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EfxINNOs Project: Objectives, Activities, Core Achievements and their impact on MSFD implementation



ΔΗΜΟΚΡΙΤΕΙΟ ΠΑΝΕΠΙΣΤΗΜΙΟ ΘΡΑΚΗΣ
DEMOCRITUS UNIVERSITY OF THRACE

Georgios Sylaios
Professor
Democritus University of Thrace

Constanta, 28/10/2026

Setting the Scene



- The catchment Black Sea area exceeds 2 million sq. km
- It covers partially or entirely 23 countries
- Three main River Basins exist: Danube, Dnipro, and the Don – total 350 km^3 annually
- 160 million people live in the Black Sea Basin
- 10 million tourists visit the region annually.

The Black Sea drainage basin

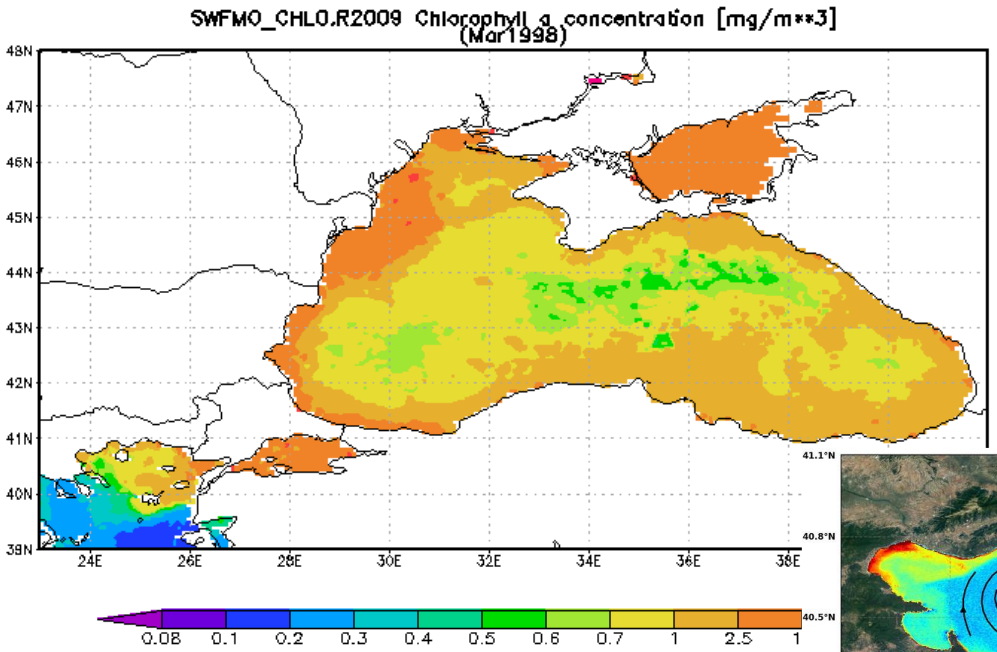
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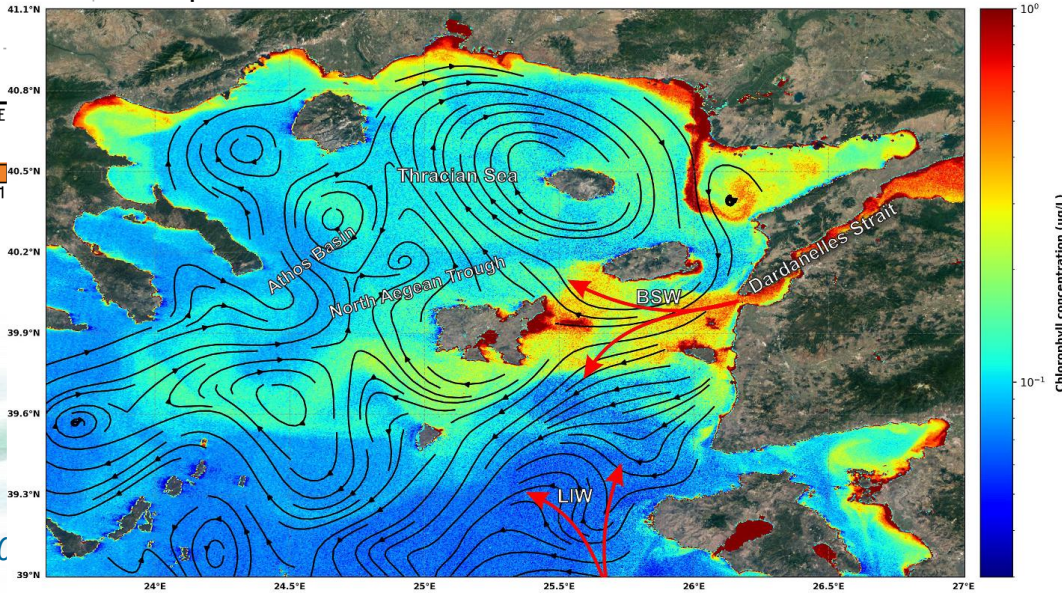
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Understanding the Environment



The Black Sea Water exits from the Bosporus Straits, covers the Maramara Sea and spreads over the North Aegean and the Thracian Sea.



BSBC

In EfxINNOs we focus on seabed ecosystems

Seagrass forms the most vital but highly vulnerable part of the seascape.
Seagrass meadows are the **“lungs” of the coastal ocean**.
They support commercial fisheries and biodiversity, clean the surrounding water, and help **remove the excessive carbon dioxide** from the atmosphere.



The value of sea-bed ecosystems

Seagrass is essential for marine biodiversity and vital for underwater life.

They **absorb the incident wave energy** and protect our coastal zones from erosion, storms and floods.

Through **carbon sequestration**, seagrasses sink and store carbon mitigating CC.

Seagrass meadows are very efficient nitrogen strippers, **removing chemical elements** that cause harmful algal blooms.

They are the oxygen pumps of the ocean:

1 sq.m. of seagrass produces 10 L O_2/day.



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The value of sea-bed ecosystems

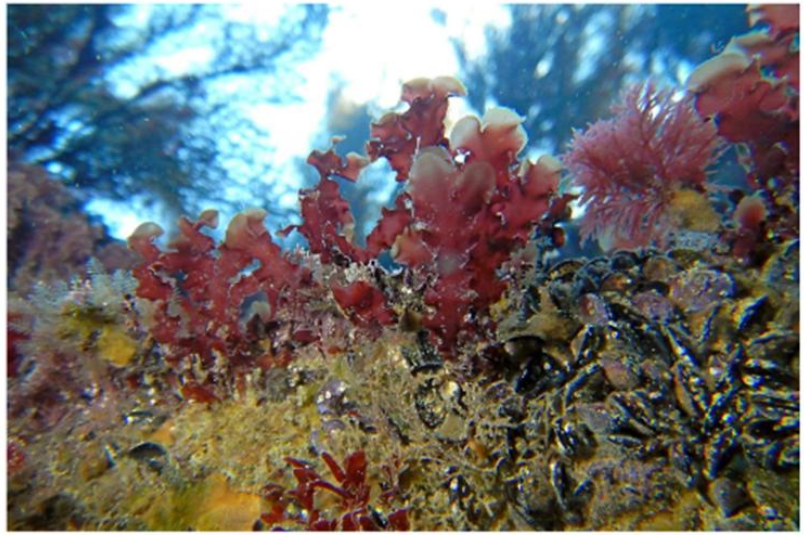
Seagrass meadows provide numerous ecosystem services, including **nursery habitats for commercially important marine species** such as bivalves, crustaceans, fish, and sea turtles, thereby enhancing coastal biodiversity.



Zostera Marina

A high bias exists in the assessment of global seagrass coverage, ranging from 17×10^6 to 60×10^6 ha.

This uncertainty highlights the need for further intensive research to map seagrass distribution worldwide and better understand their spatio-temporal changes in relation to human pressures.



Phyllophora Crispa

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The value of sea-bed ecosystems



Seagrass meadows under threat

Seagrass meadows are among the least protected coastal ecosystems. Almost 30% of global seagrass areas have been lost since the late nineteenth century. An estimated 7% of this vital habitat disappears each year.

The main threats to seagrass include **urban, industrial, and agricultural run-off; coastal development; dredging; unregulated fishing and boating activities; and climate change**.





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Seagrass meadows under threat

Approximately 19.1% of the area of monitored meadows has been lost since monitoring began in the 1900s.

However, in many parts of the world, seagrass coverage is not systematically monitored, so the areas most at risk of decline and the management actions needed there are largely unknown.

This lack of data contradicts other valuable coastal habitats, such as coral reefs, which have extensive long-term monitoring programs, and mangrove forests, which can be observed in satellite imagery.



Ulva ulva



Potamogeton pectinatus L.

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Black Sea Seagrass communities

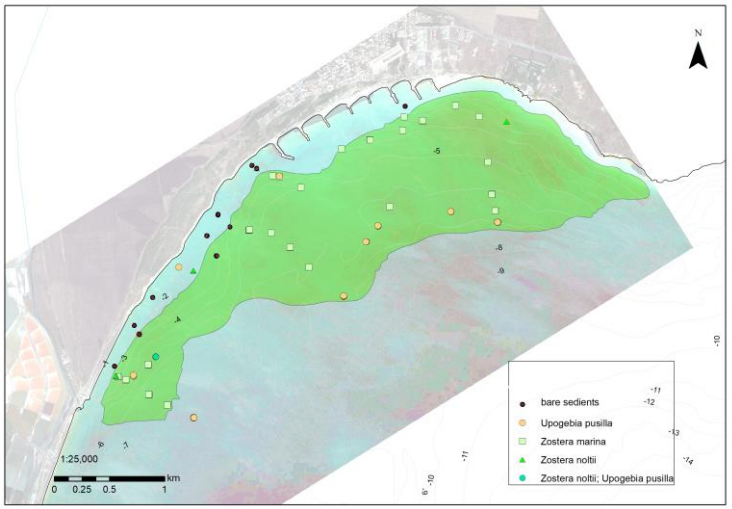
There are six species of seagrasses in the Black Sea: *Zostera marina* (eelgrass), *Z. noltii*, *Potamogeton pectinatus*, *Ruppia maritima*, *R. spiralis* and *Zannichellia major*.

The number of plant species in the Black Sea is **one-fourth** that of the Mediterranean.

Increasing anthropogenic pressure (industry, agriculture, aquaculture and tourism) in BS coastal zones resulted in the decline of seagrasses presence.

Nutrient enrichment and the consequent phytoplankton blooms limit light transparency.

Epiphytes affect seagrasses negatively through shading and hypoxia.



Zostera spp. seagrass meadow in front of Sarafovo, Inner Burgas Bay. Berov D, Klayn S, Deyanova D, Karamfilov V (2022) Current distribution of Zostera seagrass meadows along the Bulgarian Black Sea coast (SW Black Sea, Bulgaria) (2010-2020). Biodiversity Data Journal 10: e78942.

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«Establishing an Innovative Marine Technology Transfer Network for Enhancing the Transition to a Sustainable Blue Economy in the Black Sea Basin»

EfxINNOs Central Scope

To develop and operate a **novel, cost-effective, technologically advanced, sustainable network of monitoring platforms,** improving existing research infrastructures, serving the joint monitoring requirements of EU Policy Instruments and the Black Sea Integrated Monitoring Assessment Program (BSIMAP), linking the Black Sea and the North Aegean Sea.

Specific Objectives

EfxINNOs will advance knowledge on benthic marine ecosystem functioning, as well as on the impact of human stressors from land-based and maritime activities.

The project will fill the gaps in **data collection, data harmonization and policy implementation** among the BSB and the Med.

The project will develop a consistent approach for the protection and restoration of the Black Sea seabed ecosystems in line to MSFD.

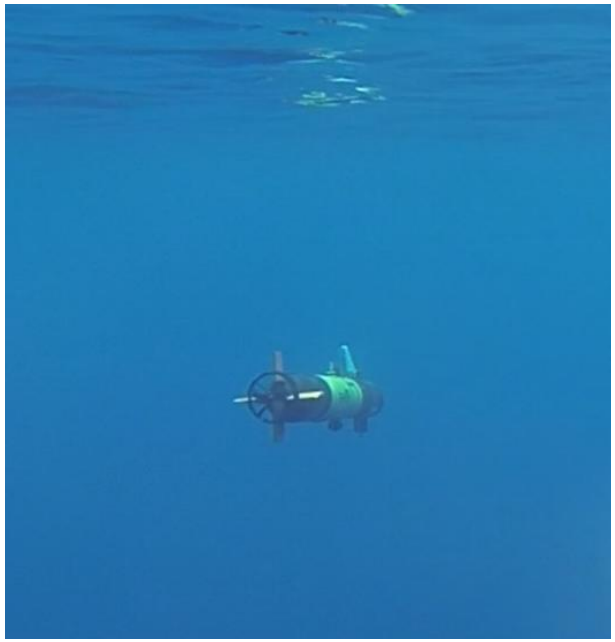
EfxINNOs will produce science-based policy tools to serve the directions set by the Commission on the Protection of the Black Sea Against Pollution.

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EfxINNOs - A Sea of Actions



a) Utilize innovative underwater platforms (like the microAUVs) for the mapping of coastal marine environment at selected regions of the BS and the NAS

b) Produce extensive digital seabed habitats maps, emphasizing on marine protected species, like the *Posidonia oceanica*, *Zostera marina* and *Zostera noltii* meadows

c) Collect new data, images and videos never earlier recorded to report on coastal marine biodiversity of the BS and NAS

d) Collect RT data on physicochemical conditions to serve maritime activities

e) Correlate the prevailing environmental seabed conditions with the present health of seabed habitats

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EfxINNOs - A Sea of Actions

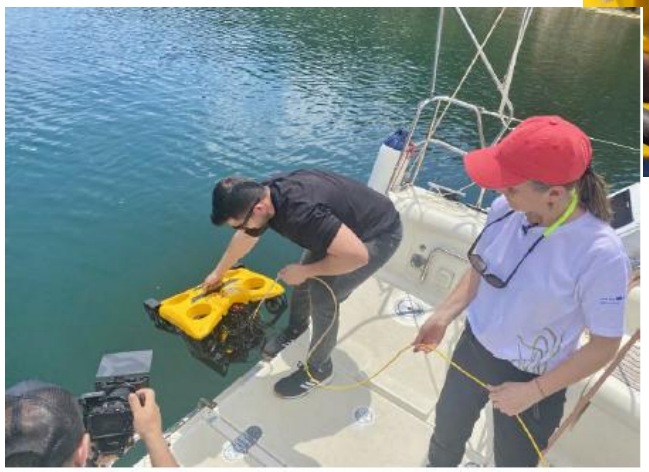
f) Assess the ecological significance and delineate ecologically-sensitive regions and prioritize potential marine protected areas

g) Evaluate the existing threats that seabed habitats and benthic biodiversity face

h) Develop policy tools and directions to protect seabed habitats from man-made impacts

i) Link project outputs to EU Environmental Legislation (e.g., MSFD, MSPD, Biodiversity Strategy) with the objectives of SRIA and BSIMAP





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j) Communicate results and raise awareness to minimize threats (e.g., marine litter at sea bottom, trawling, pollution, human actions like shipping, cables, etc.)

k) Educate people on the significance of coastal marine biodiversity protection

l) Report results and policy recommendations to the Common Maritime Agenda Steering Group of the BSEC





