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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: https://www.nautilos-h2020.eu/

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Table of contents

Executive summary

NAUTILOS WP9 is designed to demonstrate and quantify how the new sensors, the new integration in platforms and the new observation approaches can improve the modelling (hydrodynamic, biogeochemical, plastic pollution) and to set up NAUTILOS new data interoperability and legacy towards European Marine data Integrators.

NAUTILOS designed Task 9.5 - Data Integration in European Platforms, Data Legacy – that moves from the outcome of WP8 and elevates these NAUTILOS tools to the next level within the European Marine data framework.

This activity also includes the development of key performance indicators to measure and assess the system performances, according to demonstration needs and requirements.

These KPIs cover information about how much data has been made available, if marine data integrators (like EMODnet) are consuming this data, if these are used for added value products, the number of publications etc.

D9.7 describes the results of these KPIs assessment.

List of tables

List of acronyms and abbreviations

Abbreviation	Definition
AAS	Active Acoustic Sensor
AdriFOOS	Adriatic Fisheries and Oceanography Observing System
ASV	Autonomous Surface Vehicle
CEiiA	Engineering and Product Development Centre
Chl-a	Chlorophyll-a
CNR	National Research Council
CNR-IRBIM	National Research Council - Institute for Biological Resources and Marine Biotechnology
CNRS	National Centre for Scientific Research
COTS	Components-off-the-shelf
CS	Citizen Science
CSEM	Swiss Centre for Electronics and Microtechnology
CTD	Conductivity, Temperature, Depth
D	Deliverable
DAC	Data Assembly Center
DFKI	German Research Center For Artificial Intelligence
DMP	Data Management Plan
DO	Dissolved Oxygen
DOI	Digital Object Identifier
DOW	NAUTILOS document of work
EI	Expected Impacts
EMODnet	European Marine Observation and Data network
EOVs	Essential Ocean Variables
ERDDAP	Environmental Research Division's Data Access Program
ESPCE	European Strategy for Plastics in a Circular Economy
FAIR	Findable, Accessible, Interoperable, Reusable
HCMR	Hellenic Centre for Marine Research
HCMR-IMBBC	Hellenic Centre for Marine Research - Institute of Marine Biology, Biotechnology and Aquaculture
HESSO	Western Switzerland University of Applied Sciences
IMAR	Institute of the Sea
IMP	Impact
IR	Infrared
IR-T	Infrared Temperature
KPI	Key Performance Indicator
LIF-LIDAR	Laser Induced Fluorescence Light Detecting And Ranging
m	meter
MY	Multi/hyperspectral
MLTs	Marine LItter Trackers
MSFD	Marine Strategy Framework Directive
NIR	Near-Infrared
NIVA	Norwegian Institute for Water Research
NKE	NKE intrumentation
OSSE	Observing System Simulation Experiments
PAS	Passive Acoustic Sensor
pCO2	Partial pressure of carbon dioxide
PPS	Phytoplankton Sampler
SCT	SubCtech
Si	Silicate
SO	Specific Objective
SRDL	Oceanographic Satellite Relayed Data Logger

Abbreviation	Definition
SuNaMips	Submersible Nanoplastic and Microplastic Sampler
SYKE	Finnish Environment Institute
TRL	Technology Readiness Levels
UAlg	University of Algarve
UL-FE	University of Ljubljana

1. INTRODUCTION

NAUTILOS focuses on 17 instrumentation/tools that can operate from shallow coastal waters to open and deep-sea sites, providing complete datasets for studying the marine ecosystem functions and advanced data products and tools.

There is not a unique method to monitor the project performance and more indicators have to be designed for better tracking the project impact at different levels. To this end NAUTILOS had already identified a number of measurable objectives and outcomes.

KPIs have to monitor the number of developed sensors, if they are implementing the planned technology breakthrough (and reaching the planned TRL), if they are covering the targeted EOVs, if they are producing new valuable data, if this data is consumed by policy and directive assessment programs, by marine data infrastructures, by other projects and researchers, etc.

Most of these KPIs are already tracked under D10.1 and periodic reports, D9.5 defined an extended set of KPIs to capture the following categories:

- data and data product acquisition;
- data product development;
- data and data product delivery through portal and web services;
- data impact.

This Deliverable D9.7 presents the final assessment on these KPIs.

1.1. Generic project KPIs

- Amount of new data produced

At the period of writing (summer 2025), NAUTILOS backend (i.e., ERDDAP™ data server) is hosting 86 datasets (https://data-nautilos-h2020.eu/erddap/index.html). Some of these are test datasets (18), some others are already final-validated datasets (68). Dataset name is indicating the type and scope of data (see also DMP for further details).

- Delay between the data acquisition and data availability (timeliness) on data infrastructures

Approaching the conclusion of NAUTILOS, all of the acquired data were integrated into the data infrastructure. Table 1 shows the datasets valuable for NAUTILOS stakeholders.

Table 1. NAUTILOS datasets valuable for stakeholders

Description of data	# datasets	Type of stakeholder				
		Research & marine data system	National monitoring reporting	Policy maker	Business	Citizen
Active acoustic sensor - AQUATEC	2	x	x		x	
Algal bloom data from citizen science	2		x			x
Carbonate sensors - NIVA/SYKE	6	x	x	x	x	x
CEiiA Lander with Camera - CEiiA	1	x	x	x	x	
CEiiA Lander with UL-FE Deep Ocean CTD - CEiiA / UL-FE	2	x	x	x	x	
Citizen Science Low-cost drifters for marine litter coastal monitoring	1	x	x			x
Citizen Science Plastic campaign	5	x	x	x		x
Collection of chlorophyll, oxygen and temperature - Fishing Vessels profiles by AdriFOOS platform - CNR IRBIM	4	x	x	x		x
Collection of chlorophyll, oxygen and temperature - Recreational divers - CNR IRBIM	2	x	x	x		x
Deep ocean low-level radioactivity sensor - HCMR	1	x	x			
Depth and backscatter intensity extracted from the raw sonar data - CEiiA	1	x	x	x	x	
Diver Campaign from citizen science app	1	x				x
SRDL-CTD-Oxy animal tag - CNRS	1	x	x	x		

Description of data	# datasets	Type of stakeholder				
		Research & marine data system	National monitoring reporting	Policy maker	Business	Citizen
Laser induced fluorescence Light detecting and ranging (LIF-LIDAR) sensor - NIVA	1	x	x	x	x	
Biogeochemical models - HCMR	4	x	x	x		
Hydrodynamic models - HCMR/UAlg	16	x	x	x		
Plastic models - HCMR/NIVA	10	x	x	x		
Ferrybox data associated to microplastic sampler - NIVA	1	x	x	x	x	x
Fluorimetric sensor - HESSO/EdgeLab	3	x	x	x	x	
Image Annotation from citizen science (Zooniverse)	1	x				x
IR temperature sensor - NIVA / HCMR	1	x	x	x	x	x
MAANTA NAUTILOS animal tag - CEiiA / IMAR	2	x	x	x		
Microplastic sampler - NIVA	1	x	x	x	x	x
Matchup of in situ data from UAV with remote sensing from satellites - NIVA	3	x	x		x	
Passive acoustic sensor - AQUATEC	2	x	x		x	
Silicate sensor - NKE	1	x	x	x		
Submersible Sampler for Nanoplastics and Microplastics (SuNaMips) - HCMR	1	x	x			x
Dissolved oxygen sensor WiSens TD DO - NKE / Ifremer	1	x	x	x		x
Fluorescence sensor WiSens TD Chl-a - NKE / Ifremer	1	x	x	x		x
Multispectral and hyperspectral observations of plastic litter and ocean color - NIVA	1	x	x		x	

- number DOIs in NAUTILOS

NAUTILOS assigns a DOI to all the public deliverables. At the time of writing, the list includes deliverables reported in the following table.

