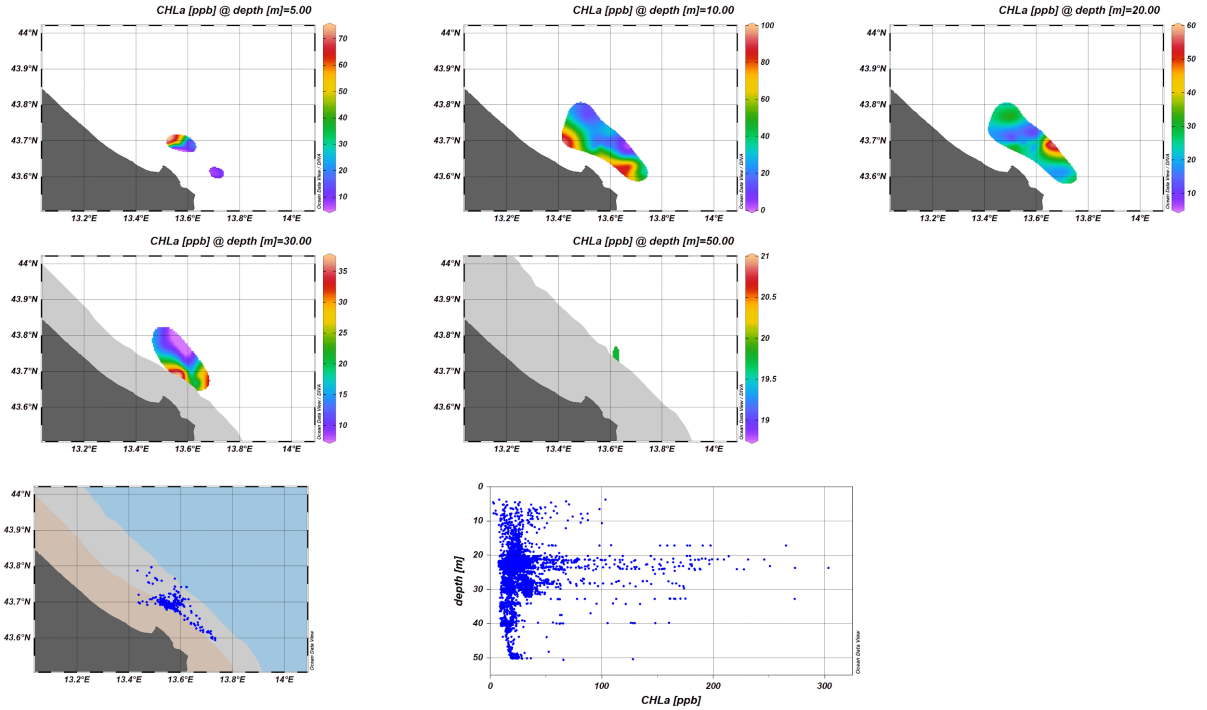


Figure 17A2: Chlorophyll concentration (RWT) maps at depths of 5, 10, 20, 30, 50 and 70 m, related to the fishing area exploited by the vessel monitored through CNR AdriFOOS and the NKE Chl-a sensor, generated from the validated dataset for the period from July to September 2024.

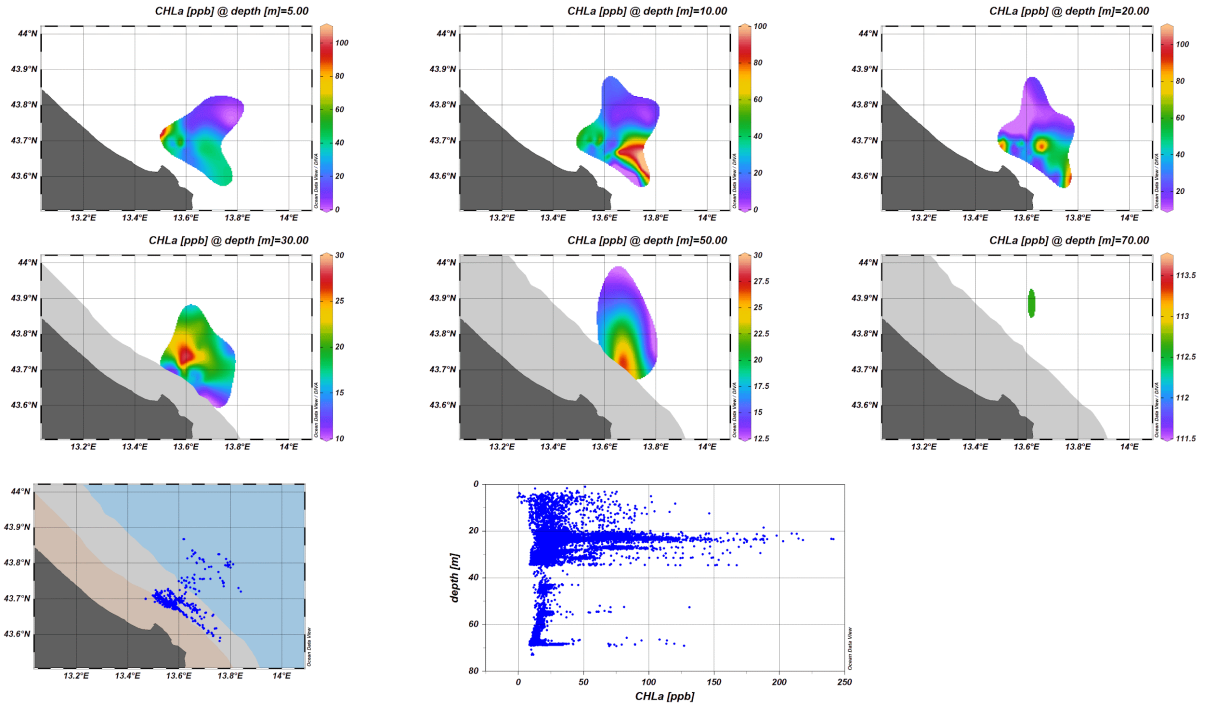


Figure 18A2: Chlorophyll concentration (RWT) maps at depths of 5, 10, 20, 30, 50 and 70 m, related to the fishing area exploited by the vessel monitored through CNR AdriFOOS and the NKE Chl-a sensor, generated from the validated dataset for the period from October to December 2024.