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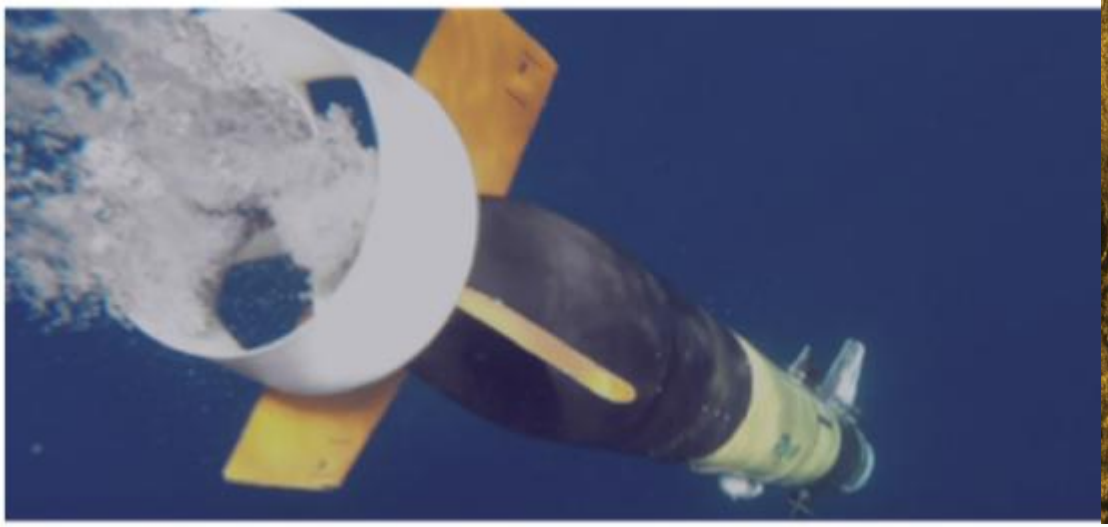
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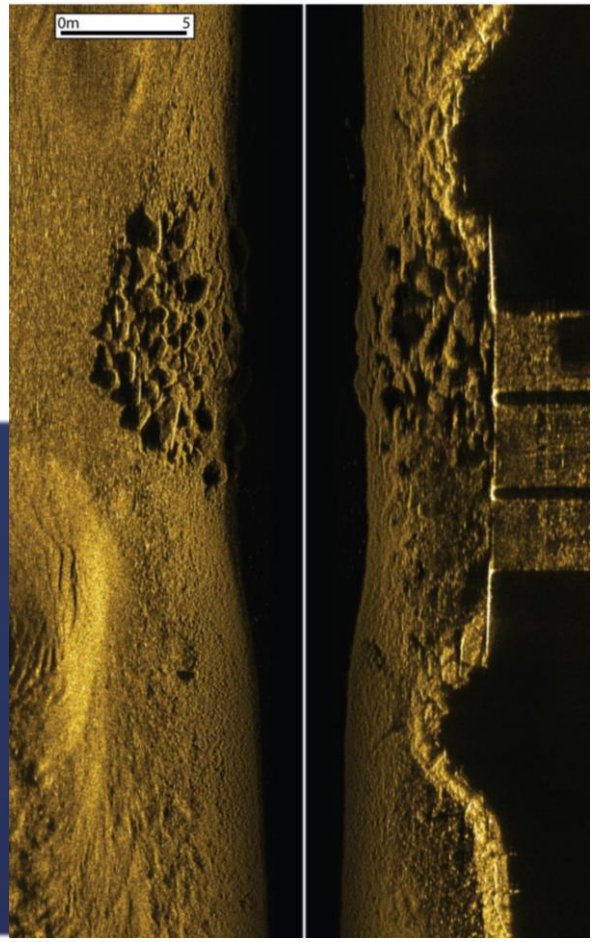
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The microAUV

EfxINNOs has purchased and deployed a fleet of versatile microAUVs for the underwater exploration of seagrass meadows.

Max Operational Depth	300 m
Endurance	<10 hours[1]
Length	<0.9 m[1]
Hull Diameter	124 mm
Weight	<9 kg
Max Speed	8 knots
Positioning	GPS, INS, SPARSE-LBL





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The microAUV

Technology platform and data collection

RTSYS NEMOSENS mAUV equipped with:

- **RBRlegato CTD**: salinity and temperature data
- **GoPro Camera**: RGB videos and images
- **StarFish 454 Side Scan Sonar**: acoustic images



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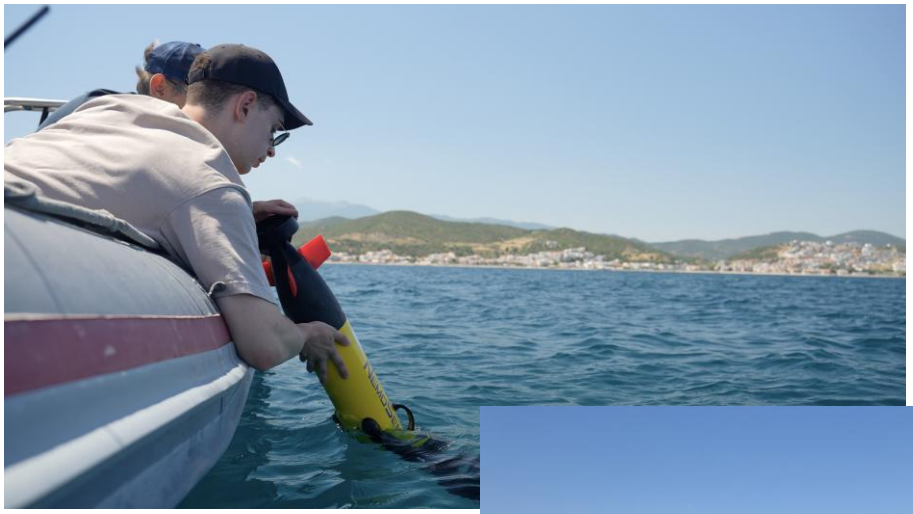
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Instrumentation Training Workshops – mAUV (Greece)









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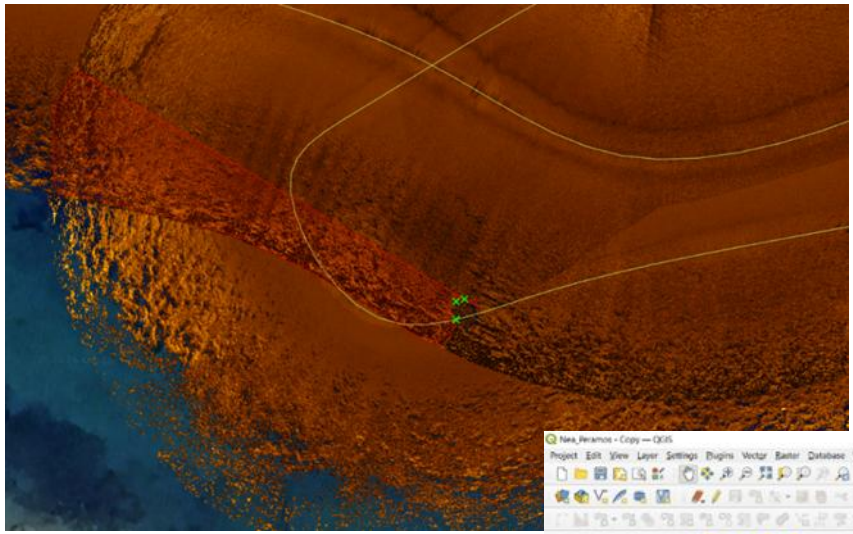
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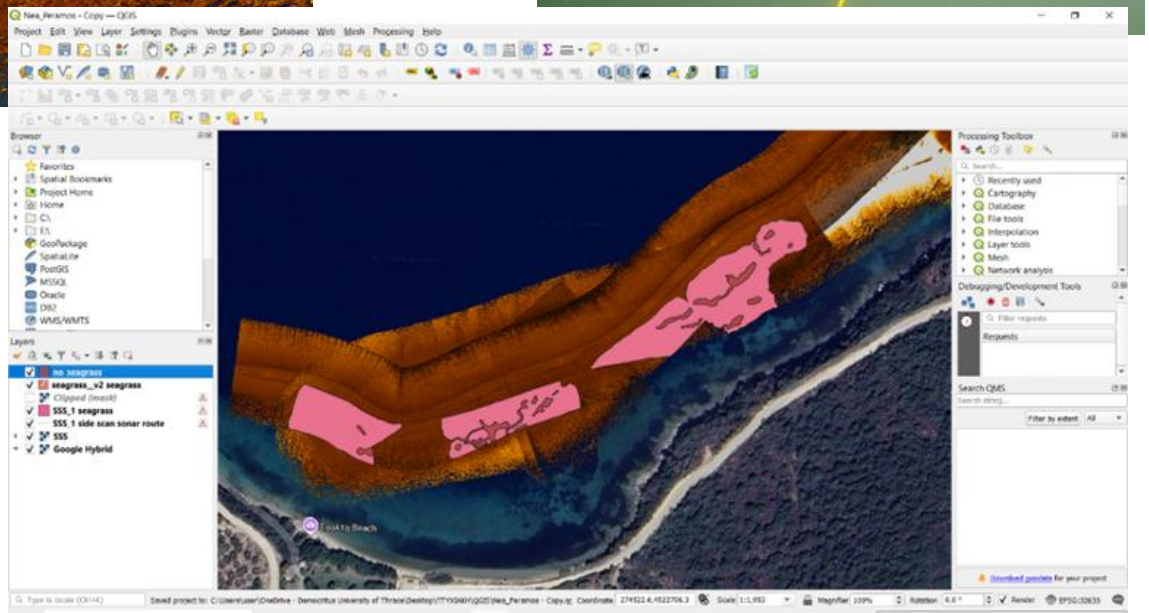
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Initial Sampling Efforts using the mAUV (Greece)







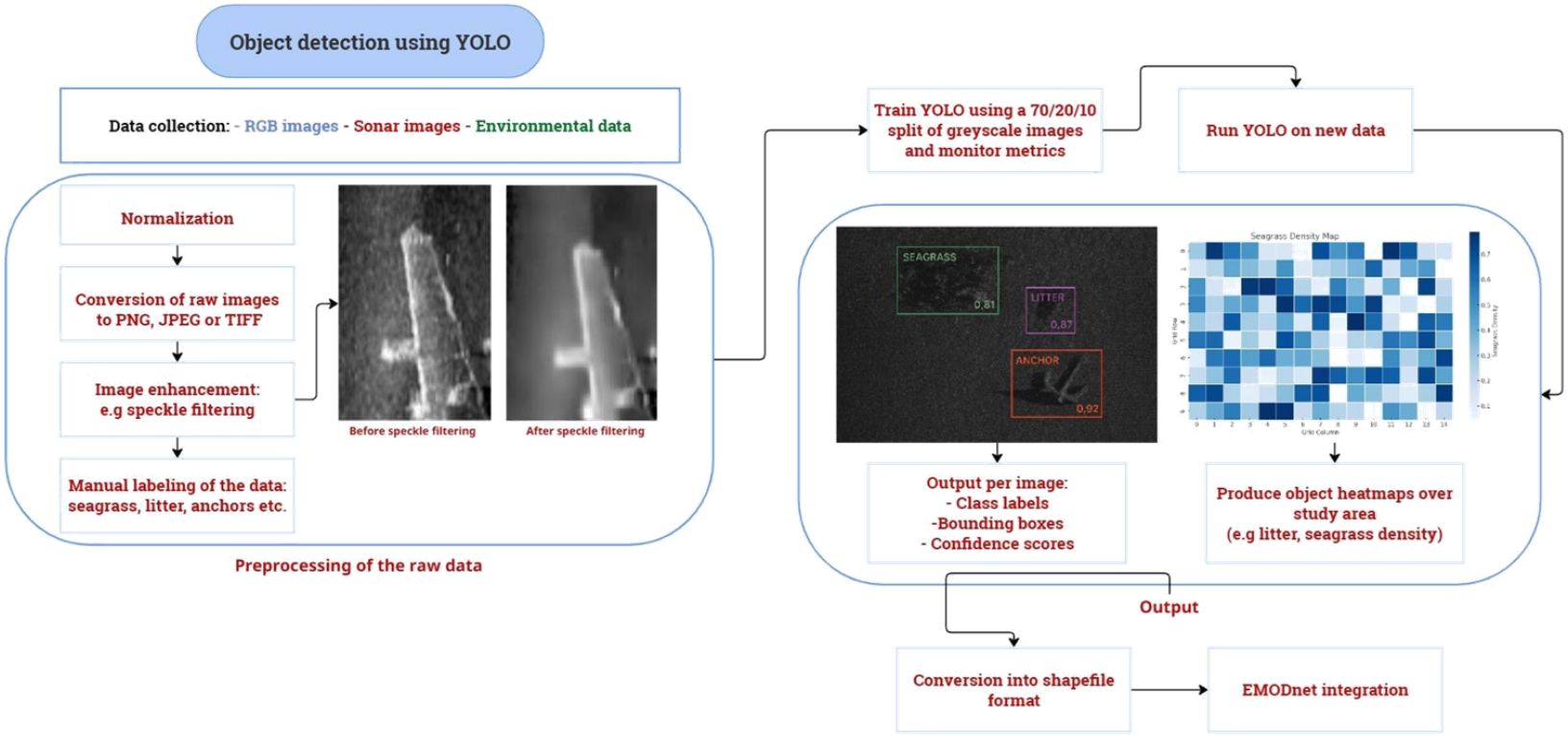
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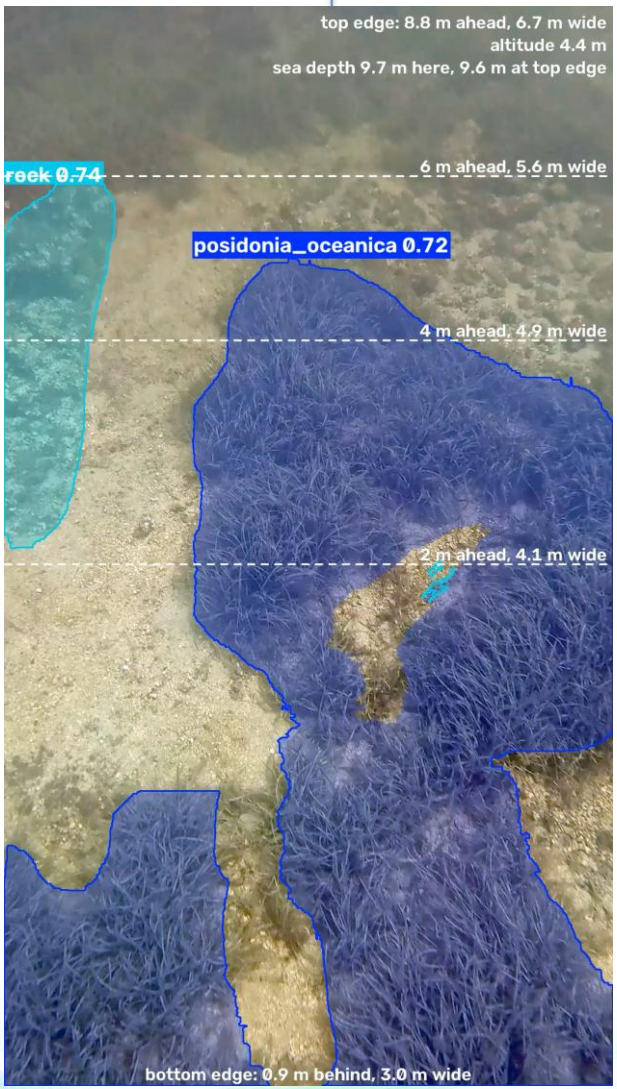
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Object detection workflow