Table 2. Metrics on the NAUTILOS docs in Zenodo (@18/06/2025)

Deliverable	https://zenodo.org/record/	views	downloads
D1.1 - 10.5281/zenodo.7162213	https://zenodo.org/record/7162213	50	61
D1.2 - 10.5281/zenodo.7163583	https://zenodo.org/record/7163583	45	63
D1.3 - 10.5281/zenodo.7163625	https://zenodo.org/record/7163625	70	81
D1.4 - 10.5281/zenodo.7163673	https://zenodo.org/record/7163673	48	72
D.1.6 - 10.5281/zenodo.7886901	https://zenodo.org/record/7886901	43	38

Deliverable	https://zenodo.org/record/	views	downloads
D1.9 - 10.5281/zenodo.7886929 (v3 -10.5281/zenodo.14938116)	https://zenodo.org/records/14938116	84	68
D1.10 - 10.5281/zenodo.7163783	https://zenodo.org/record/7163783	58	57
D1.11 - 10.5281/zenodo.10664813	https://zenodo.org/records/10664813	25	53
D1.12 - 10.5281/zenodo.14283187	https://zenodo.org/records/14283187	10	16
D2.1 - 10.5281/zenodo.7163906	https://zenodo.org/record/7163906	143	82
D3.1 - 10.5281/zenodo.7224501	https://zenodo.org/record/7224501	43	54
D5.1 - 10.5281/zenodo.7224543	https://zenodo.org/record/7224543	47	66
D5.3 - 10.5281/zenodo.10664994	https://zenodo.org/records/10664994	54	47
D5.4 - 10.5281/zenodo.10665459	https://zenodo.org/records/10665459	31	31
D5.5 - 10.5281/zenodo.14260491	https://zenodo.org/records/14260491	6	9
D5.6 - 10.5281/zenodo.10909202	https://zenodo.org/records/10909202	165	161
D5.7 - 10.5281/zenodo.10666218	https://zenodo.org/records/10666218	25	36
D5.8 - 10.5281/zenodo.7224624	https://zenodo.org/record/7224624	49	60
D6.2 - 10.5281/zenodo.10909227	https://zenodo.org/records/10909227	86	53
D6.3 - 10.5281/zenodo.10675287	https://zenodo.org/records/10675287	27	25
D6.4 - 10.5281/zenodo.10909234	https://zenodo.org/records/10909234	77	39
D6.5 - 10.5281/zenodo.10909246	https://zenodo.org/records/10909246	82	62
D7.1 - 10.5281/zenodo.14260995	https://zenodo.org/records/14260995	47	43
D8.1 - 10.5281/zenodo.7211768	https://zenodo.org/record/7211768	54	58
D8.2 - 10.5281/zenodo.7211792	https://zenodo.org/record/7211792	63	73
D8.3 - 10.5281/zenodo.7211798	https://zenodo.org/record/7211798	62	63
D8.4 - 10.5281/zenodo.7211817	https://zenodo.org/record/7211817	41	52
D8.5 - 10.5281/zenodo.7224664	https://zenodo.org/record/7224664	53	187
D8.6 - 10.5281/zenodo.7224676	https://zenodo.org/record/7224676	43	62
D8.7 - 10.5281/zenodo.7224688	https://zenodo.org/record/7224688	77	77
D8.8 - 10.5281/zenodo.7224700	https://zenodo.org/record/7224700	88	
D8.9 - 10.5281/zenodo.7224729	https://zenodo.org/record/7224729	94	96
D9.5 - 10.5281/zenodo.7886949 (v.2 - 10.5281/zenodo.7889278)	https://zenodo.org/record/7889278	70	75
D9.6 - 10.5281/zenodo.10694778	https://zenodo.org/records/10694778	39	36
D10.1 - 10.5281/zenodo.7163695	https://zenodo.org/record/7163695	40	78
D10.2 - 10.5281/zenodo.7224747	https://zenodo.org/record/7224747	45	69
D10.3 - 10.5281/zenodo.10702521	https://zenodo.org/records/10702521	31	32
D10.4 - 10.5281/zenodo.7886990 (v2 - 10.5281/zenodo.14937862)	https://zenodo.org/records/14937862	65	88
D10.5 - 10.5281/zenodo.7886996	https://zenodo.org/record/7886996	39	38
D10.6 - 10.5281/zenodo.10702531	https://zenodo.org/records/10702531	27	21
D10.8 - 10.5281/zenodo.7887010	https://zenodo.org/record/7887010	56	50
D10.9 - 10.5281/zenodo.14856149	https://zenodo.org/records/14856149	9	17
D11.1 - 10.5281/zenodo.7211802	https://zenodo.org/record/7211802	49	55
D11.2 - 10.5281/zenodo.7887016	https://zenodo.org/record/7887016	43	43

Deliverable	https://zenodo.org/record/	views	downloads
D11.3 - 10.5281/zenodo.14283472	https://zenodo.org/records/14283472	9	7
D11.4 - 10.5281/zenodo.14283263	https://zenodo.org/records/14283263	13	12
D11.5 - 10.5281/zenodo.14283327	https://zenodo.org/records/14283327	8	11
D11.6 - 10.5281/zenodo.7887025 (v.2 - 10.5281/zenodo.7887035)	https://zenodo.org/record/7887035	80	97
D11.8 - 10.5281/zenodo.7887043	https://zenodo.org/record/7887043	63	184
D12.4 - 10.5281/zenodo.14856249	https://zenodo.org/records/14856249	6	8

NAUTILOS DMP considers the submission of validated datasets to a repository that can assign a DOI, and, at the time of writing, the following NAUTILOS related (in situ based) datasets have been assigned a DOI:

- https://doi.org/10.17882/73008 - https://doi.org/10.5194/essd-15-3513-2023 - https://zenodo.org/records/16900553 (Temperature profiles 2012-2020 - Fishing Vessels profiles by AdriFOOS platform - CNR IRBIM);
- https://zenodo.org/records/15397170 (Depth, Temperature, Dissolved oxygen and Chlorophyll-a dataset collected by Fishing Vessels, CNR IRBIM AdriFOOS platform in the Adriatic Sea - validated dataset 2023-2025);
- https://doi.org/10.3390/s23020935 - https://doi.org/10.13127/misc/73 - https://zenodo.org/records/16903569 (Citizen Science low-cost drifters for marine litter coastal monitoring)
- https://zenodo.org/records/16909968 (Algal Bloom from citizen science);
- https://zenodo.org/records/16912228 (CEiiA Lander with AQUATEC Active Acoustic sensor);
- https://zenodo.org/records/16900819 (NRT Collection of chlorophyll and temperature - recreational divers profiles - CNR IRBIM);
- https://zenodo.org/records/16900911 (NRT Collection of oxygen and temperature - recreational divers profiles - CNR IRBIM);
- https://zenodo.org/records/16901424 (Elephant Seals Data - Valdes peninsula in October 2021);
- https://zenodo.org/records/16901495 (MAANTA animal tag with O2 sensor - CEiiA / IMAR);
- https://zenodo.org/records/16912144 (CEiiA Lander with Camera - CEiiA);
- https://zenodo.org/records/16901786 (CEiiA Lander with UL-FE Deep Ocean CTD - CEiiA / UL-FE);
- https://zenodo.org/records/16902851 (Depth and backscatter intensity extracted from the raw sonar data - CEiiA);
- https://zenodo.org/records/16903067 (Deep Ocean Radioactivity Sensor - HCMR);
- https://zenodo.org/records/16873528 (Carbonate pCO2 - NIVA);
- https://zenodo.org/records/16902985 (Carbonate pH HONEYWELL - NIVA);
- https://zenodo.org/records/16909778 (Carbonate pH Memosens sensor - NIVA/SYKE);
- https://zenodo.org/records/16903105 (IR temperature sensor - NIVA / HCMR);