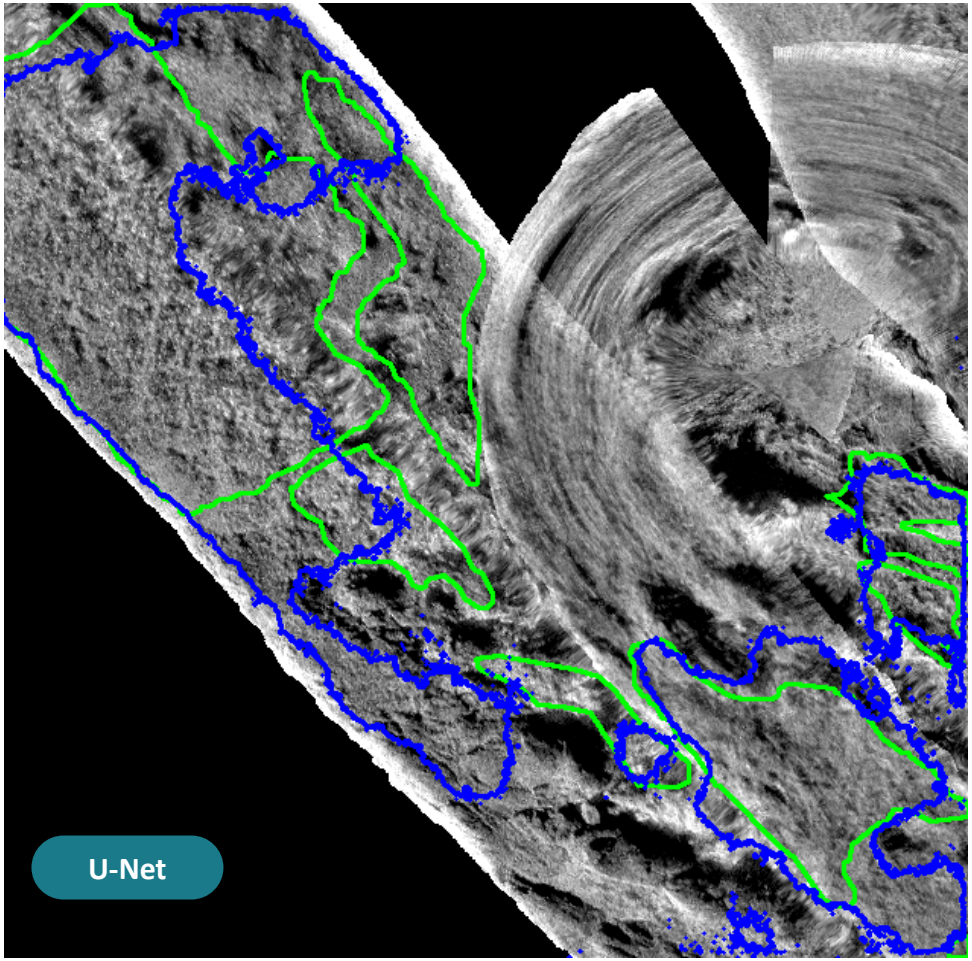

top edge: 8.8 m ahead, 6.7 m wide
altitude 4.4 m
sea depth 9.7 m here, 9.6 m at top edge
reek 0.74
6 m ahead, 5.6 m wide
posidonia_oceanica 0.72
4 m ahead, 4.9 m wide
2 m ahead, 4.1 m wide
bottom edge: 0.9 m behind, 3.0 m wide

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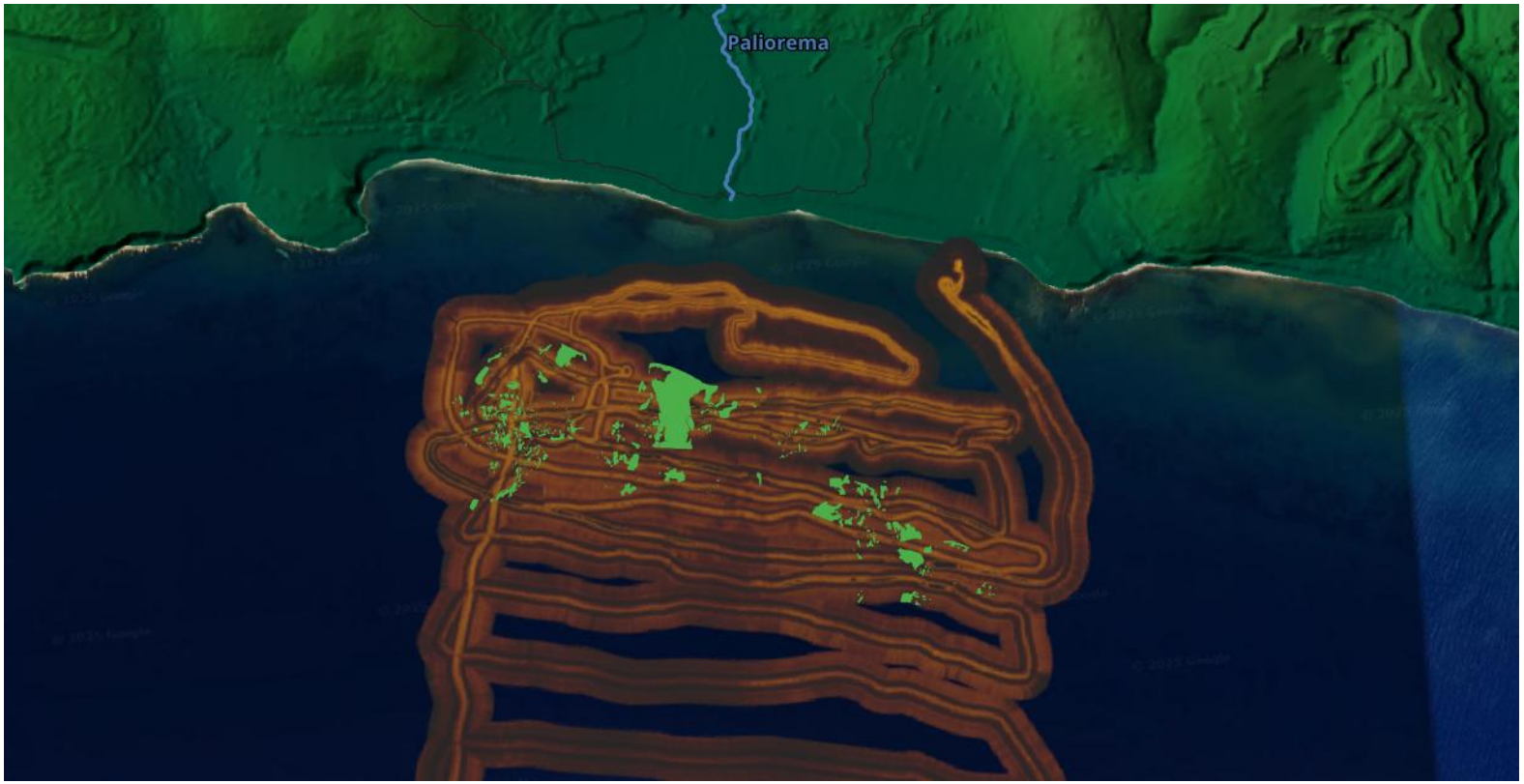
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SONARWIZ

Digitizing features



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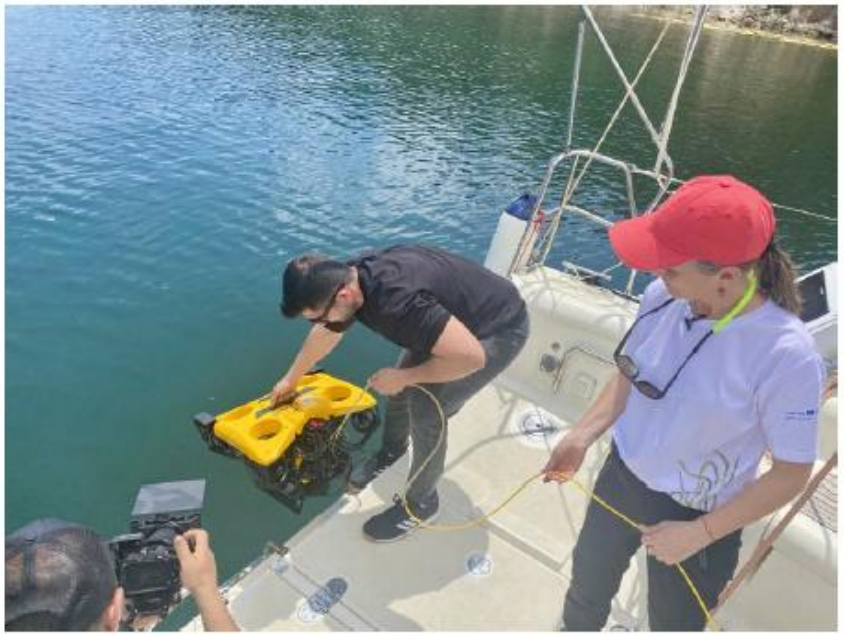
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Seagrass Mapping with ROV (Turkey)





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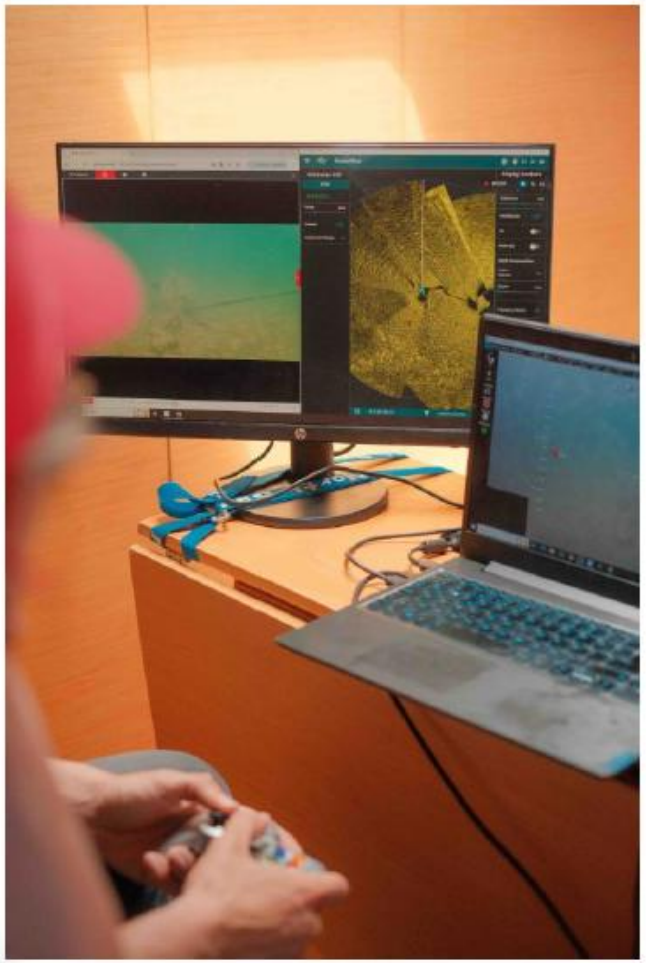
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Seagrass Mapping with ROV (Turkey)





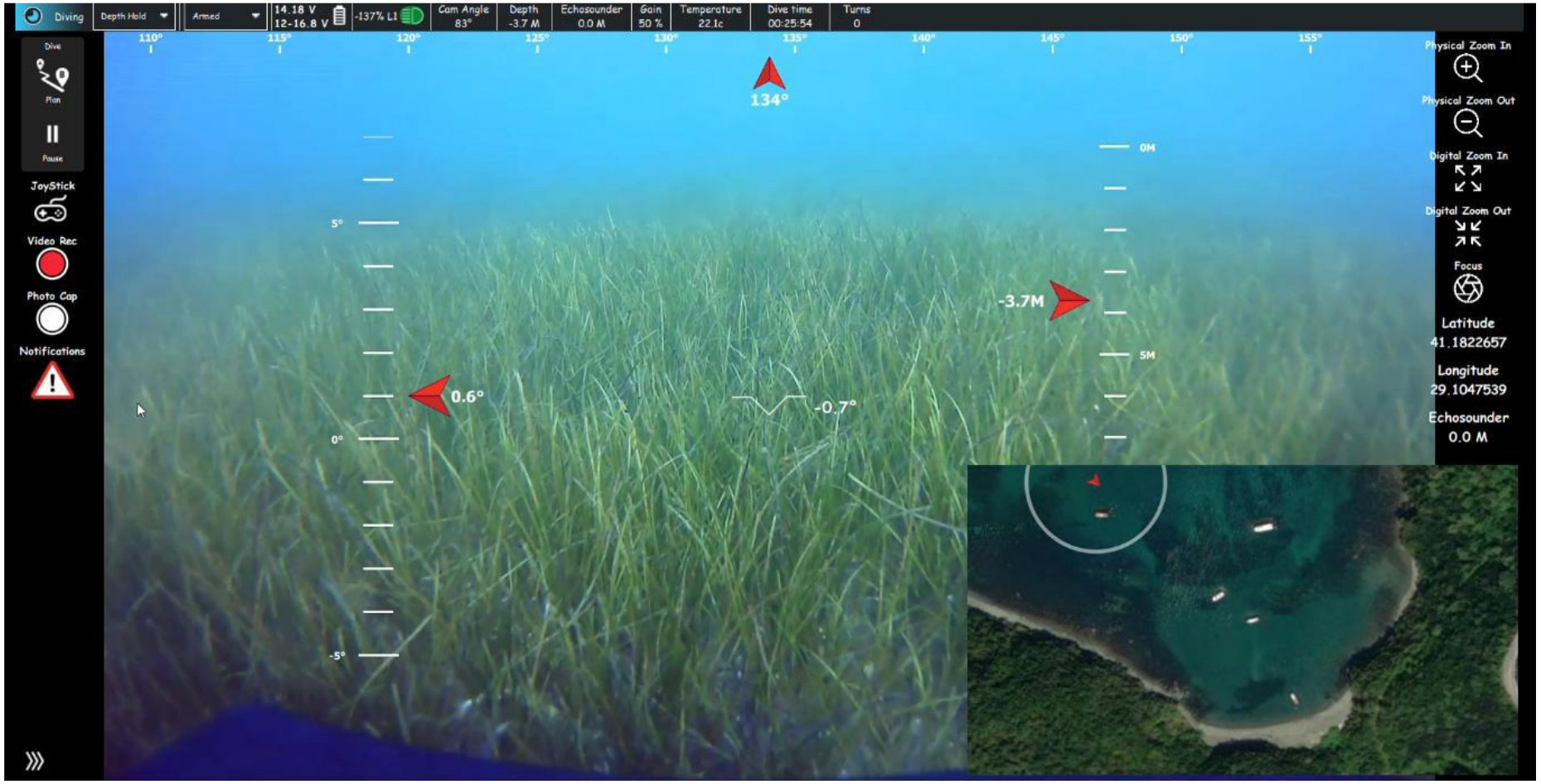
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Seagrass Mapping with ROV (Turkey)



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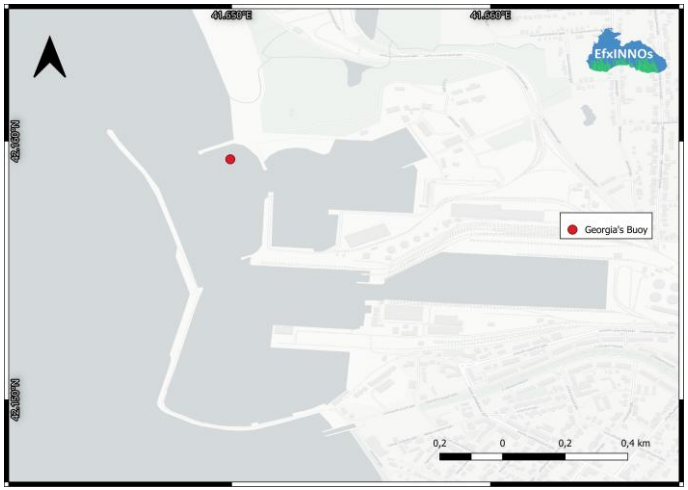
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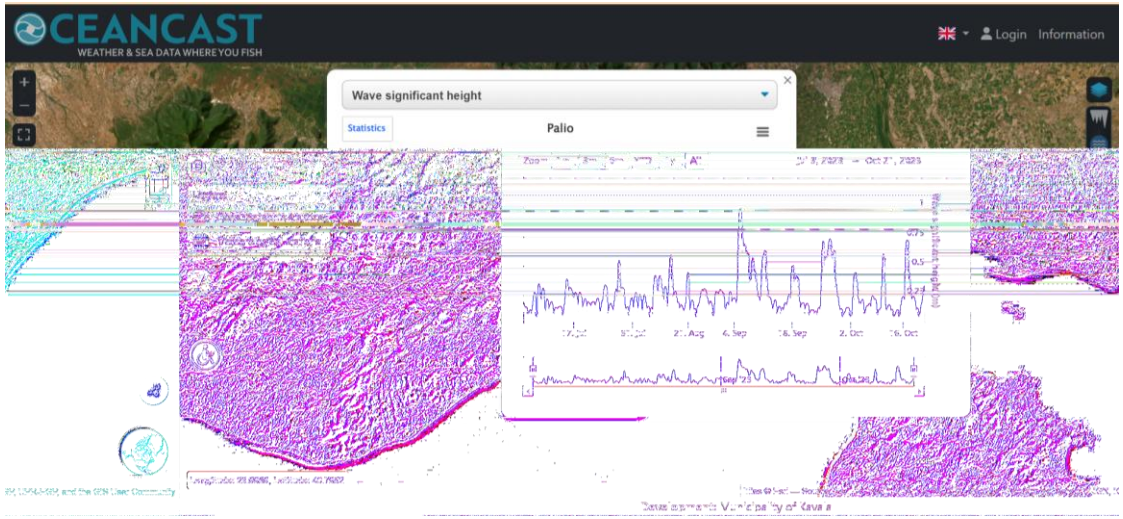
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Buoy Tendering, Delivery, and Deployment in Georgia (ISU)



- RT recording of physicochemical parameters from the water surface
- Water quality measurements of sea surface temperature, electrical conductivity, turbidity, and dissolved oxygen
- Buoy deployment at Poti Port
- Platform to collect, process, and visualize data





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https://envrio.org/oceancast/



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EfxINNOs

The Target Audience

EfxINNOs aims to familiarize the broad BSB public with the conditions prevailing on the seabed, the current status of key benthic habitats and ecosystems, the level of marine litter pollution, and the harm humans exert on these vulnerable ecosystems.

The target audience of EfxINNOs at the first level is the broad public.

At the second level, the target audience is all supranational, national, regional, **and municipal authorities** responsible for the protection of the BSB environment, the establishment of MPAs, and the minimization of human pressures.

Finally, the third-level target audience for EfxINNOs is **marine and maritime users**, namely fishers, aquaculture operators, port authorities, shipping companies, oil and gas operators, touristic agents, etc.

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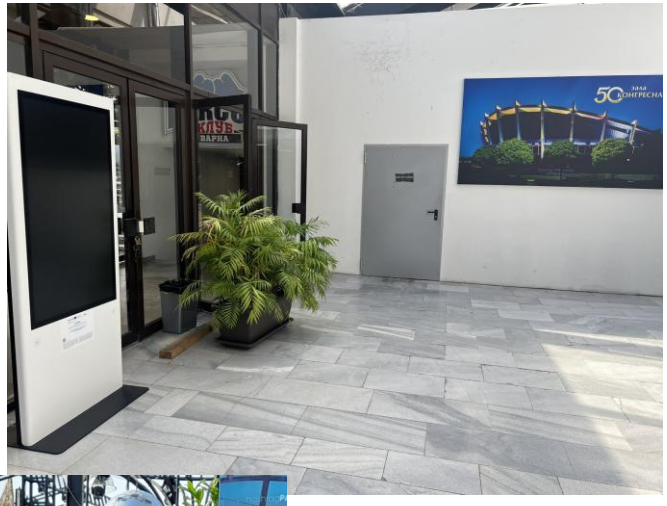
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Kiosks installed and Video production in preparation

The four purchased information kiosks have been installed in three locations in Varna, Burgas, and Nessebar, with visualization stickers adhered to them according to the program rules.









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The Marine Directive

EU's legal instrument for the protection of our seas



Ecosystem-based, adaptive and integrated approach to the management of all human activities which have an impact on the marine environment

Achieve Good Environmental Status (GES)

Good Environmental Status *is "the environmental status of marine waters where these provide ecologically diverse and dynamic oceans and seas which are clean, healthy and productive" (MSFD, art. 3(5)).*

In addition, GES means that:

- The different uses made of the marine resources are conducted at a sustainable level, ensuring their continuity for present and future generations
- Ecosystems are fully functioning and resilient to human-induced environmental change
- The decline of biodiversity caused by human activities is prevented and biodiversity is protected
- Human activities introducing substances and energy into the marine environment do not cause pollution effects

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Supporting EU Policies



Descriptor 1: Biodiversity is maintained



Descriptor 2: Non-indigenous Species do not adversely alter the ecosystem



Descriptor 3: The population of commercial fish species is healthy



Descriptor 4: Elements of food webs ensure long-term abundance and reproduction



Descriptor 5: Eutrophication is minimised



Descriptor 6: The sea floor integrity ensures functioning of the ecosystem



Descriptor 7: Permanent alteration of hydrographical conditions does not adversely affect the ecosystem



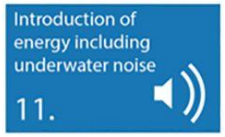
Descriptor 8: Concentrations of contaminants are at levels not giving rise to pollution effects.



Descriptor 9: Concentrations of contaminants are at safe levels.



Descriptor 10: Marine litter does not cause harm



Descriptor 11: Energy including Underwater Noise







Black Sea Integrated Monitoring and Assessment Program

Descriptor 6 – Seabed Integrity

Table 1: Monitoring Programmes contributing to this monitoring strategy

Monitoring Programme	Code	Related 2014 Monitoring Factsheets	GES criteria addressed[10]
Physical Loss – distribution and extent	MICMT-D06-01	Monitoring Sub-Programme 4: Information on relevant anthropogenic activities (MICMT-D010406.1)	D6C1 (Primary): Spatial extent and distribution of physical loss (permanent change) of the natural seabed.
Physical disturbance –bottom-contacting fishing gear	MICMT-D06-02		D6C2 (Primary): Spatial extent and distribution of physical disturbance pressures on the seabed.
Physical disturbance –dredging and disposal of dredged material	MICMT-D06-03		
Physical disturbance – infrastructure and other activities	MICMT-D06-04		

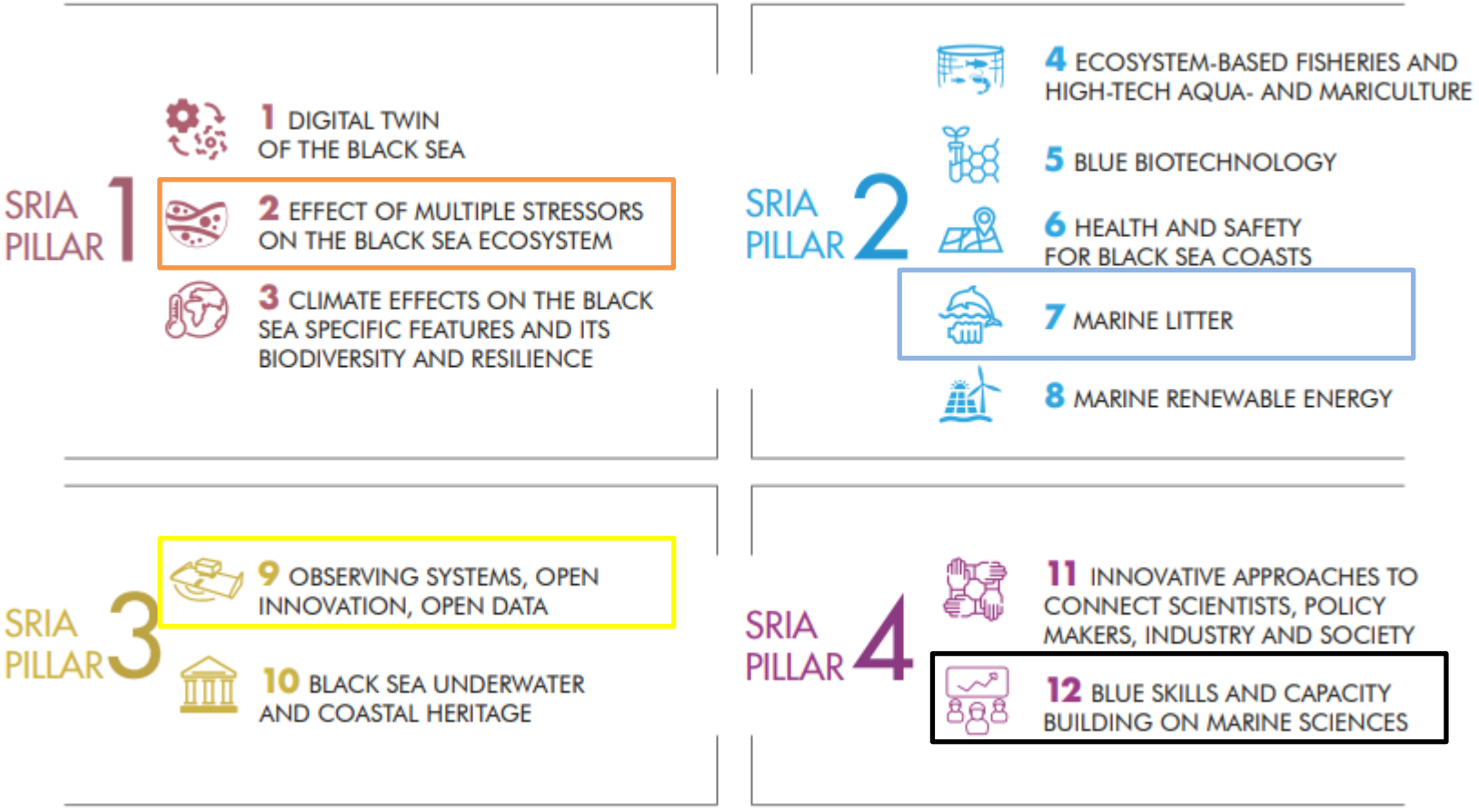
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Supporting SRIA Implementation



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Interconnect EfxINNOs to EU Infrastructures



EfxINNOs databases and ecological indicators

dynamic, and directly connected

Copernicus Marine Service

Copernicus

Implemented by MERCATOR OCEAN INTERNATIONAL

EMODnet

European Marine Observation and Data Network

EDITOInfra

European Digital Twin Ocean

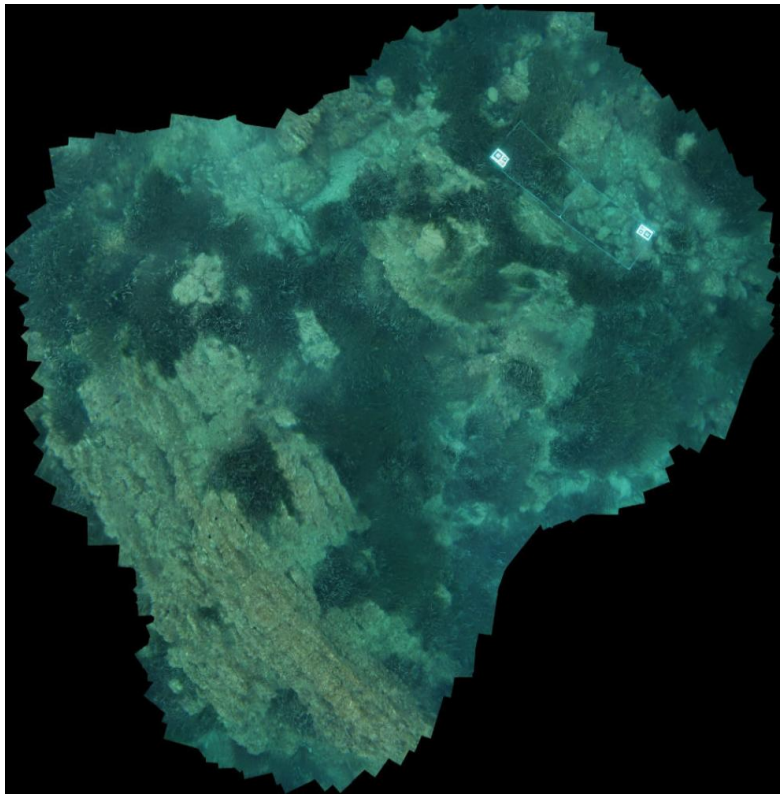


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Budget Overview



Interreg Funds	1,479,283.56 Euros
Other public contribution	164,364.84 Euros
Total project budget	1,643,648.40 Euros

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The EfxINNOs Partnership



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The Consortium

1. Democritus University of Thrace – DUTH (EL, Leader)
2. Union of Bulgarian Black Sea Local Authorities - UBBSLA (BG, P1)
3. National Institute for Marine Research and Development “Grigore Antipa” – NIMRD (RO, P2)
4. Ilya State University – ISU (GE, P3)
5. Istanbul University – IU (TR, P4)
6. Technical University of Varna – TUV (BG, P5)

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INCDM

PUBLICA HELIAE UNIVERSITAS

T.C. İSTANBUL ÜNİVERSİTESİ 1453

ТЕХНИЧЕСКИ УНИВЕРСИТЕТ - ВАРНА
Technical University of Varna

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The EfxINNOs Web Site



About Us

Efxinnos Project

EfxINNOs is a collaborative project aimed at developing a sustainable and advanced marine monitoring network to assess and protect the benthic ecosystems of the Black Sea and North Aegean Sea. Utilizing a combination of mobile and static platforms, including autonomous underwater vehicles (AUVs) and remotely operated vehicles (ROVs), the project will collect and analyze data on marine biodiversity, human impacts, and ecosystem health using machine learning and AI tools. The initiative aligns with EU environmental policies and promotes transnational cooperation to fill gaps in data collection, harmonization, and policy implementation. EfxINNOs will produce science-based recommendations, foster professional development through workshops and training, and raise public awareness about marine pollution, conservation, and the sustainable Blue Economy. The project involves a diverse partnership of research institutions across the Black Sea Basin, aiming to create a lasting network for ecosystem protection and responsible marine resource management.

https://envrio.eu/efxinnos/

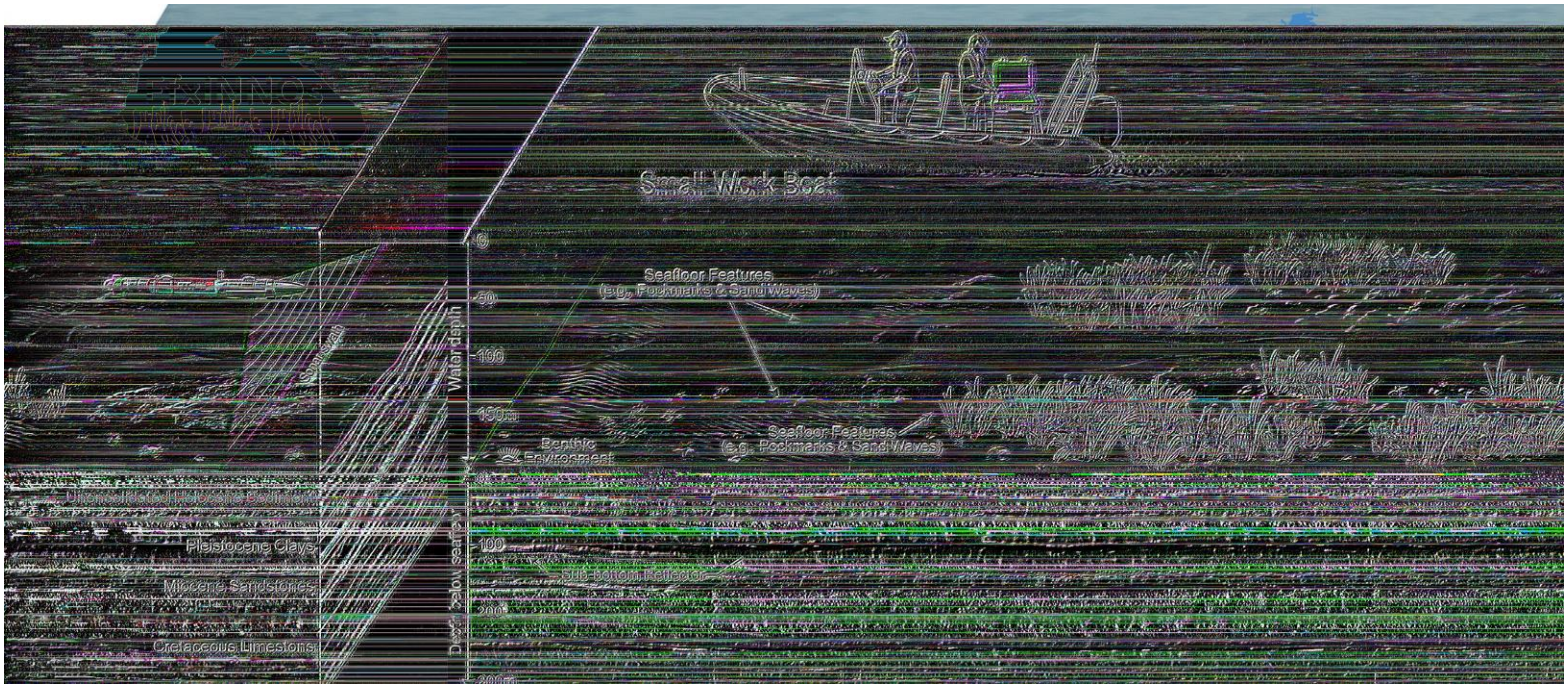
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Thank you!