- https://zenodo.org/records/16903248 (Laser induced fluorescence light detecting and ranging (LIF-LIDAR) sensor - NIVA);
- https://zenodo.org/records/16903541 (Microplastic sampler - NIVA);
- https://zenodo.org/records/16903493 (Ferrybox data associated to microplastic sampler - NIVA);
- https://zenodo.org/records/16903642 (Seabird CDT associated to Silicate Electrochemical Sensor - NKE);
- https://zenodo.org/records/16903708 (Silicate Electrochemical Sensor - NKE);
- https://zenodo.org/records/16910132 (Matchups of in situ data from UAV during Norwegian and Aegean Sea demonstration with remote sensing from OLI or OLI-2 imager collected by L8 or L9 satellite platform - NIVA);
- https://zenodo.org/records/16910210 (Matchups of in situ data from UAV during Norwegian and Aegean Sea demonstration with remote sensing from MSI imager collected by S2-A or S2-B satellite platform - NIVA);
- https://zenodo.org/records/16910240 (Matchups of in situ data from UAV during Norwegian and Aegean Sea demonstration with remote sensing from OLCI imager collected by S3-A or S3-B satellite platform - NIVA);
- https://zenodo.org/records/16910279 (Marine Litter - NAUTILOS Summer School 2023);
- https://zenodo.org/records/16911020 (Citizen Science Plastic Campaign);
- https://zenodo.org/records/16911020 (Citizen Science Plastic Image);
- https://zenodo.org/records/16911020 (Citizen Science Plastic Litter);
- https://zenodo.org/records/16903745 (Collection of plastic litter by AdriFOOS platform - CNR IRBIM);
- https://zenodo.org/records/16903925 (Eco Med10 Assimilation Model of 110 Random TEM/SAL Profiles (2010) - HCMR);
- https://zenodo.org/records/16903892 (Eco Med10 Assimilation Model of 78 Random TEM/SAL Profiles (2010) - HCMR);
- https://zenodo.org/records/16903945 (Eco Med10 Forecast Model (2010) - HCMR);
- https://zenodo.org/records/16903959 (Eco Med10 Nature Run (2010) - HCMR);
- https://zenodo.org/records/16904010 (Hydro Med10 Assimilation Model of 110 Random TEM/SAL Profiles (2010) - HCMR);
- https://zenodo.org/records/16903968 (Hydro Med10 Assimilation Model of 78 Random TEM/SAL Profiles (2010) - HCMR);
- https://zenodo.org/records/16904025 (Hydro Med10 Forecast Model (2010) - HCMR);
- https://zenodo.org/records/16904072 (Hydro Med10 Nature Run (2010) - HCMR);
- https://zenodo.org/records/16908905 (Plastic Med10 Assimilation Model of 110 Uniform Scattered TEM/SAL Profiles (2010) - HCMR);
- https://zenodo.org/records/16908878 (Plastic Med10 Assimilation Model of 78 Uniform Scattered TEM/SAL Profiles (2010) - HCMR);
- https://zenodo.org/records/16908939 (Plastic Med10 Forecast Model (2010) - HCMR);
- https://zenodo.org/records/16908953 (Plastic Med10 Nature Run (2010) - HCMR);

- https://zenodo.org/records/16910445 (SOMA daily averaged 3D fields forecast (DAILY 3D 1km best) - UAlg);
- https://zenodo.org/records/16910520 (SOMA daily averaged 3D fields forecast (DAILY 3D 2km best) - UAlg);
- https://zenodo.org/records/16910534 (SOMA hourly averaged 2D fields forecast (HOURLY SURFACE 1km best) - UAlg);
- https://zenodo.org/records/16910566 (SOMA hourly averaged 2D fields forecast (HOURLY SURFACE 2km best) - UAlg).

1.2. Data management KPIs

NAUTILOS developed both operational flows and delaymode flows (Table 3). Considering data integration in EMODnet, while some data (like Animal tagging, AdriFOOS) can be made available to integrators since the collection (via ERDDAP™), other data (like the citizens campaign to monitor the beach litter) have to be submitted to systems to be considered for the integration into specific products (e.g. Litter Maps). NAUTILOS conducted 192 campaigns (demonstrations), 87 of which were submitted to EMODnet Ingestion, 86 reached phase 1 status. For some of these, the flow for integration into specific themes and achievement of phase 2 has already been prepared.

Table 3. Data Management KPIs

number of NAUTILOS datasets integrated into EMODnet thematic projects/products (*)	24
number of registered datasets DOI in NAUTILOS (**)	46
number of NAUTILOS citations (DOI or prj code) (***)	362

*)
https://ingestion-erddap.emodnet-physics.eu/erddap/search/index.html?page=1&itemsPerPage=1000&searchFor=nautilos
https://emodnet.ec.europa.eu/geonetwork/srv/ita/catalog.search#/search?any=NAUTILOS&from=1&to=30

- AdriFOOS Depth/Temperature profiles dataset July 2021 (EMODnet Ingestion & Physics);
- AdriFOOS Temperature, oxygen and chlorophyll dataset 2023-2025 (EMODnet Ingestion & Physics - 3 dataset);
- Elephant Seals Data - SRDL-CTD-Oxy animlal tag on elephant seals in Peninsula Valdes and Kerguelen Island (EMODnet Ingestion & Physics);
- NAUTILOS Citizen Science Plastic Litter Crete 2022-2023 (EMODnet Ingestion);
- NAUTILOS Citizen Science Plastic Litter Crete 2023-2024 (EMODnet Ingestion);
- NAUTILOS Citizen Science Plastic Litter Crete 2024-2025 (EMODnet Ingestion - submitted);
- CEiiA Lander with AQUATEC Active Acoustic sensor (EMODnet Ingestion);
- CEiiA Lander with UL-FE Deep Ocean CTD (EMODnet Ingestion);
- Carbonate pCO2 (EMODnet Ingestion);
- Carbonate pH Honeywell sensor (EMODnet Ingestion);
- Carbonate pH Memosens sensor (EMODnet Ingestion);
- Citizen Science Low-cost drifters for marine litter coastal monitoring (EMODnet Ingestion);
- Deep Ocean Radioactivity Sensor (EMODnet Ingestion);
- Ferrybox data associated to microplastic sampler (EMODnet Ingestion);
- Fluorimetric sensor AUV Tau data (EMODnet Ingestion);
- IR temperature sensor (EMODnet Ingestion);

- Laser induced fluorescence light detecting and ranging (LIF-LIDAR) sensor (EMODnet Ingestion);
- MAANTA animal tag with O2 sensor (EMODnet Ingestion);
- Collection of chlorophyll and temperature - recreational divers profiles (EMODnet Ingestion);
- Collection of oxygen and temperature - recreational divers profiles (EMODnet Ingestion);
- Passive Acoustic Sensor (EMODnet Ingestion);
- Seabird CDT associated to Silicate Electrochemical Sensor (EMODnet Ingestion).

**) see previous section

***) List of NAUTILOS related scientific communications (from Publish or Perish) at the end of the document (Table 20).

2. Specific Objectives (SO) KPIs

SO1: Develop and demonstrate improved observing systems in coastal and shelf-sea environments

NAUTILOS sensors are going to improve our understanding of environmental change and anthropogenic impacts related to aquaculture, fisheries, and plastic litter in coastal and shelf-sea environments

Demonstrations were planned in Adriatic Sea, Aegean Sea, Baltic Sea, Coast of Norway and Archipelago of the Azores islands. By the end of the project, the demonstrations exceeded expectations and were performed in more sites than originally planned: Adriatic Sea, Ligurian Sea, Tyrrhenian Sea, Ionian Sea, Bay of Biscay, Aegean Sea, Baltic Sea, Norwegian Sea, North Sea, Barents Sea, Portuguese coastal, Archipelago of the Azores islands, Valdes Peninsula, Atlantic Ocean, Pacific Ocean.

The integration platforms were ships of opportunity, fixed platforms, unmanned vehicles, and animals.

The number of overall demonstrations is 97.

The SO1 KPIs are reported in Tables 4 and 5.

Table 4. SO1 KPIs

	Description	Target	Achieved	Comments
DOW SO1.1	Number of sensors and samplers developed for coastal and shelf sea environments	13	19	1. Fluorometric sensors/dissolved oxygen (HESSO) 2a. Dissolved oxygen sensors (NKE) 2b. Fluorescence sensors (NKE) 3a. Downward-looking multi/hyperspectral and laser induced fluorescence sensors and cameras (NIVA) - LIF-LIDAR * 4. Passive broadband acoustic recording sensor for noise monitoring (AQUATEC) 5. Passive acoustic event recorder (porpoise & dolphin clicks for abundance estimation) (AQUATEC) 6. Active acoustic profiling sensor (AQUATEC) 7. Sampler for phytoplankton and other suspended matter (NIVA) 8a. Carbonate system/Ocean acidification sensors (NIVA) - pH 8b. Carbonate system/Ocean acidification sensors (NIVA) -pCO2 9. Silicate electrochemical sensor (NKE) 10. Sampler for Nanoplastics and Microplastics SuNaMips (SCT) 11a. Microplastic sensor (NIVA) - sampler 11b. Microplastic sensor (CSEM) - detector 11c. Microplastic sensor (NIVA/CSEM) - sampler&detector 12. Deep ocean CTD (UL-FE) 13. Deep ocean low-level radioactivity sensor (HCMR) 14a. Animal-borne instruments (CEiiA/IMAR) 14b. Animal-borne instruments (CNRS/SMRU)