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BSB00193 EfxINNOs

Outputs&Results

Output 1.1 Marine Environmental Monitoring Netework

Output Title
Marine Environmental Monitoring Netework

Programme Output Indicator
110784: Research organisations participating in joint research projects

Measurement Unit	Target Value
research institutions	5,00

Delivery Period
Period 8, month 29 - 30, 12/29/2026 - 02/27/2027

Output Description
An advanced and cost-effective monitoring network for seabed habitats to assess benthic ecosystems health will be developed, using high-tech platforms and vehicles, like microAUVs, ROV and a surface buoy. The network is comprised from five leading University /research institutes of the BSB area, namely NIMRD, ISU, IU, TUV and DUTH.

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Output 1.2 Joint Public Events

Output Title

Joint Public Events

Programme Output Indicator

1111584: Public events across borders jointly organised

Measurement Unit	Target Value
events	2,00

Delivery Period

Period 8, month 29 - 30, 12/29/2026 - 02/27/2027

Output Description

Two major public events will be organized over the 30 month implementation period. Notably, the Final Conference (1) and 1 International Hackathon at the end of the project.

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Output 1.3 EfxINNOs Project Partnership Joint Events

Output Title
EfxINNOs Project Partnership Joint Events

Programme Output Indicator
118784: Organisations cooperating across borders

Measurement Unit	Target Value
organisations	6,00

Delivery Period
Period 8, month 29 - 30, 12/29/2026 - 02/27/2027

Output Description
progress reports (8) and its final report (1), together with the Project Management Toolkit (1), the Financial Management & Organizational Chart (1), and the Quality Assurance Plan (1) and the Common Action Plans (8), Communication activities.

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NEXT Black Sea Basin

Output 1.4 Harmonised Data collection and processing methods & Common methods for delineating marine natural assets and assessing human impacts

Output Title
assessing human impacts

Programme Output Indicator
11116104: Jointly developed solutions

Measurement Unit
solutions

Target Value
1,00

Delivery Period
Period 6, month 21 - 24, 04/29/2026 - 08/28/2026

Output Description
Harmonized methods for data collection and data analysis on sea bed habitats, harmonized data storage and transfer to all relevant BSB and EU authorities and initiatives, Common methods to delineate seagrass meadows, assess their ecological significance, based on common indices, evaluate the impact of human activities on each

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Output 1.5 microAUV, ROV and surface buoy databases containing raw and processed data

Output Title
microAUV, ROV and surface buoy databases containing raw and processed data

Programme Output Indicator
1184104: Pilot actions developed jointly and implemented in projects

Measurement Unit	Target Value
pilot actions	1,00

Delivery Period
Period 6, month 21 - 24, 04/29/2026 - 08/28/2026

Output Description
Jointly developed, cloud-stored databases with all surveyed raw and processed data collected for the selected BSB pilot sites.

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NEXT Black Sea Basin

Output 1.6 ML and AI tools and algorithms

Output Title
ML and AI tools and algorithms

Programme Output Indicator
11116104: Jointly developed solutions

Measurement Unit
solutions

Target Value
1,00

Delivery Period
Period 5, month 17 - 20, 12/29/2025 - 04/28/2026

Output Description
Jointly developed and applied ML and AI algorithms for side scan sonar, images and videos collected by the microAUV and ROV, image analysis ML algorithms for marine litter object detection, and tools and algorithms for physicochemical short-term forecasting.

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NEXT Black Sea Basin

C.5 Project Results

What do you expect to improve or change following the implementation of the activities and the delivery of the project outputs? Please take a look at the programme result indicators and select those that you will contribute to.

Result 1

Programme result indicator

P11_RCR84: Organisations cooperating across borders after project completion

Measurement unit	Baseline
organisations	0,00

Target value

6,00

Result description

The EfxINNOs partnership will continue cooperating in the field of sustainable management of marine natural assets after the official project completion. This commitment will be reflected in a Cooperation Agreement which will be followed up by an Annual Sustainability Report.

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Result 2

Programme result indicator

P11_RCR104: Solutions taken up or up-scaled by organisations

Measurement unit	Baseline	Target value
solutions	0,00	1,00

Result description

A joint solution related to marine environmental monitoring will be developed by EfxINNOs and will upscaled across the BSB area. It will entail, a) Common databases for raw and processed side-scan sonar data from all study sites, b) Common databases ofgeo-referenced images and videos from all study sites, c) Common data analysis methods on seagrass meadows delineation, health assessment, human impact evaluation and ecosystems prioritization, d) Joint technical recommendations to monitor and protect BSB benthic ecosystems, in the framework of MSFD, MSP and CMA. It will resolve the issue of lack of data and harmonization across the BSB.

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EfxINNOs

EfxINNOs

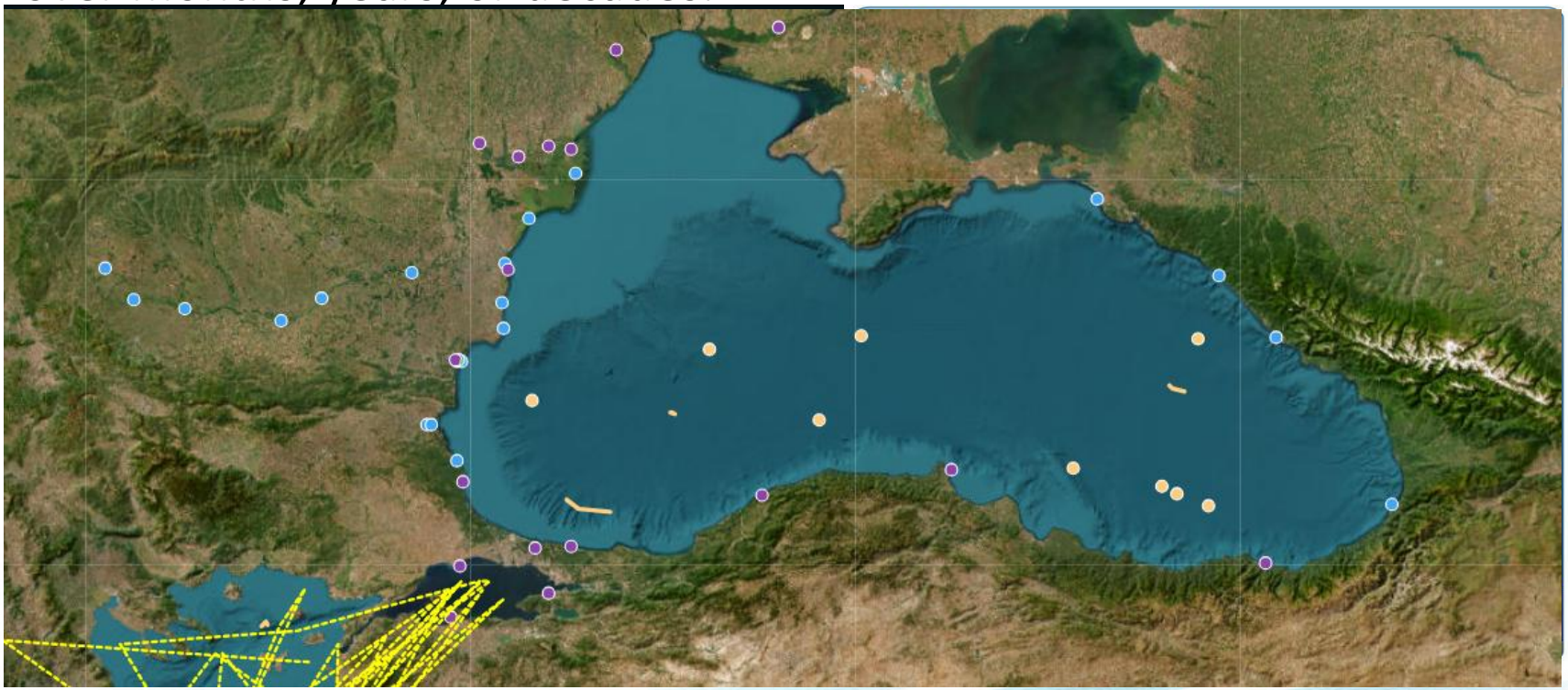
4th EfxiNNOs Joint Open Workshop:
An Innovative Marine Technology Transfer Network for Blue Growth in the Black Sea Basin

Considerations regarding the selection and use of autonomous oceanographic instruments to complement a potential observatory network in the Black Sea, based on the experience of the EfxINNOs project.

Project Speakers: Razvan Mateescu and Dragos Niculescu, PhD in Oceanography, NIMRD

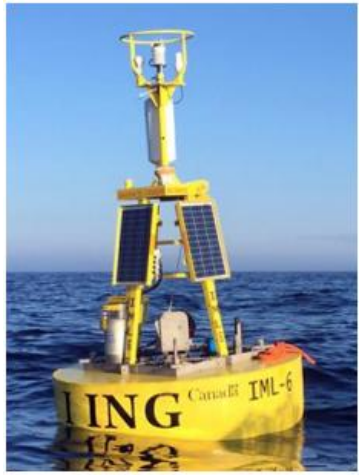
DATE: WwnwsdY 28 October 2026, Constanta

Marine observatories - fixed science networks, and platforms that collect continuous, long-term data from the sea. They move past short-term ship expeditions to study marine and coastal processes over months, years, or decades.



Main Functions & Goals

- **Climate & Weather Tracking:** Monitoring ocean heat, marine heatwaves, currents, and storms.
- **Ecosystem Research:** Studying marine biodiversity, plankton dynamics, and coastal habitats health, etc
- **Geological Monitoring:** Observing underwater emissions, tectonic plate movement, and hydrothermal vents.
- **Public Safety & Industry Support:** Delivering real-time info for fisheries, coastal risk assessment, and operational oceanography through frameworks like the Global Ocean Observing System (BS-GOOS) and the Ocean Observatories Initiative

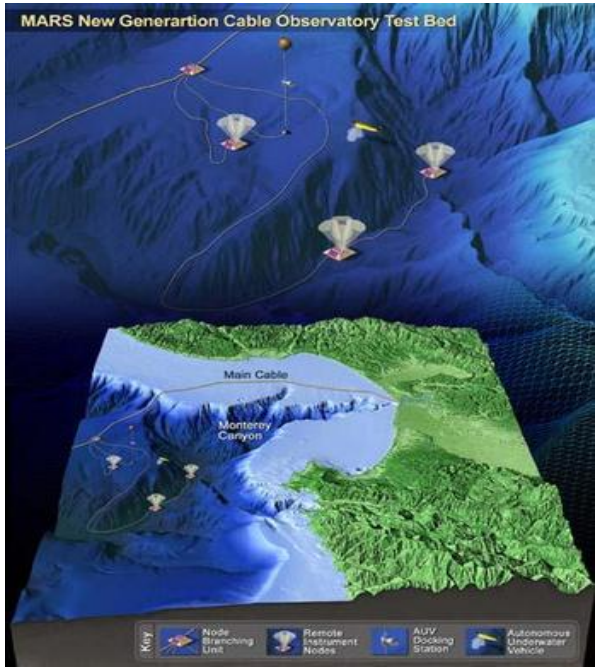




Cabled Observatories

MARS

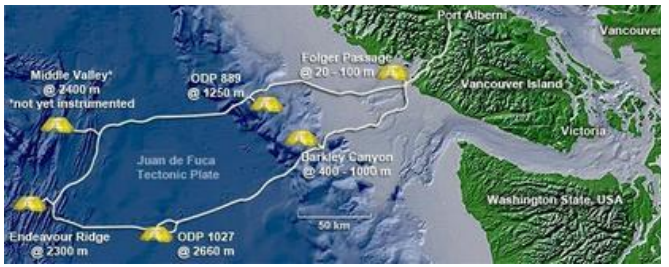
- 62 km of fiber optic cable
- Single undersea node at 1.2 km depth
- 100 Mbits per second data rate
- 10 kW of power to 4 instrument ports
- Capability of siting instruments on "extension cords"
- Serviced using *Ventana* ROV



MBARI



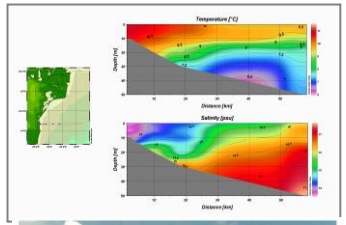
NEPTUNE/VENUS Canada



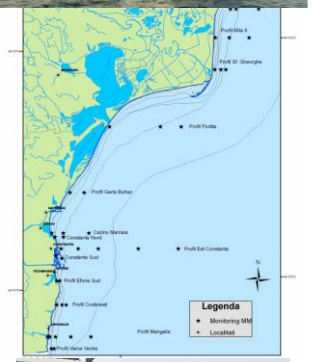
OOI Regional and Endurance

Requirements for a Black Sea Ocean Observing Network

- Autonomous oceanographic instruments and integrated monitoring infrastructure
- The development of an integrated Black Sea Ocean Observing Network would significantly strengthen the capacity of Black Sea countries to monitor oceanographic conditions, understand marine environmental changes, and support operational forecasting and early-warning systems.
- In Black Sea, particular attention should be given to its semi-enclosed nature, strong vertical stratification, anoxic env. after 200m depth, coastal vulnerability, and exposure to increasing anthropogenic and climate-related pressures
- An observing network should combine RVs operations, autonomous oceanographic instruments, fixed monitoring stations, satellite observations, and numerical modelling systems, ensuring continuous, interoperable, and near-real-time access to essential oceanographic and environmental data.









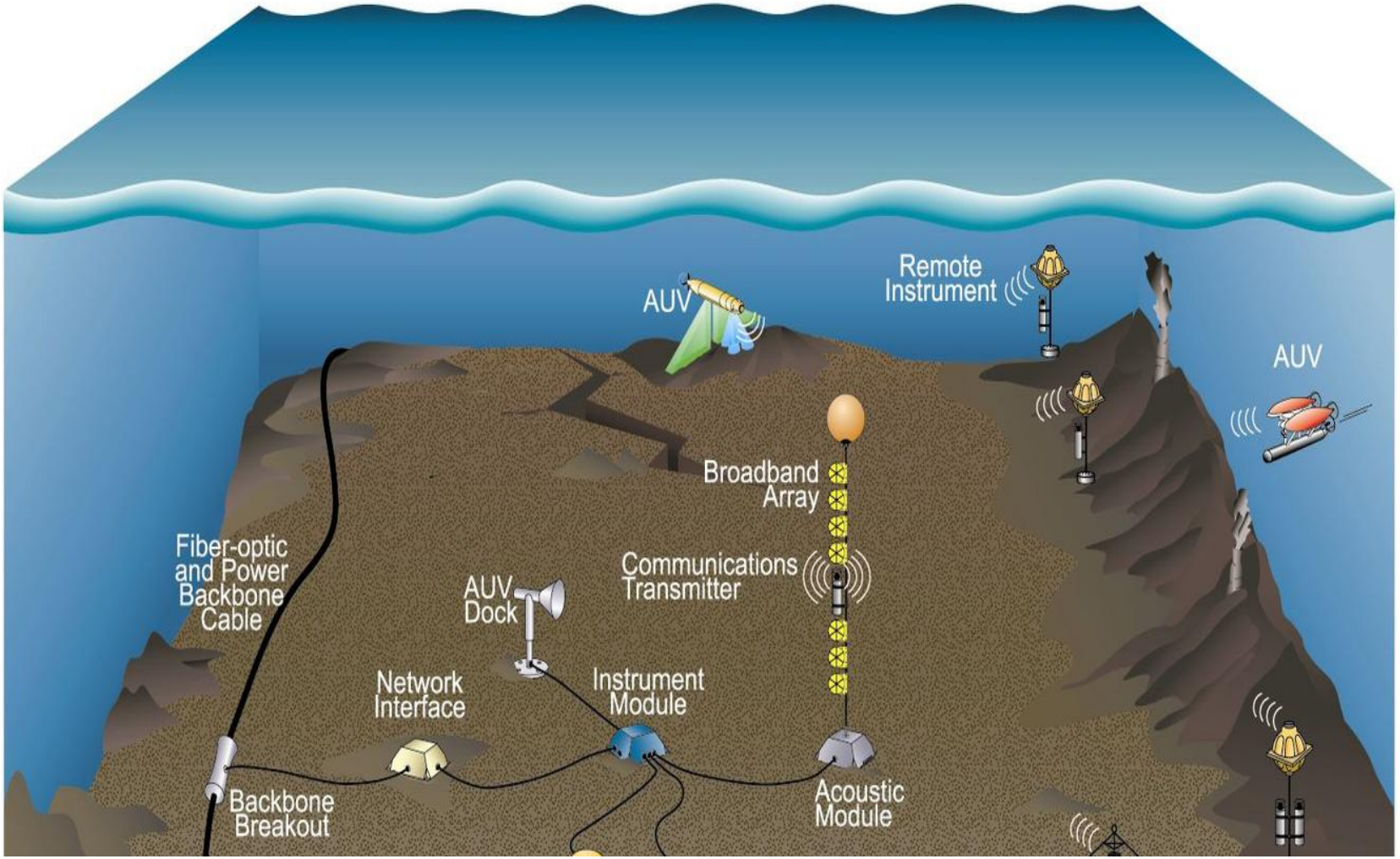
Interreg

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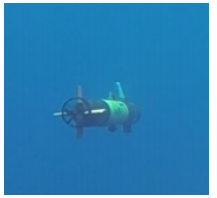
EfxINNOs

Autonomous instruments on Observatories



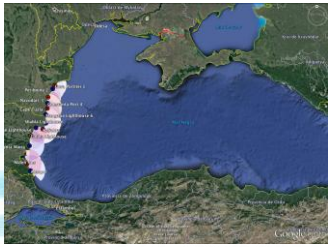
Recommended autonomous oceanographic instruments

- Autonomous profiling floats (Argo and BGC-Argo)Vertical profiles of temperature, salinity, dissolved oxygen, chlorophyll-a, pH and other biogeochemical variables. Particularly valuable for monitoring stratification, the cold intermediate layer and oxygen dynamics.
- Autonomous underwater gliders High-resolution transects across coastal and offshore waters, providing information on thermohaline structure, circulation, fronts and mesoscale variability.
- Multiparameter moored buoys Continuous measurements of waves, currents, temperature, salinity, dissolved oxygen, turbidity and meteorological conditions, with near-real-time transmission.
- Bottom-mounted ADCP systems Current profiles, current variability and water-column dynamics, especially in coastal areas, near ports and along the continental shelf.
- GPS-tracked surface drifters Surface circulation, transport pathways and dispersion processes, supporting oil-spill response, floating debris tracking and search-and-rescue applications.
- Coastal High-Frequency (HF) radar systems Spatially distributed measurements of surface currents, supporting operational oceanography, navigation safety and pollution dispersion forecasts. Coverage depends on coastal station geometry.









Requirements for an observing network

- Spatial coverage Representative coastal, shelf, slope and deep-basin monitoring locations across the Black Sea
- Temporal resolution Continuous measurements at fixed stations, complemented by repeated autonomous surveys
- Core parameters Temperature, salinity, sea level, waves, currents, dissolved oxygen, chlorophyll-a and turbidity
- Data transmission Near-real-time telemetry and delayed-mode quality-controlled data Interoperability Alignment with GOOS, Ocean OPS, SeaDataNet, EMODnet and Copernicus Marine standards
- Data management Standardised metadata, quality control, FAIR principles and open access where appropriate
- Operational sustainability Long-term maintenance, calibration, replacement plans and coordinated regional governance
- Model integration Data assimilation, forecast validation and support for early-warning services









Priority requirements specific to the Black Sea

Gaps in geographical coverage, near-real-time observations, biogeochemical monitoring, standardisation and regional data exchange.



Developments:

- **An integrated coastal observing network, with fixed multiparameter stations and wave/current measurements in environmentally sensitive and economically important areas.**
- **Expanded offshore autonomous monitoring, using profiling floats and gliders to resolve vertical stratification, circulation and oxygen variability.**
- **Regional data interoperability, connecting national monitoring systems to Copernicus Marine, EMODnet and existing Black Sea GOOS initiatives.**
- **Sustained operational capacity, including shared protocols, qualified personnel, calibration facilities, long-term funding and maintenance.**

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NEXT Black Sea Basin
EfxINNOs

AUV Technology and Application Basics

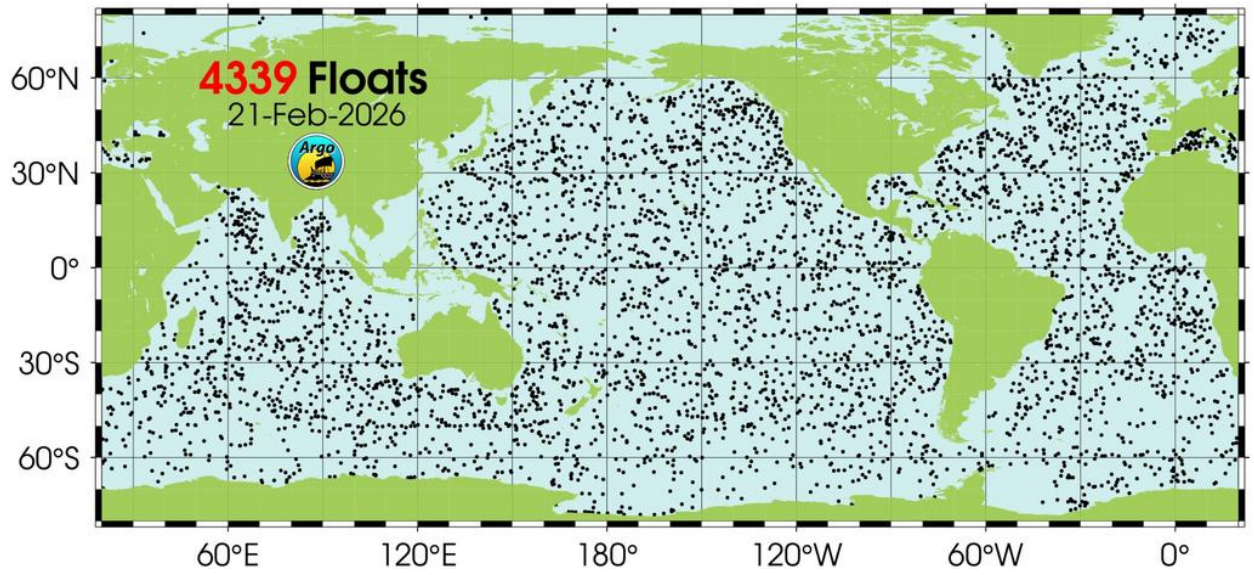
Types of AUVs

What's an AUV?

AUV

u	n	e
t	d	h
o	e	i
n	r	c
o	w	l
m	a	e
o	t	
u	e	
s	r	

AUVs?: Floats and profilers



Sea-Bird
Navis
Autonomous
Profiling Float







Sea-Bird
BGC
float

Teledyne Webb
Argo Float



Del Mar
Oceanographic
Wirewalker



Coastal Profiling
Float
(imgGeneMassion)

AUVs: Gliders

Buoyancy-Driven, Low-Speed, Long Endurance



Scripps Spray



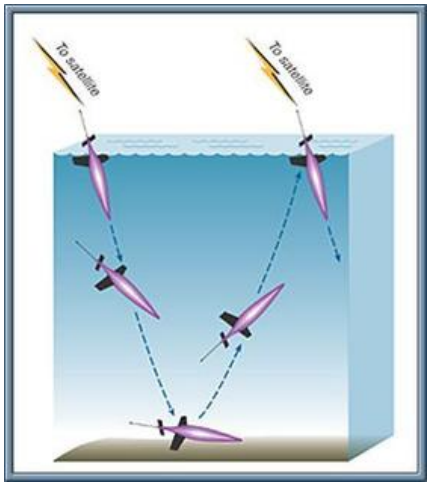
Teledyne Webb Slocum Electric Glider



ALSEAMAR
Seaexplorer



UW SeaGlider



http://www.apl.washington.edu/projects/seaglider/summary.html



AUVs: Propeller-driven



Hydroid Remus 100



Bluefin 9”



ISE Explorer



WHOI Sentry



Teledyne Gavia



Bluefin HAUV



WHOI Seabed



Kongsberg Hugin



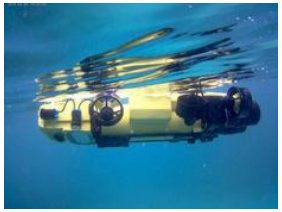
L3Harris Iver4



JAMSTEC Urashima



ECA
Alistar



QUT RangerBot





NOCS Autosub

AUVs: Propeller-driven

Huge variation in scale!



RTSYS NemoSens
(image RTSYS)



Boeing Echo Voyager/XLUUV
(image Boeing)

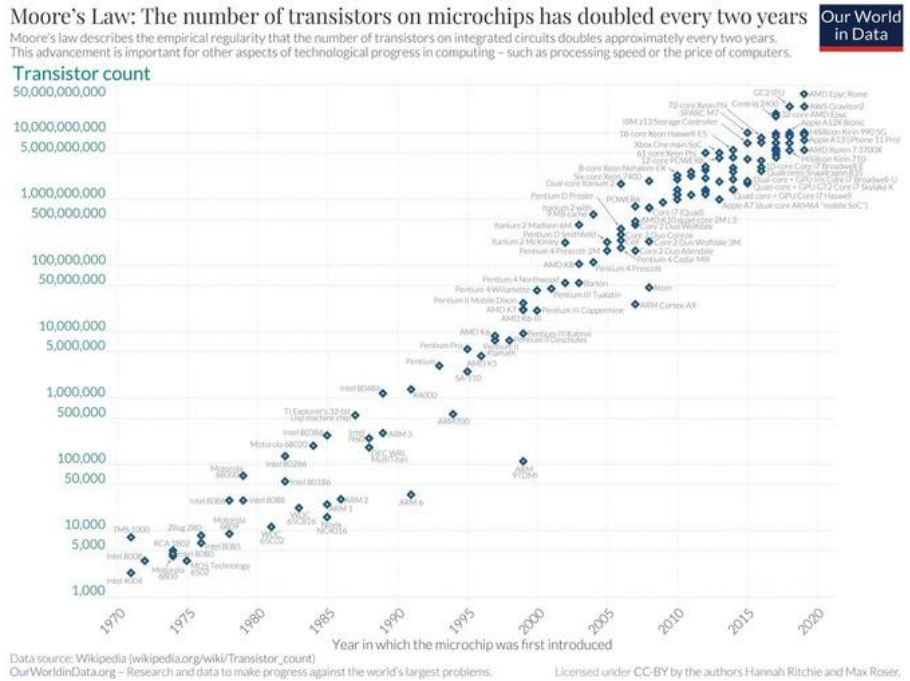


Advanced Navigation Hydrus
(image Advanced Navigation)



Kongsberg Hugin Endurance
(image Kongsberg Discovery)

Frontier: Miniaturization





Bluefin Sandshark



Seaber MicroAUV

Propulsion

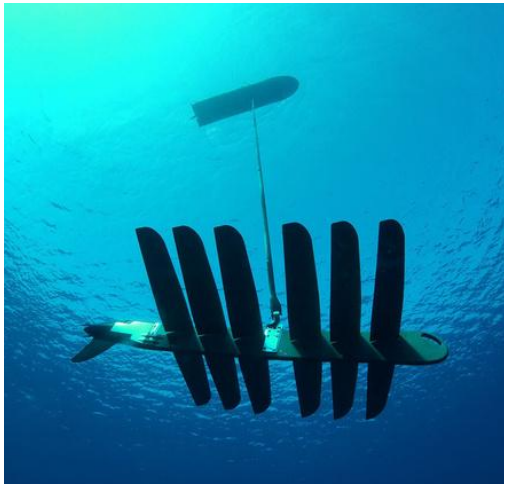
- Oscillating foils or undulating body
- Wind
- Wave
- Solar



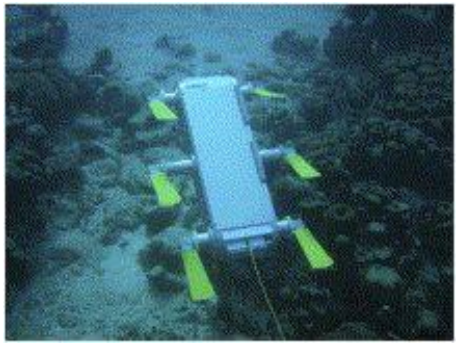
Falmouth Solar AUV



MOST AutoNaut Wave driven ASV



Liquid Robotics Wave Glider



McGill Aqua

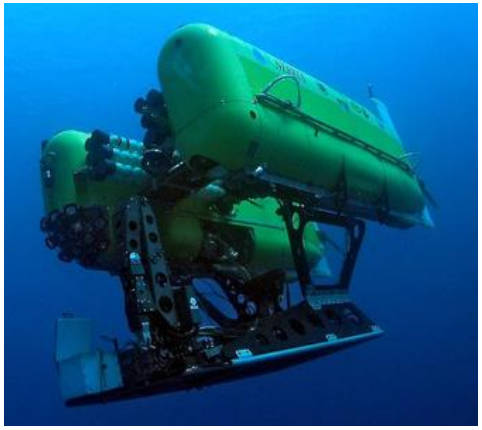


Harbor Wing Technologies Inc. X1 prototype (Elkaim and Boyce, 2008)

AUVs: AUV/ROV hybrids



Saab Sabertooth



WHOI Nereus
(imageWHOIAdv.Img.andVis. Lab.)