	Description	Target	Achieved	Comments
DOW SO1.2	Number of field demonstrations at coastal and shelf-sea sites carried out	4	97	2 Mediterranean Sea - Adriatic Sea 5 Mediterranean Sea - Ligurian Sea 3 Mediterranean Sea - Tyrrhenian Sea 3 Mediterranean Sea - Ionian Sea 1 Mediterranean Sea - Gulf of Lion 6 Mediterranean Sea - Aegean Sea 2 Atlantic Ocean - Bay of Biscay 5 Atlantic Ocean - Baltic Sea 6 Atlantic Ocean - Norwegian Sea 4 Atlantic Ocean - North Sea 1 Atlantic Ocean - Barents Sea 14 Atlantic Ocean - Portugal - Mainland 30 Atlantic Ocean - Portugal - Azores Archipelago 10 Southern Ocean 1 Pacific Ocean 4 Indian Ocean

*) The “Downward-looking multi/hyperspectral and laser induced fluorescence sensors and cameras (NIVA)” also includes two other sensors that were not developed or improved in NAUTILOS (COTS) but have been tested and whose demonstrations are included in DOW SO1.2 and Table 5:

- 3b. Downward-looking multi/hyperspectral and laser induced fluorescence sensors and cameras (NIVA) - Multi/hyperspectral camera;
- 3c. Downward-looking multi/hyperspectral and laser induced fluorescence sensors and cameras (NIVA) - IR temperature sensor.

Table 5. SO1 KPIs for data management and dissemination

Demo site	ships of opportunity (ferrybox, fishing vessel)			fixed platforms			unmanned vehicles			animals			research vessels			aquaculture regions/facilities		
	sensor	demo	dataset	sensor	demo	dataset	sensor	demo	dataset	sensor	demo	dataset	sensor	demo	dataset	sensor	demo	dataset
Adriatic Sea	2 DO NKE 2 Chl-a NKE	1 DO NKE 1 Chl-a NKE	2 DO NKE 2 Chl-a NKE															
Ligurian Sea				1 PAS Aquatec	4 PAS Aquatec	1 PAS Aquatec	1 DO Hesso	1 DO Hesso	2 DO Hesso									
Tyrrhenian Sea				1 PAS Aquatec 1 DO Hesso	2 PAS Aquatec 1 DO Hesso	1 PAS Aquatec 1 DO Hesso												
Ionian Sea	1 IR-T NIVA	1 IR-T NIVA	1 IR-T NIVA										1 radioactivity HCMR	1 radioactivity HCMR	1 radioactivity HCMR	1 IR-T NIVA	1 IR-T NIVA	1 IR-T NIVA
Gulf of Lion				1 Si NKE	1 Si NKE	1 Si NKE												
Bay of Biscay	1 DO NKE 1 Chl-a NKE	1 DO NKE 1 Chl-a NKE	1 DO 1 Chl-a															
Aegean Sea	1 IR-T NIVA	1 IR-T NIVA	1 IR-T NIVA	1 radioactivity HCMR	1 radioactivity HCMR	1 radioactivity HCMR	1 pH ASV CEiiA	1 pH ASV CEiiA	1 pH ASV CEiiA				1 radioactivity HCMR 1 SuNaMips HCMR	1 radioactivity HCMR 1 SuNaMips HCMR	1 radioactivity HCMR 1 SuNaMips HCMR	1 IR-T NIVA	1 IR-T NIVA	1 IR-T NIVA
Baltic Sea	1 pCO2 NIVA 3 pH NIVA 1 PAS Aquatec	1 pCO2 NIVA 3 pH NIVA 1 PAS Aquatec	1 pCO2 NIVA 3 pH NIVA 1 PAS Aquatec															
Norwegian Sea	1 microplastic sampler NIVA 1 PPS NIVA	1 microplastic sampler NIVA 1 PPS NIVA	1 microplastic sampler NIVA 1 PPS NIVA													1 DO NKE 1 Chl-a NKE 1 pH NIVA 1 CO2 NIVA	1 DO NKE 1 Chl-a NKE 1 pH NIVA 1 CO2 NIVA	1 DO NKE 1 Chl-a NKE 1 pH NIVA 1 CO2 NIVA
North Sea	1 microplastic sampler NIVA 1 PPS NIVA	1 microplastic sampler NIVA 1 PPS NIVA	1 microplastic sampler NIVA 1 PPS NIVA				1 MY camera NIVA 1 LIF-LIDAR NIVA	1 MY camera NIVA 1 LIF-LIDAR NIVA	1 LIF-LIDAR NIVA									

Demo site	ships of opportunity (ferrybox, fishing vessel)			fixed platforms			unmanned vehicles			animals			research vessels			aquaculture regions/facilities		
	sensor	demo	dataset	sensor	demo	dataset	sensor	demo	dataset	sensor	demo	dataset	sensor	demo	dataset	sensor	demo	dataset
Barents Sea	1 microplastic sensor NIVA	1 microplastic sensor NIVA	1 microplastic sensor NIVA															
Portugal - Mainland				1 CTD UL-FE	11 CTD UL-FE	1 CTD UL-FE	1 PAS Aquatec 1 AAS Aquatec 1 pH NIVA	1 PAS Aquatec 1 AAS Aquatec 1 pH NIVA	1 PAS Aquatec 1 AAS Aquatec 1 pH NIVA									
Portugal - Azores Archipelago										1 animal born CEiiA/IMAR	30 animal born CEiiA/IMAR	1 animal born CEiiA/IMAR						
Southern Ocean										1 animal born CNRS/SMRU	10 animal born CNRS/SMRU	1 animal born CNRS/SMRU						
Pacific Ocean										1 animal born CEiiA/IMAR	1 animal born CEiiA/IMAR	1 animal born CEiiA/IMAR						
Indian Ocean										1 animal born CEiiA/IMAR	4 animal born CEiiA/IMAR	1 animal born CEiiA/IMAR						

*) In addition to the demonstration of the passive acoustic sensor in Sweden on fishing vessels, a demonstration in the Kolmården Dolphinarium (Sweden) was performed.

SO2: Develop and demonstrate improved observing systems in the open ocean and deep-sea environments

Long-term observation was planned to be in open-ocean and deep-sea environments with the following systems:

- sampler for phytoplankton and other suspended matter;
- silicate electrochemical sensor;
- deep ocean CTD;
- deep ocean low-level radioactivity sensor.

And finally it was planned they would be demonstrated in deep sea deployments using lander and Argo floats platforms supported by R/Vs missions.

While in the design phase of the project the sampler for phytoplankton and other suspended matter was evaluated for deep-sea, during the project it was developed only for the coastal area. On the other hand, the animal born instruments by CNRS/SMRU and CEiiA and active acoustic sensor by Aquatec have been developed for deep-sea.

The SO2 KPIs are reported in Tables 6 and 7.

Table 6. SO2 KPIs

	Description	Target	Achieved	Comments
DOW SO2.1	Number of deep-sea capable (> 2000 m water depth rated) sensors developed and demonstrated	4	6	* 9. Silicate electrochemical sensor (NKE) 12. Deep ocean CTD (UL-FE) 13. Deep ocean low-level radioactivity sensor (HCMR) 14a. Animal-borne instruments (CEiiA/IMAR) 14b. Animal-borne instruments (CNRS/SMRU) 6. Active acoustic sensor (Aquatec)
DOW SO2.2	Number of field demonstrations at deep-water sites (> 200 m water depth) carried out	3	20	

*) https://data-nautilos-h2020.eu/erddap/tabledap/silicate_sensor_nke.html
https://data-nautilos-h2020.eu/erddap/tabledap/CTD_lander_ceiia_data.html
https://data-nautilos-h2020.eu/erddap/tabledap/CTD_lander_ceiia_metadata.html
https://data-nautilos-h2020.eu/erddap/tabledap/radioactivity_sensor_hcmr.html
https://data-nautilos-h2020.eu/erddap/tabledap/elephant_seals_cnrs.html
https://data-nautilos-h2020.eu/erddap/tabledap/animal_tag_ceiia_data.html
https://data-nautilos-h2020.eu/erddap/tabledap/animal_tag_ceiia_metadata.html
https://data-nautilos-h2020.eu/erddap/tabledap/active_acoustic_sensor_aquatec_test.html

Deeper information on laboratory demonstrations are reported in Deliverable 6.1 for animal-born instruments, phytoplankton phytoplankton and other suspended matter sampler, and active acoustic sensor, and in Deliverable 6.2 (https://zenodo.org/records/10909227) for silicate sensor, deep ocean CTD and radioactivity sensor.

Table 7. Advanced KPIs specifies the details of the SO2

Sampler/Sensor	**Reached depth (during NAUTILOS field demonstrations)**	**Cost-benefit analysis classification ***
Phytoplankton and other suspended matter	Sub-surface	n.a.
Silicate electrochemical sensor	530 m	Improved technology / Cheaper in class
Deep ocean CTD	1616 m (data collected at 151 m)	Cheaper in class
Deep ocean low-level radioactivity sensor	2100 m	Improved technology / Cheaper in class
Animal born instruments	1054 m CNRS/SMRU 1244 m CEiiA/IMAR	New to market
Active acoustic sensor	4.1 m	Improved technology / Cheaper in class

*) see Deliverable 11.5 (https://zenodo.org/records/14283327)

In addition to the previous sensors, also the Sampler for Nanoplastics and Microplastics (SuNaMips) was tested at 400 m depth.

SO3: Develop and demonstrate improved observing systems for anthropogenic debris (i.e. macro-, micro-, nano-plastics)

The develop and demonstrate improved observing systems for anthropogenic debris are:
- microplastic sensor;
- micro- and nano-plastic sampler technologies;
- NIR scanner device for citizen science.

Sensors and samplers were targeted to be demonstrated in the coastal areas of Norway, Gulf of Finland and Aegean Sea and were used in Norway, Aegean Sea, Barents Sea and India. Citizen science efforts were performed on an explorer cruise ship that transects Northern European Seas.

The SO3 KPIs are reported in Tables 8 and 9.

Table 8. SO3 KPIs

	Description	Target	Achieved	Comments
DOW SO3.1	Number of cost-effective, portable micro and nanoplastics sensing and sampling technologies developed and demonstrated	3	3	10. Sampler for Nanoplastics and Microplastics SuNaMips (SCT) 11a. Microplastic sensor (NIVA) - sampler NIR scanner device for CS
DOW SO3.2	Number of field demonstrations carried out for micro- and nano-plastics detection	3	17	* 1 Sampler for Nanoplastics and Microplastics SuNaMips 3 Microplastic sensor sampler 13 NIR scanner

*) https://data-nautilos-h2020.eu/erddap/info/sunamips_plastic_hcmr/index.html
https://data-nautilos-h2020.eu/erddap/tabledap/microplastic_sensor_niva.html

In addition, a macro-plastic collection campaign was conducted with OTB gear by AdriFOOS platform: https://data-nautilos-h2020.eu/erddap/tabledap/plastic_litter_cnr_irbim.html.

Table 9. Advanced KPIs specifies the details of the SO3

Demo site	Number of demonstrations for sensor		
	Sampler for Nanoplastics and Microplastics (SCT)	Microplastic sensor sampler (NIVA)	NIR scanner device for citizen science
Norway		2	1 NAUTILOS Summer School 10 high schools
Aegean Sea	1		1 NAUTILOS Summer School
Barents Sea		1	
India			1

See Table 5 for specifications.

SO4: Develop and demonstrate improved observing systems in commercial operations, i.e. fishing vessels, aquaculture facilities, ships of opportunity

A new generation of sensors have been specifically developed for use on vessels of opportunity and commercial facilities:

- dissolved oxygen and chlorophyll-a fluorescence sensor;
- sampler for phytoplankton and other suspended matter;
- hyperspectral and laser induced fluorescence sensors;
- ocean acidification sensors;
- microplastic sensors;
- marine mammal passive click recorder.

The SO4 KPIs are:

Table 10. SO4 KPIs

	Description	Target	Achieved	Comments
DOW SO4.1	Number of sensors and samplers developed and demonstrated on vessels of opportunity and commercial facilities	5	10	2a. Dissolved oxygen sensor (NKE) 2b. Chlorophyll-a sensor (NKE) 7. Sampler for phytoplankton and other suspended matter (NIVA) 3a. Downward-looking multi/hyperspectral and laser induced fluorescence sensors and cameras (NIVA) - Multi/hyperspectral camera 3b. Downward-looking multi/hyperspectral and laser induced fluorescence sensors and cameras (NIVA) - LIF-LIDAR 3c. Downward-looking multi/hyperspectral and laser induced fluorescence sensors and cameras (NIVA/HCMR) - IR temperature sensor 4. Passive broadband acoustic recording sensor for noise monitoring (AQUATEC) 8a. Carbonate system/Ocean acidification sensors (NIVA) - pH 8b. Carbonate system/Ocean acidification sensors (NIVA) - pCO2 11a. Microplastic sensor (NIVA) - sampler
DOW SO4.2	Number of field demonstrations carried out with vessels of opportunity and commercial facilities	3	22	* 2 Adriatic Sea 2 Ionian Sea 2 Aegean Sea 2 Bay of Biscay 5 Baltic Sea 6 Norwegian Sea 2 North Sea 1 Barents Sea

*)
https://data-nautilos-h2020.eu/erddap/search/index.html?page=1&itemsPerPage=1000&searchFor=adrifoos+temperature
https://data-nautilos-h2020.eu/erddap/tabledap/dissolved-oxygen_nke_ifremer_test.html
https://data-nautilos-h2020.eu/erddap/tabledap/chlorophyll_nke_ifremer_test.html
https://data-nautilos-h2020.eu/erddap/tabledap/lif_lidar_niva.html
https://data-nautilos-h2020.eu/erddap/tabledap/ir_temperature_sensor_niva_hcmr.html
https://data-nautilos-h2020.eu/erddap/tabledap/passive_acoustic_sensor_aquatec_test.html
https://data-nautilos-h2020.eu/erddap/search/index.html?page=1&itemsPerPage=1000&searchFor=carbonate+NIVA
https://data-nautilos-h2020.eu/erddap/tabledap/pps-reference_niva_test.html

Table 11. Advanced KPIs specifies the details of the SO4

Sensors	Demo Site							
	Adriatic Sea	**Ionian Sea**	**Aegean Sea**	**Bay of Biscay**	**Baltic Sea**	**Norwegian Sea**	**North Sea**	**Barents Sea**
Dissolved oxygen sensor (NKE)	X			X		X		
Chlorophyll-a sensor (NKE)	X			X		X		
Sampler for phytoplankton and other suspended matter (NIVA)						X	X	
Multi/hyperspectral camera (NIVA)							X	
LIF-LIDAR (NIVA)							X	
IR temperature sensor (NIVA/HCMR)		X	X					
Carbonate system/Ocean acidification sensors (NIVA)					X	X		
Microplastic sensors sampler (NIVA)						X	X	X
Passive acoustic sensor (Aquatec)					X			

See Table 5 for specifications.

SO5: Develop and demonstrate improved observing systems that utilise animal-borne instruments

Oxygen sensors on animal tags were deployed across the Atlantic, Pacific, Indian and Southern Oceans. The identified SO5 KPIs are exhaustive, therefore no other KPI for data management and dissemination are proposed.

The SO5 KPIs are reported in Table 12.

Table 12. SO5 KPIs

	Description	Target	Achieved	Comments
DOW SO5.1	Number of sensing devices (oxygen sensors) demonstrated as part of animal-borne instrument campaigns	1	2	14a. Animal-borne instruments (CEiiA/IMAR) 14b. Animal-borne instruments (CNRS/SMRU)
DOW SO5.2	Number of deployments in the oceans at regions of interest on a variety of animals for a richer dataset than currently available	60	45	* 10 Southern Ocean (CNRS/SMRU) 30 Atlantic Ocean (CEiiA/IMAR) 1 Pacific Ocean (CEiiA/IMAR) 4 Indian Ocean (CEiiA/IMAR)
DOW SO5.3	Amount of data retrieved from the animals and to feed into NAUTILOS data and modelling activities, inserted into the MEOP initiative and sharing with the wider community	1TB		The volume of data is not significant because higher compression levels have been introduced and the target of interest is the number of demonstrations (45).

*) https://data-nautilos-h2020.eu/erddap/tabledap/elephant_seals_cnrs.html
https://data-nautilos-h2020.eu/erddap/tabledap/animal_tag_ceiia_data.html
https://data-nautilos-h2020.eu/erddap/tabledap/animal_tag_ceiia_metadata.html

SO6: Quantitatively assess the potential improvements on ocean simulation, ocean forecasting and remote sensing derived from NAUTILOS developments

Oceanographic mathematical models were used to perform Observing System Simulation Experiments (OSSE) to statistically assess the impact of data quality (accuracy, precision, completeness, relevance, and fit to use) in different scenarios and analysed from a cost-benefit perspective.