Oceaneering Freedom
(image courtesy Oceaneering)



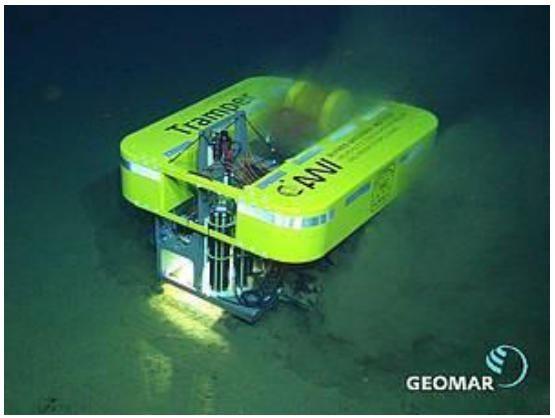
Kawasaki SPICE
(image courtesy Kawasaki)

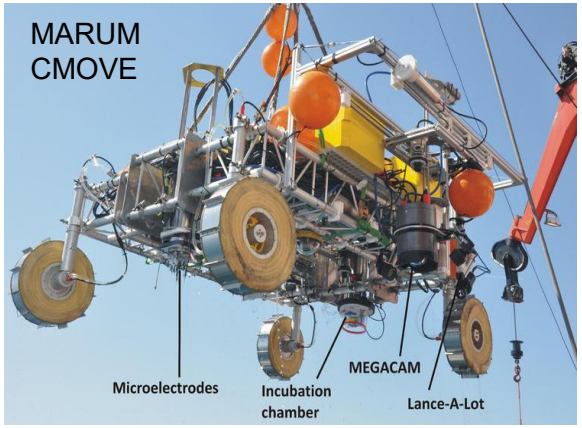


HMI Aquanaut
(imagecourtesyIEEE)

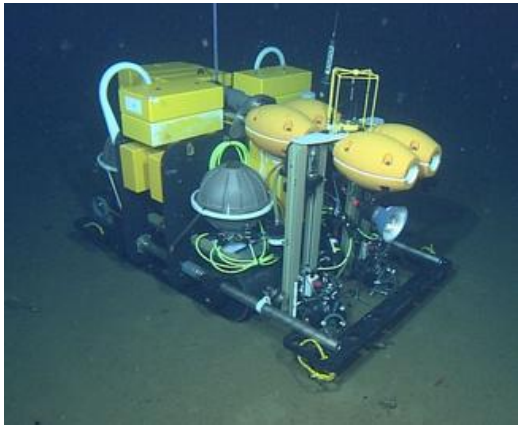
AUVs: Crawlers/landers/biomimetic vehicles

AWI Tramper





MBARI Benthic Rover

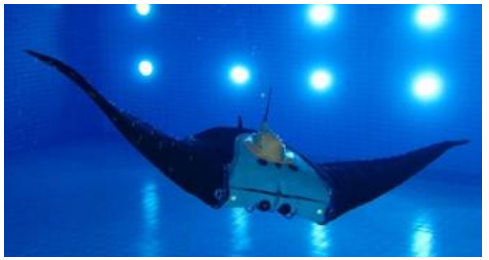




NEPTUNE Canada Wally Rover



Kongsberg Eelume



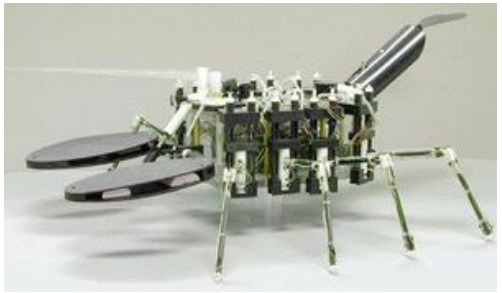
EvoLogics Fin Ray Effect Glider



EvoLogics Quadrion



Nekton
T15ranaphibian



RoboLobster – Joe Ayers

Peers: Uncrewed Surface Vehicles (USV)



Northwind Marine Sea Fox Mark II



Liquid Robotics Wave Glider



Marine Advanced Robotics WAM-V



Sea Robotics – 4.0



Saildrone



OpenOcean Robotics DataXplorer



EvoLogics SonoBot 5



OceanAero Triton



ASV C-Enduro and C-Worker

Peers: Uncrewed Aerial Vehicles (UAV)



DJI Mavic Air 2



Boeing Insitu ScanEagle



Edge Autonomy VXE30



Quantum Systems Trinity

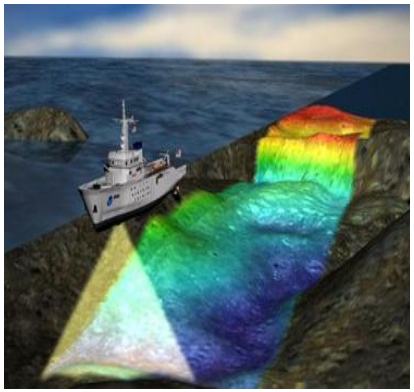


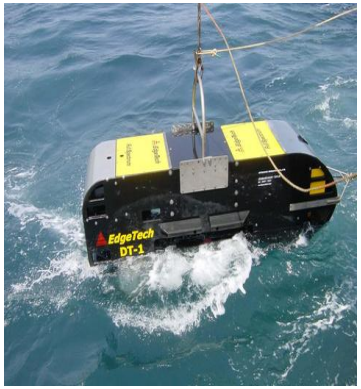
Martin UAV V-Bat

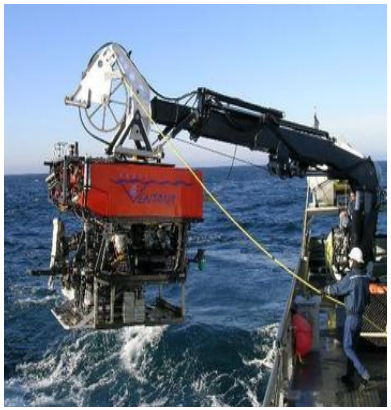
Why use an AUV?

Alternatives:

- Remote sensing - Ship-hull mounted sensors
- Cabled Towfish or ROV
- Crewed Submersible
- Moored Platform







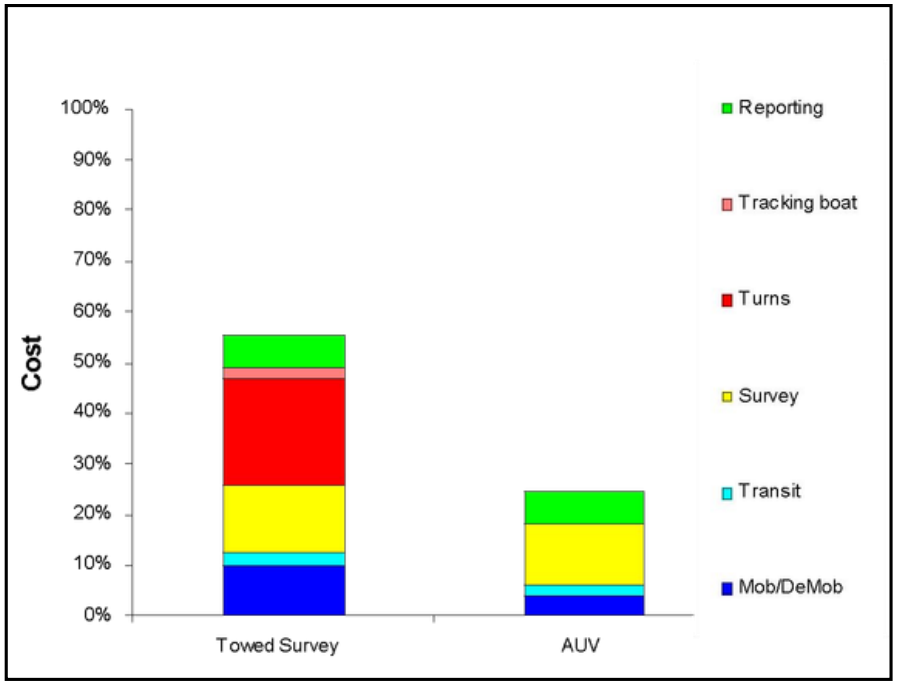


AUV Advantages:

- Less expensive
- Higher quality data, especially when deep
- Safer
- Mobile

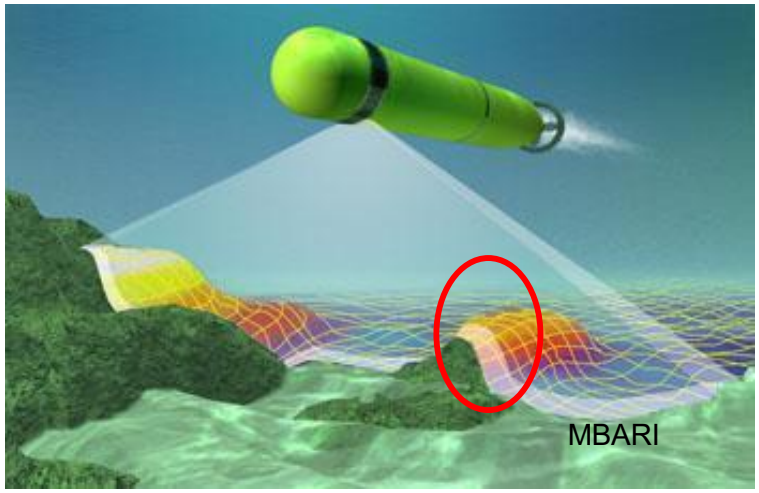
Why use an AUV? - Less Expensive

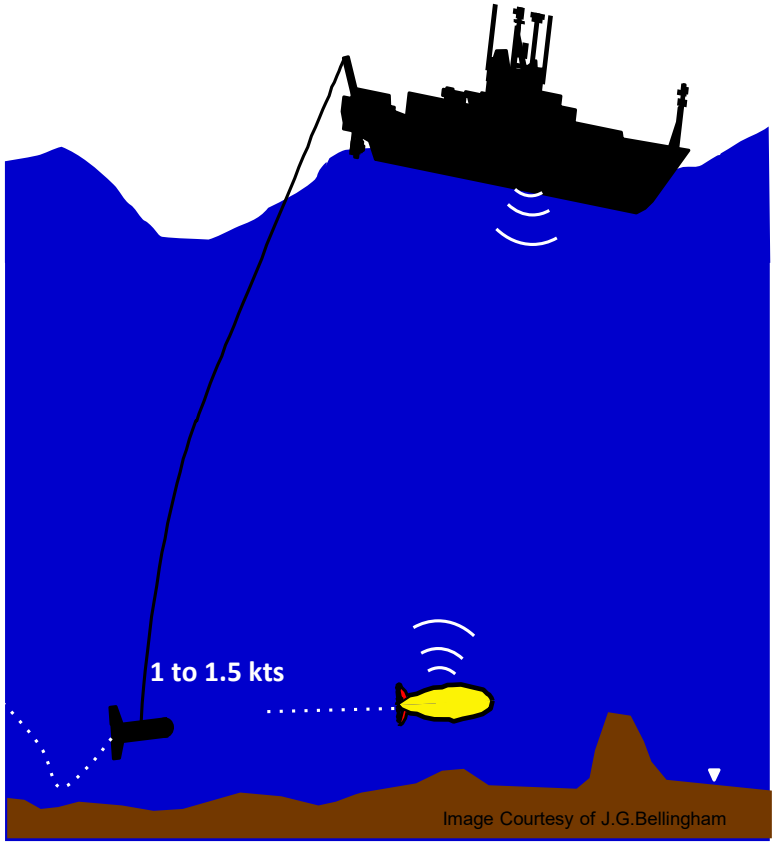
- Faster – in deep water 4-5 knots verses 2-3 knots for towfish in deep water
  - quick turns
- Expensive ship can perform other tasks
- Or, it's possible to operate AUV without a ship
- AUV day rate: ~$3k+
  Research vessel day rate: ~$30k+



Towed sonar versus AUV Survey Cost Comparison

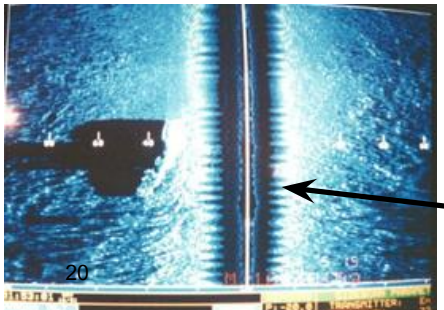
Why use an AUV? Higher Quality Data





- Higher resolution than hull mounted sonar
  - Sonar beams diverge:
    - 1 degree beam footprint
    - @50m range =0.9m spot
    - @500m = 9m
    - @5000m = 90m
- Better altitude control than towfish

Ship motion affects towfish



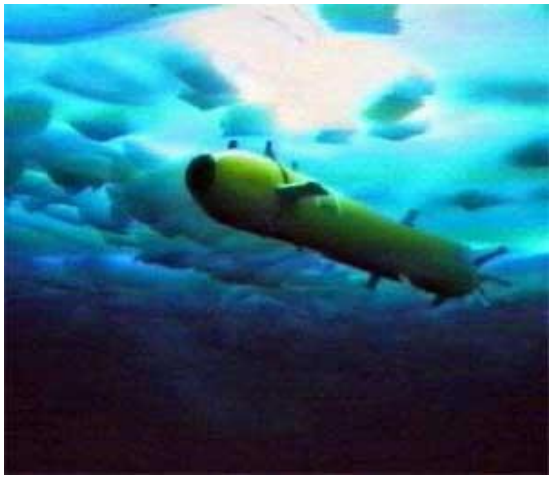
Surface wave induced noise

Why use an AUV? Safer

- Mine hunting
- Under ice
- Tunnels
- Contested/protected waters



Atlas-Elektronik Seafox



ISE Theseus AUV

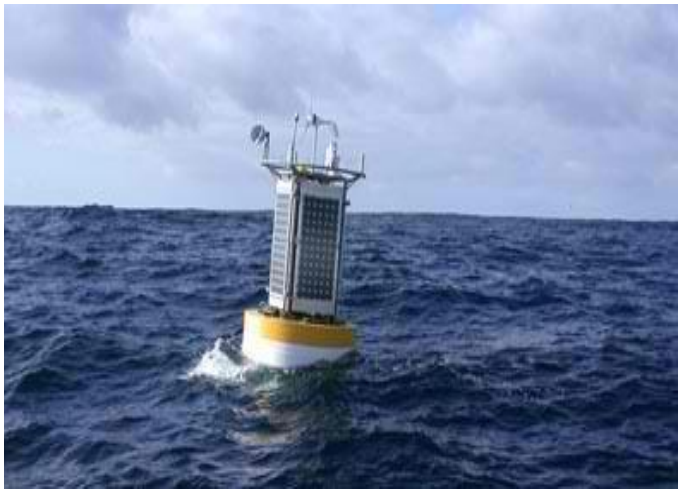


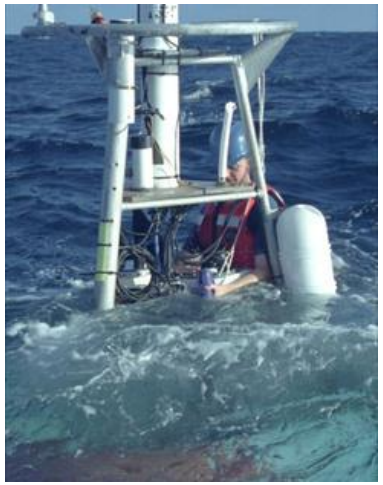
WHOI Tunnel AUV

Why use an AUV?
Mobility and Persistence

Moorings have persistence, but are not mobile

Ships are mobile but not persistent

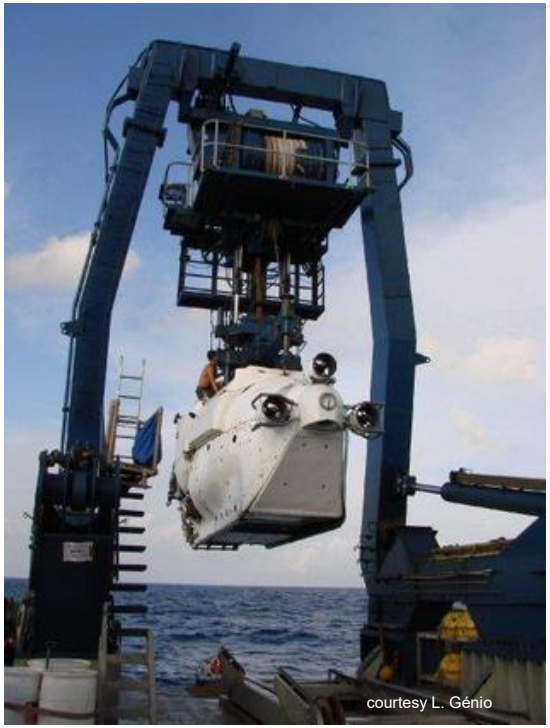


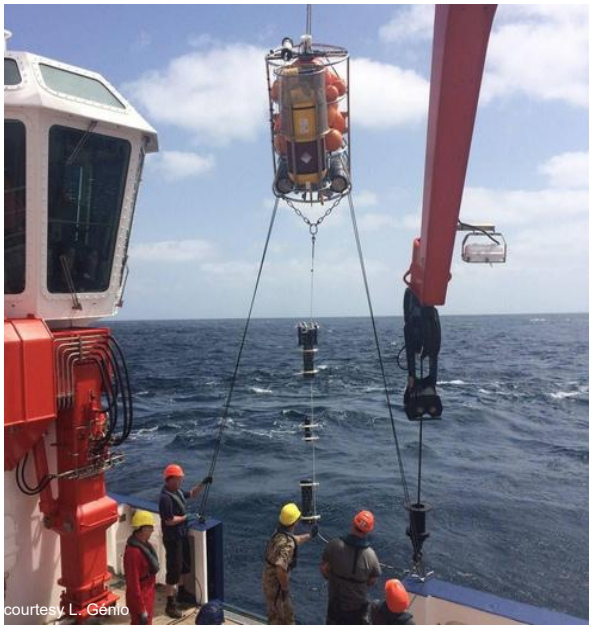




In a changing and dynamic ocean it is difficult to capture episodic natural events with traditional "expeditionary" sampling.