The identified SO6 KPs are exhaustive, therefore no other KPIs for data management and dissemination are proposed.

The SO6 KPIs are reported in Table 13.

Table 13. SO6 KPIs

	Description	Target	Achieved	Comments
DOW SO6.1	Number of physical and biogeochemical model implementations benefiting from new sensors and observing strategies emerging from NAUTILOS	5	100%	* New data assimilation schemes were put in place or improved for all the models, allowing a better integration of observed data in the models. OSSE experiments have shown that more NAUTILOS-like observations significantly improve the quality of model forecasting. With the use of OSSE, more efficient strategies of ocean observation were delineated, favouring a higher diversity of observed variables and sampling strategies
DOW SO6.2	Number of marine plastic pollution model implementations benefiting from new sensors and observing strategies emerging from NAUTILOS	2	100%	** New data assimilation schemes were put in place or improved for all the models, allowing a better integration of observed data in the models. OSSE experiments have shown that more NAUTILOS-like observations significantly improve the quality of model forecasting. With the use of OSSE, more efficient strategies of ocean observation were delineated, favouring a higher diversity of observed variables and sampling strategies

*)
https://data-nautilos-h2020.eu/erddap/search/index.html?page=1&itemsPerPage=1000&searchFor=hcmr+model+ecomed10
https://data-nautilos-h2020.eu/erddap/search/index.html?page=1&itemsPerPage=1000&searchFor=hcmr+model+hydromed10
https://data-nautilos-h2020.eu/erddap/search/index.html?page=1&itemsPerPage=1000&searchFor=ualg+model+soma
NIVA hydrophysical and biogeochemical models have been completed and will soon be integrated into ERDDAP™.

**)
https://data-nautilos-h2020.eu/erddap/search/index.html?page=1&itemsPerPage=1000&searchFor=hcmr+model+plasticmed10
NIVA particles tracking models have been completed and will soon be integrated into ERDDAP™.

SO7: Appropriately collate, process, and archive all primary environmental data generated during NAUTILOS to ensure that it is maximally Findable, Accessible, Interoperable, and Reusable.

- Amount of data made available and consumed by National Oceanographic Data Centres, EMODnet, SeaDataNet, Copernicus Marine Services, etc.
- Number and type of interoperability interfaces

The SO7 KPIs are reported in Table 14.

Table 14. SO7 KPIs

	Description	Target	Achieved	Comments
DOW SO7.1	Amount of data transferred to external repositories (i.e. data integrators)	80%	100%	The focus is no longer on transferability, but on FAIRness, which makes the data directly available at its source. Where the type of data required a transfer (e.g. marine litter in EMODnet), the transfer was carried out via ingestion according to the stakeholder's instructions. All data produced by the project and integrated into NAUTILOS data infrastructure is 100% available.
DOW SO7.2	Qualified data vs uncontrolled data (note: some data may be confidential and not-releasable)	50%	100%	Test data and operational data have been defined and distinguished. All operational data considered valid for the scientific community have undergone quality control; therefore, all operational project data are validated and made 100% available (final-validated datasets).
DOW SO7.3	Publicly accessible data vs total produced data (note: some data might be available after an embargo period to allow scientific production)	80%	100%	NAUTILOS back end is offering full access to all data. NAUTILOS data portal allows access to all operational final-validated data collected with NAUTILOS sensors (data collected with additional instrumentations is excluded).

SO7 is very pertinent with the specific goal of task 9.6, the advanced KPI for SO7 are indeed the ones identified in DOW.

SO8: Promote and enable the widespread adoption of the NAUTILOS developments to the widest possible range of users and stakeholders (UN legislators to citizen scientists)

NAUTILOS enabled the widespread adoption of the instrumentation developed within the project by a wide range of typical and non-typical data users thus achieving sustainable and scalable results and the long-term sustainability of the system:

- low-cost *in situ* observation technologies for citizens science;
- online tools for data and opinion collection;
- policy round table and presentations;
- project-specific capacity building initiatives for young researchers;
- citizen science initiatives.

The overall citizen science demonstrations (campaigns) were 95.

The SO8 KPIs are reported in Tables 15 and 16.

Table 15. SO8 KPIs

	Description	Target	Achieved	Comments
DOW SO8.1	Number of citizen science campaigns carried out	5	93	42 in Greece 16 in Norway 34 in Italy 1 India
DOW SO8.2	Number of capacity building activities carried out	2	2	NAUTILOS Summer Schools in Oslo and Crete
DOW SO8.3	Policy-related initiatives carried out	4	6	*

*) 1) European Martime Day (EMD) 2022, 19-20/05/2022 Ravenna (Italy); 2) NAUTILOS Policy Brief at the Ocean Data Week - The Ocean Race Village, 27/07/2023 Genova (Italy); 3) Policy Round Table at The Ocean Race Grand Finale, 27/07/2023 Genova (Italy); 4) Horizon Result Booster Common Policy, Session: Nourishing Blue Economy and Sharing Ocean Knowledge, October 2021 online; 5) NAUTILOS Satellite Event - Beyond Climate Change: Sustained Observation... (UN Ocean Decade), April 2024 Barcelona (Spain); 6) NAUTILOS Final Conference - Advancing the Democratisation of Ocean Science, June 2025 Faial, Azores (Portugal).

Complementary KPI is the number of low-cost[1] in situ observation technologies for citizen science. CS observations are organized in specific datasets that are accessible at:

- https://data-nautilos-h2020.eu/erddap/search/index.html?searchFor=Citizen
- https://data-nautilos-h2020.eu/erddap/tabledap/passive_acoustic_sensor_aquatec_test.htmlTable?&Sample_ID=%22DEMOCreteSummerSchool%22

[1] Low-cost technology to enable citizen science is a technology with an affordable cost, i.e. tens of Euros.

Table 16. Advanced KPIs specifies the details of the SO8

CS campaigns	Demo Site			
	Greece	Norway	Italy	India
Algal bloom	15	6	17	
Beach cleaning campaigns - plastic collection (HCMR-IMBBC)	24			
Collection of plastic litter by AdriFOOS platform (CNR IRBIM)			4	
Divers activity with NKE Chl and DO sensors (CNR IRBIM)			1	
Passive acoustic sensor (AQUATEC)	3			
NIR scanner (NIVA)		10		1
MLTs (plastics dispersion) (CNR-ISMAR)			9	
Plastic litter identification in drone photos			3	

During the Citizen Science campaigns, other technologies were tested as complementary tools, contributing to the dissemination and raising of awareness regarding the potential of instruments available to citizens to support scientific research (e.g., surface temperature measurement devices EnvLogger and Brizo).

SO9: Promote and develop a broad range of collaborations and contributions to international, regional, and national for a concerned with the sustainable management of marine resources and the protection of marine biodiversity with a specific focus on the European Strategy for Plastics in a Circular Economy

NAUTILOS has implemented several measures required by The European Strategy for Plastics in a Circular Economy (ESPCE):

- monitoring and mapping of marine plastics, harmonised protocols and validated methods to implement measures under the MSFD;
- engagement with working ESPCE working groups.

The identified SO9 KPI are exhaustive, therefore no other KPI for data management and dissemination are proposed.

The SO9 KPIs are reported in Table 17.

Table 17: SO9 KPIs

	Description	Target	Achieved
DOW SO9.1	Number of collaborations targeted within the timeframe of the project	>30	75
DOW SO9.2	Number of collaborations in relation to ESPCE targeted within the timeframe of the project	>20	* 52

*) The detailed list of the ESPCE synergies is reported in Deliverables 12.1 and 10.7

3. Expected Impacts (EI) KPIs

This section presents the progress towards the expected impact (EI) KPIs. Table 18 shows the evolution of the TRL of the sensors developed by NAUTILOS. Table 19 illustrates the use of NAUTILOS technologies in legislation related documents.

Table 18. Sensors and TRL

Marine Technologies Demonstrated in NAUTILOS	Starting TRL	Maximum Operating Depth (m)	(Aimed) Ending TRL	Final TRL	IMP
Sensing and Sampling Technologies					
1. Fluorometric Sensors/dissolved oxygen (ref. ST3.1.1)	3	250 m	7	7	2.1
2a. Dissolved Oxygen Sensors (ref. ST3.1.2)	5	600 m	8	9	2.1
2b. Fluorescence Sensors (ref. ST3.1.2)	5	600 m	8	7	2.1
3. Downward-looking multi/hyperspectral and laser induced fluorescence sensors and cameras - LIF-LIDAR, Multi/hyperspectral camera, IR temperature sensor (ref. T3.2)	4	subaerial	7	7	2.1
4. Passive broadband acoustic recording sensor for noise monitoring (ref. ST3.3.1)	4	1000 m	7	7	2.1
5. Passive acoustic event recorder (porpoise & dolphin clicks for abundance estimation) (ref. ST3.3.2)	5	300 m	7	7	2.1
6. Active Acoustic Profiling Sensor (ref. T3.4)	5	1000 m	7	6	2.1
7. Sampler for phytoplankton and other suspended matter (ref. T3.6)	3	5500 m	8	8	2.2
8a. Carbonate system/ocean acidification sensors - pH (ref. T4.1)	5	<100 m	9	Memosens sensor 7/8; Honeywell sensor 5	2.1
8b. Carbonate system/ocean acidification sensors - pCO2 (ref. T4.1)	5	<100 m	9	9	2.1
9. Silicate Electrochemical Sensor (ref. T4.2)	5	2000 m	8	8	2.1
10. Sampler for Nanoplastics and Microplastics (ref. T4.3)	7	600 m	7	7	2.2
11a. Microplastic sampler component of MP Sensor (ref. T4.4)	3	0 m	7	7	2.2
11b. Microplastic detector component of MP Sensor (ref. T4.4)	3	0 m	6	4	
11c. Microplastic sampler&detector components of MP Sensor (ref. T4.4)	3	0 m	6	3	
12. Deep Ocean CTD (ref. T4.5)	4	2000 m	7	6	2.1
13. Deep Ocean low-level radioactivity sensor (ref. T4.6)	4	5000 m	7	7	2.1
14a. Animal Borne Instruments (CEiiA/IMAR)	5	2000 m	8-9	8	n.a.
14b. Animal Borne Instruments (CNRS/SMRU)	5	2000 m	8-9	8	n.a.

Marine Technologies Demonstrated in NAUTILOS	Starting TRL	Maximum Operating Depth (m)	(Aimed) Ending TRL	Final TRL	IMP
Data management and sharing					
*Data Products: Services and tools for data transfer towards external DACs **	4	N/A	8	8	2.3
Modelling Products	7	N/A	9	9	2.3

*) The data transfer to external DACs has been completed, with a focus on finalising the transfer chains for the most ready datasets. In particular, temperature, chlorophyll and dissolved oxygen data from AdriFOOS are directly federated into EMODnet Physics. For marine litter data, a preparation process has been developed to allow submission through EMODnet Ingestion, after which the data will be made available via EMODnet Chemistry.

The project also led to the development and initial implementation of new tools and services that did not previously exist, bringing them to a maturity level of 4 out of 5, such as:

- Citizen Science application for data collection;
- tools for monitoring algal blooms;
- NIR scanner;
- event detection system and ferrybox stream data analysis.

Table 19. Sensors and legislations

	NAUTILOS Marine Technologies	Task	Variables targeted	Target disciplinary groups	MSFD Descriptor	Delivered/ adopted	Proof (NAUTILOS deliverable and other documents)
1	Dissolved Oxygen Sensors	(ref. Sub-Task 3.1.1 & Sub-Task 3.1.2)	Dissolved oxygen	Marine biogeochemistry	D3 - Population of commercial fish/shell	Chemistry	https://doi.org/10.1371/journal.pone.0270703
				Regulatory environmental monitoring	D4 - Elements of Marine food webs	Physics	
					D5 - Eutrophication		D7.2
2	Fluorescence Sensor	(ref. Sub-Task 3.1.2)	Chlorophyll-a fluorescence	Marine biology/ecology	D5 - Eutrophication	Chemistry	
				Regulatory environmental monitoring		Physics	
3	Ocean surface multi/hyperspectral and laser induced chlorophyll-a fluorescence sensors and cameras	(ref. Task 3.2)	Sea surface temperature, Laser induced chlorophyll-a fluorescence, Ocean color	Marine biology/ecology	D4 - Elements of Marine food webs	Physics	D7.3, D6.1, D3.3, D6.5, D5.4, D9.4
				Regulatory environmental monitoring Ocean colour community	D5 - Eutrophication	Chemistry	D6.1, D9.4, D6.5
4	Passive broadband acoustic recording sensor	(ref. Sub-Task 3.3.1)	Marine noise (anthropogenic and natural sources, including marine mammals, sea ice cracking, seismic activity, meteorological sources)	Marine biology/ecology	D11 - Energy and Water noise	Physics	
				Regulatory environmental monitoring	D1 - Biological diversity	Biology	
5	Passive acoustic event recorder	(ref. Sub-Task 3.3.2)	Marine mammal sound detection (porpoise & dolphin clicks for abundance estimation)	Marine biology/ecology	D1 - Biological diversity	Biology	
				Regulatory environmental monitoring			
6	Active Acoustic Profiling Sensor	(ref. Task 3.4)	Suspended particle concentration / distribution (zooplankton, microplastics, organic and inorganic sediment)	Marine biology/ecology Marine pollution	D10 - Marine litter	Chemistry	
					D1 - Biological diversity	Physics	
						Biology	
7	Sampler for phytoplankton and other suspended matter	(ref. Task 3.5)	Concentrated suspended matter samplers for analyses of phyto-pigments, particulate organic matter, microbe biomass and diversity	Marine biology	D1 - Biological diversity	Biology	
				Marine ecological monitoring Climate research	D5 - Eutrophication	Chemistry	
				Marine pollution		Physics	

	NAUTILOS Marine Technologies	Task	Variables targeted	Target disciplinary groups	MSFD Descriptor	Delivered/ adopted	Proof (NAUTILOS deliverable and other documents)
8	Carbonate system/ocean acidification sensors	(ref. Task 4.1)	pH, pCO2,Total Alkalinity	Marine biogeochemistry Climate research	D1 - Biological diversity	Chemistry	D4.1,D6.2,D7.2
9	Silicate Electrochemical Sensor	(ref. Task 4.2)	Silicate concentration (Si)	Marine biogeochemistry	D5 - Eutrophication	Chemistry	
10	Submersible Nano- and Microplastics Sampler	(ref. Task 4.3)	Concentrated suspended matter samples	Marine ecology Marine pollution	D10 - Marine litter	Physics	
11	Low-cost Microplastic sensors	(ref. Task 4.4)	Concentration and characterisation of microplastics	Marine ecology Marine pollution	D10 - Marine litter	Chemistry	
12	Deep Ocean CTD	(ref. Task 4.5)	Conductivity, Temperature, Pressure (Salinity and Density derived)	Physical oceanography	D7 - Alteration of hydrographical	Physics	
13	Deep ocean low-level radioactivity sensor	(ref. Task 4.6)	Radon gas, potassium 40K, radium 226Ra and 228Ra, and other natural isotopes	Environmental monitoring	D9 - Contaminants in fish and seafood	-	
14	Integration of existing technologies in animal tagging systems	(ref. Task 5.5)	Temperature, Salinity, Chlorophyll-a fluorescence, Dissolved oxygen	Physical oceanography Marine biology/ecology	D7 - Alteration of hydrographical	Physics	
15	Demonstration of novel equipment for key seabed habitat mapping	(ref. Tasks 6.2, 6.3.1)	Live corals, hard corals, seafloor sponges	Marine biology	D6 - Seafloor integrity	Seabed habitats	D6.3, https://doi.org/10.3390/jmse13030611
16	Smartphone NIR Scanner	(citizen science application, ref. Tasks 8.4, 12.2)	Plastics	Marine pollution	D10 - Marine litter	Chemistry	D12.3
17	Visual marine image annotation	(citizen science application, ref. Task 10.4)	Macroplastics, Sponge and cold-water coral cover, major seafloor organism types.	Marine pollution Marine biology/ecology	D1 - Biological diversity D10 - Marine litter	Biology Chemistry	D10.9

4. Comments

NAUTILOS worked on substantial progress in developing innovative instrumentation and tools capable of functioning in diverse marine environments.

NAUTILOS has assigned DOIs to all public deliverables and related datasets, ensuring traceability and accessibility and its backend hosts 79 datasets, showcasing progress in data acquisition.

This final report provides evidence in data accessibility, technological advancements, and its integration into legislative frameworks of NAUTILOS.

In conclusion, the KPIs initially set for the project have been largely achieved and, in most cases, exceeded. Notably, outcomes have surpassed expectations both in terms of sensor development and in the number and quality of collaborations established. The most significant result concerns the number of demonstrations carried out, which far exceeds the original plan. These achievements highlight the strong impact of the project and lay a solid foundation for further developments and future applications.

5. Appendix 1: References and Related Documents

ID	Reference or Related Document	Source or Link/Location
1	NAUTILOS D9.5	*https://zenodo.org/records/7889278*
2	NAUTILOS D9.6	*https://zenodo.org/records/10694778*

Table 20. NAUTILOS related doc as extracted from Publish&Perish (at least 1 citation)

Authors	Title	Year	Source	Publisher	ArticleURL
S Merlino, M Paterni, M Locritani, U Andriolo…	Citizen science for marine litter detection and classification on unmanned aerial vehicle images	2021	Water	mdpi.com	https://www.mdpi.com/2073-4441/13/23/3349
A Cózar, M Arias, G Suaria, J Viejo, S Aliani…	Proof of concept for a new sensor to monitor marine litter from space	2024	nature …	nature.com	https://www.nature.com/articles/s41467-024-48674-7
G Suaria, M Berta, A Griffa, A Molcard…	Dynamics of transport, accumulation, and export of plastics at oceanic fronts	2021	… Oceanography of Frontal …	Springer	https://link.springer.com/content/pdf/10.1007/698_2021_814?pdf=chapter%20toc
M Reggiannini, D Moroni	The use of saliency in underwater computer vision: A review	2020	Remote Sensing	mdpi.com	https://www.mdpi.com/2072-4292/13/1/22
E Rosas, F Martins, J Janeiro	Marine litter on the coast of the algarve: Main sources and distribution using a modeling approach	2021	Journal of Marine Science and …	mdpi.com	https://www.mdpi.com/2077-1312/9/4/412
S Merlino, M Locritani, A Guarnieri, D Delrosso…	Marine litter tracking system: a case study with open-source technology and a citizen science-based approach	2023	Sensors	mdpi.com	https://www.mdpi.com/1424-8220/23/2/935
EA Weideman, V Perold, V Donnarumma…	Proximity to coast and major rivers influence the density of floating microplastics and other litter in east African coastal waters	2023	Marine Pollution …	Elsevier	https://www.sciencedirect.com/science/article/pii/S0025326X23000759
C Van Vranken, J Jakoboski, JW Carroll…	Towards a global Fishing Vessel Ocean Observing Network (FVON): state of the art and future directions	2023	Frontiers in Marine …	frontiersin.org	https://www.frontiersin.org/articles/10.3389/fmars.2023.1176814/full
G Pieri, M Ntoumas, M Martinelli…	New technology improves our understanding of changes in the marine environment	2021	9th EuroGOOS …	hal.science	https://hal.science/hal-03329200/
BM Saraiva, BCL Macena…	First insights into the shortfin mako shark (Isurus oxyrinchus) fine-scale swimming behaviour	2023	Royal Society …	royalsocietypublishing.org	https://royalsocietypublishing.org/doi/abs/10.1098/rsos.230012
E Rosas, F Martins, M Tosic, J Janeiro…	Pathways and hot spots of floating and submerged microplastics in Atlantic Iberian marine waters: a modelling approach	2022	Journal of Marine …	mdpi.com	https://www.mdpi.com/2077-1312/10/11/1640
J Fontes, B Macena, S Solleliet-Ferreira, F Buyle…	The advantages and challenges of non-invasive towed PILOT tags for free-ranging deep-diving megafauna	2022	Animal …	Springer	https://link.springer.com/article/10.1186/s40317-022-00310-1

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AE Oudijk, O Hasler, H Øveraas, S Marty…	Campaign for hyperspectral data validation in north atlantic coastal waters	2022	2022 12th Workshop …	ieeexplore.ieee.org	https://ieeexplore.ieee.org/abstract/document/9955134/
GFA Brunetti, M Maiolo, C Fallico…	Unraveling the complexities of a highly heterogeneous aquifer under convergent radial flow conditions	2024	Engineering with …	Springer	https://link.springer.com/article/10.1007/s00366-024-01968-2
M Reggiannini, J Janeiro, F Martins, O Papini…	Mesoscale Patterns Identification through SST Image Processing.	2021	ROBOVIS	openportal.isti.cnr.it	https://openportal.isti.cnr.it/data/2021/458165/2021_458165.published.pdf
FC Mihai, LAT Markley, FR Khan…	Microplastics in freshwater environments	2023	Microplastics in the …	Wiley Online Library	https://onlinelibrary.wiley.com/doi/abs/10.1002/9781119879534.ch10
D Moroni, G Pieri, M Reggiannini…	A mobile crowdsensing app for improved maritime security and awareness	2022	… Workshops and other …	ieeexplore.ieee.org	https://ieeexplore.ieee.org/abstract/document/9767516/
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ML Haarr, L Bach, CP Chambers…	Beach litter sources around Nuuk, Greenland: An analysis by UArctic summer school graduate course students	2023	Marine Pollution …	Elsevier	https://www.sciencedirect.com/science/article/pii/S0025326X23003454
O Papini, M Reggiannini, G Pieri	SST image processing for mesoscale patterns identification	2021	Engineering Proceedings	mdpi.com	https://www.mdpi.com/2673-4591/8/1/5
P Penna, F Domenichetti, A Belardinelli…	Dataset of depth and temperature profiles obtained from 2012 to 2020 using commercial fishing vessels of the AdriFOOS fleet in the Adriatic Sea	2023	Earth System …	essd.copernicus.org	https://essd.copernicus.org/articles/15/3513/2023/essd-15-3513-2023.html
M Reggiannini, O Papini, G Pieri	An automated analysis tool for the classification of Sea surface temperature imagery	2022	Pattern Recognition and Image Analysis	Springer	https://link.springer.com/article/10.1134/S1054661822030336
G Pieri	A New Approach to Underwater Technologies for Innovative, Low-cost Ocean Observation: NAUTILOS	2020	ERCIM News		
G Pieri, J Janeiro, F Martins, O Papini, M Reggiannini	MEC: A Mesoscale Events Classifier for oceanographic imagery	2023	Applied Sciences	mdpi.com	https://www.mdpi.com/2076-3417/13/3/1565
M Martinelli, D Medveek, F Domenichetti…	Italy and Croatia: Pomo Pits, Central Adriatic Sea (GSA 17) Adriatic UWTV Surveys and Pomo monitoring activity	2023	ICES SCIENTIFIC …	publications.cnr.it	https://publications.cnr.it/doc/478824

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D Lukats, F Stahl	On reproducible implementations in unsupervised concept drift detection algorithms research	2023	… on Innovative Techniques and Applications of Artificial …	Springer	https://link.springer.com/chapter/10.1007/978-3-031-47994-6_16
F Conti, O Papini, D Moroni, G Pieri…	Analysis of sea surface temperature maps via topological machine learning	2023	2023 IX International …	ieeexplore.ieee.org	https://ieeexplore.ieee.org/abstract/document/10139044/
F Mendonça, F Martins, J Janeiro	SMS-Coastal, a new Python tool to manage MOHID-based coastal operational models	2023	Journal of Marine Science and …	mdpi.com	https://www.mdpi.com/2077-1312/11/8/1606
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V Ortiz, J Tintoré, N Köstner	EuroSea Guide of communication and dissemination activities for enhanced visibility of innovation in ocean observing and forecasting for a sustainable ocean	2023		oceanrep.geomar.de	https://oceanrep.geomar.de/id/eprint/59820
A Novellino, A Arnaud, A Schiller, L Wan	End-user applications for ocean forecasting: present status description	2025	State of the Planet	sp.copernicus.org	https://sp.copernicus.org/articles/5-opsr/25/2025/
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F Misurale, C Scarone, L Pezzolesi…	An integrated in vitro approach for human health and environmental risk assessment of Mediterranean Ostreopsis cf. ovata, Prorocentrum lima, and Coolia monotis …	2022	Applied In Vitro …	liebertpub.com	https://www.liebertpub.com/doi/abs/10.1089/aivt.2022.0008

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