Why use a Ship?



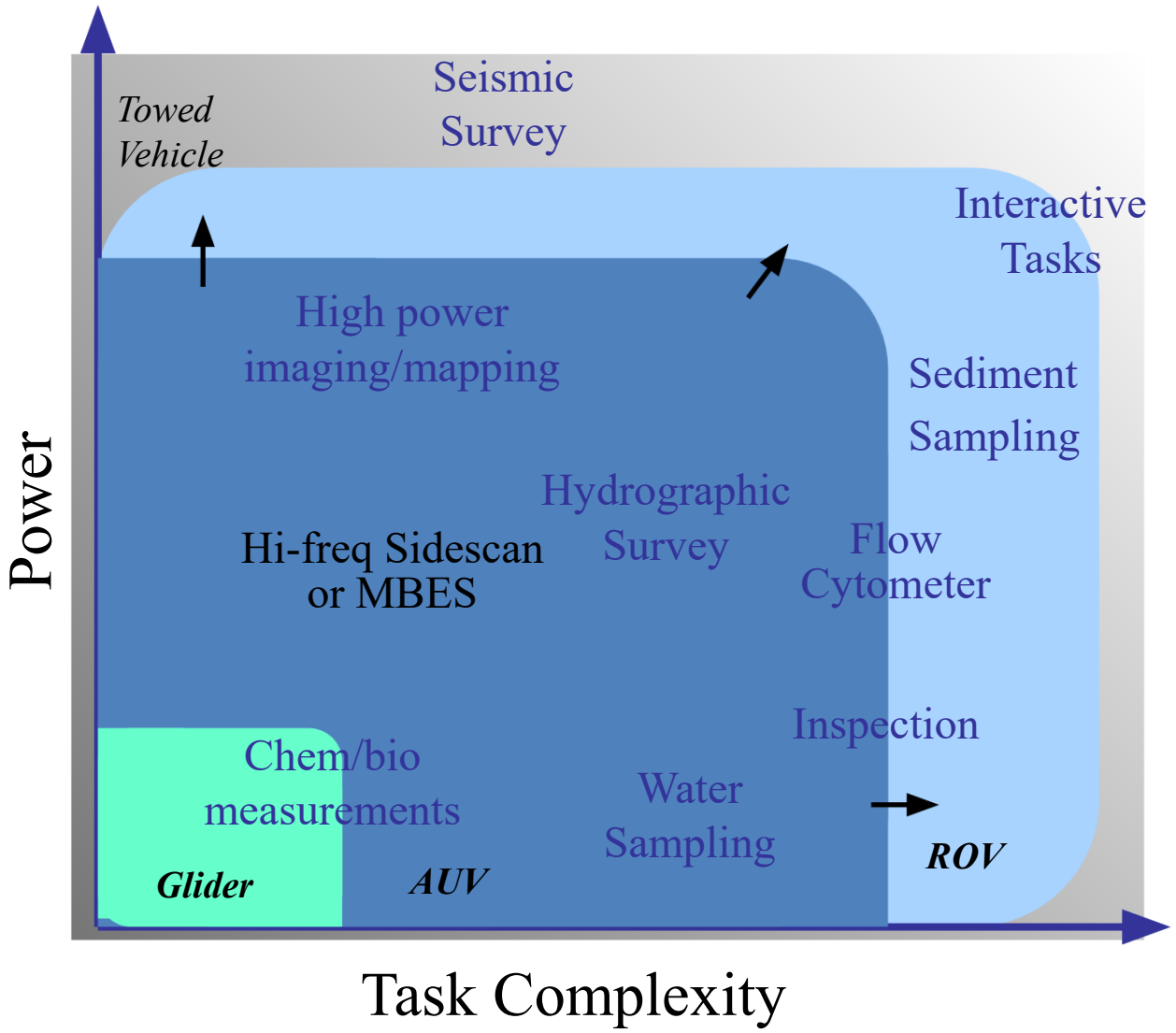








AUV Operational Domain



Choose Your AUV

SLOCUM GLIDER G3



ENDURANCE

Depth	1000m
Endurance	1–4 mo
Distance	1500+km
Speed	0.5m/s
Payload	~1W

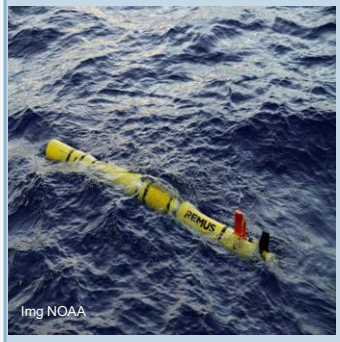
MBARI LRAUV



SCIENCE

Depth	300m
Endurance	~2 wks
Distance	1000km
Speed	1.4m/s
Payload	~10W

REMUS 600



SURVEY

Depth	600m
Endurance	70 hrs
Distance	530km
Speed	2.5m/s
Payload	<100W

KONGSBERG HUGIN 6000



DEEP WATER

Depth	6000m
Endurance	52–72h
Distance	~400km
Speed	2.7m/s
Payload	>100W

Interreg NEXT Black Sea Basin

Co-funded by the European Union

EfxINNOs

AUV Technology and Application Basics

AUV Operational Overview

MBARI

Operational Scenarios: People



Role	Example	Your responsibility
Own & operate	Purchase a vehicle	Everything
Own, ops support	Lab owns vehicle, hire/partner for operations	Science requirements, mission planning, data analysis
Collaborative deployment	Join someone else's deployment	Science requirements, at-sea presence, data analysis
Contracted survey	Charter a survey	Science requirements, data analysis
Data consumer	Download from a repository	Analysis only

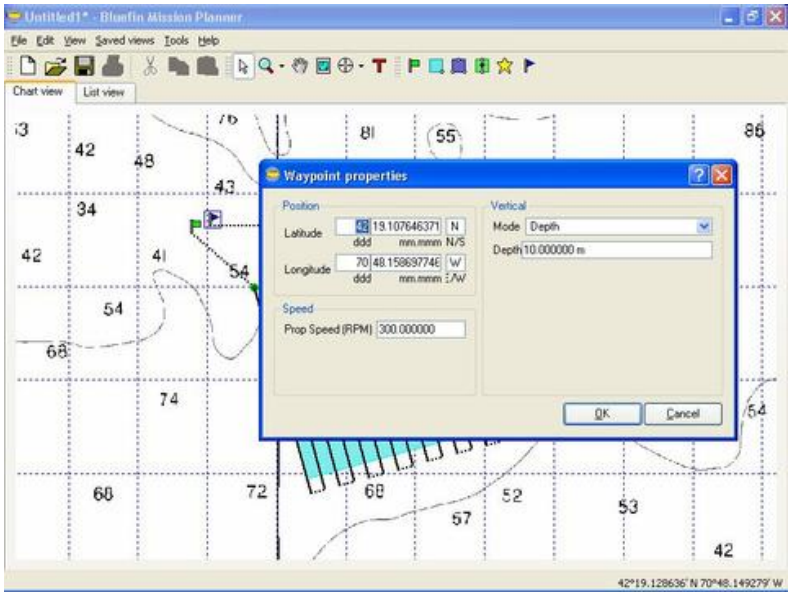
AUV Operations

Mission Planning

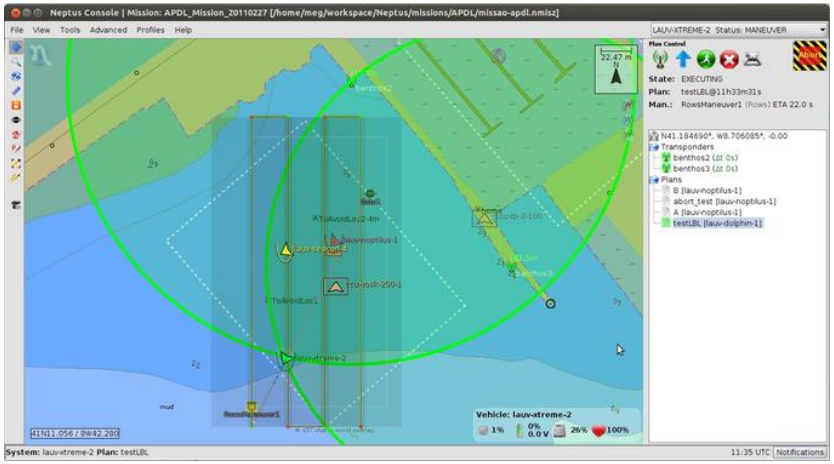
- Describe CONOP
- Determine routes (waypoints, depth, etc) and/or behaviors (patch tracking, pipeline following, etc)
- Alter mission-level safety envelopes as needed (min altitude, max depth, exclusion zones, etc)
- Run simulation

Vehicle Software

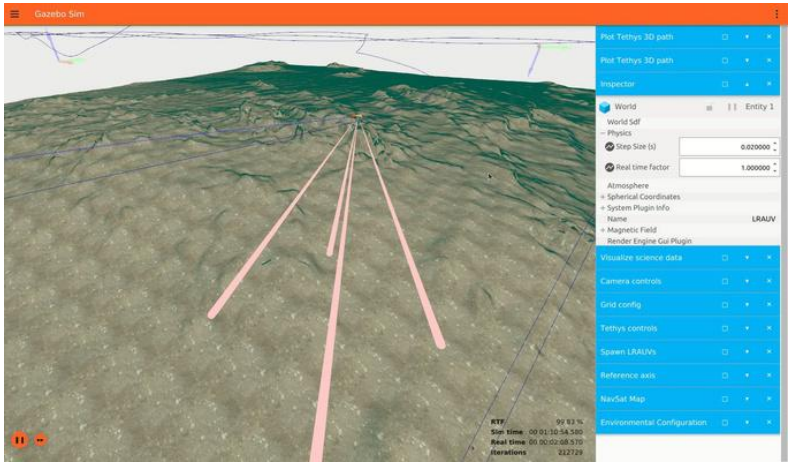
- Configure for payload
- Load necessary missions
- Alter vehicle-level safety thresholds (e.g. abort depth)
- Complete pre-deployment checklists
- Run vehicle self-test



Courtesy Bluefin Robotics



Neptus- LSTS Porto



Open Robotics Gazebo sim

AUV Operations

Vehicle Launch

- Verify two-way communications
- Verify backup location systems
- Launch vehicle
- Check for leaks once in water (e.g. ground fault scan, humidity, etc)
- Start mission via communication with vehicle
- User interactions with vehicle: track, monitor from shore, adjust missions…



Image courtesy of Bonaire 2008: Exploring Coral Reef Sustainability with New Technologies.





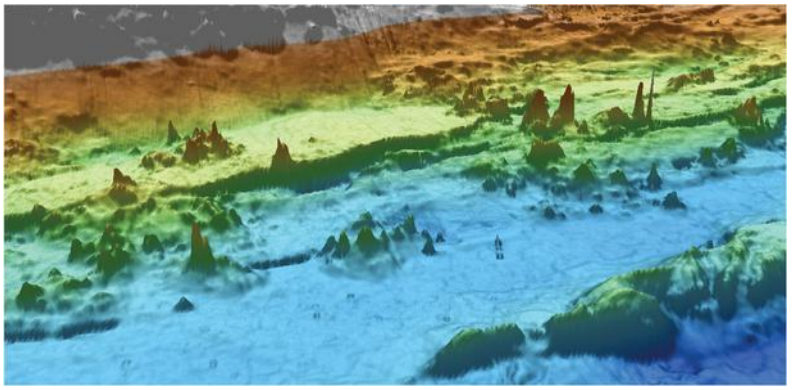
AUV Operations

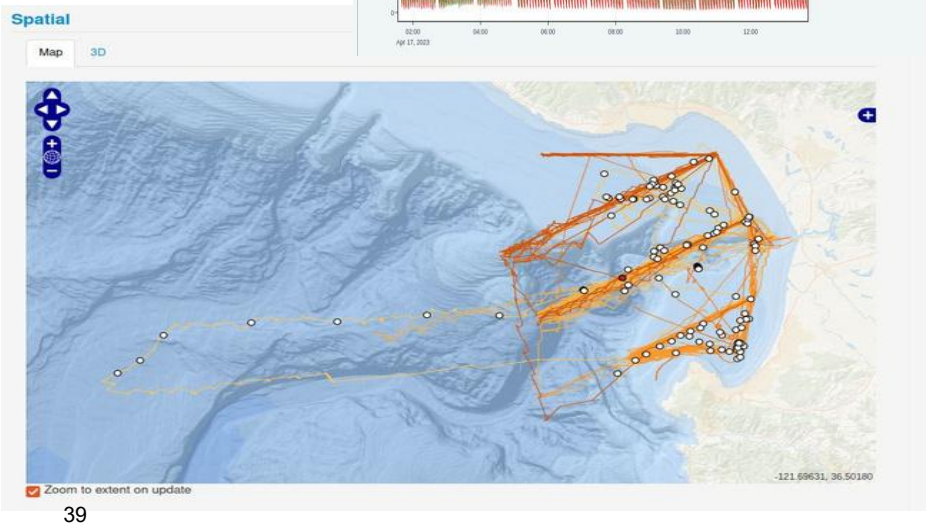
Deployment End

- Locatevehicle if unattended
- Recover vehicle on-board ship/shore
- Download and review full resolution data (Science and Engineering)
- Note failures or large deviations from simulation and adjust
- Prepare for next mission: charge/change batteries, clean sensors









Launch and Recovery Methods

Overboard Crane

- Simple and effective for ships of opportunity with minimum freeboard
- Quick release to launch
- Reattach with pole from low-freeboard ship
- Small boat usually required for high freeboard ship
- Difficult to attach tag-lines

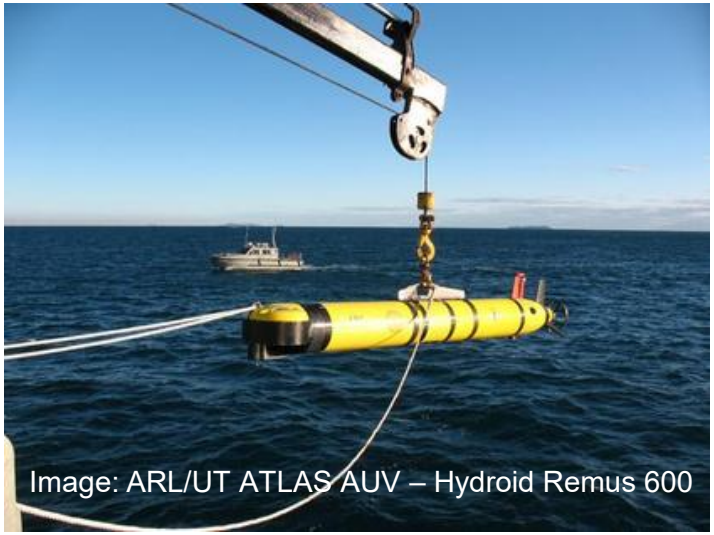


Image: ARL/UT ATLAS AUV – Hydroid Remus 600

A – Frame

- Standard on many vessels of opportunity
- Usually mounted on stern, where pitch motions are high
- Large distance between sheave and AUV: must constrain swing
  - Need two tag-lines



Simple/FixedRamp

- Generally good for low freeboard
- Low-cost
- Requires instruments to be protected from rollers



Launch and Recovery cont.

Ramps and Nose-lift

- Usually built as Fly-Away
- Good control during transition
- Long extensions must be very strong



Kongsberg Hugin LRS

Specialized L & R systems (LARS)

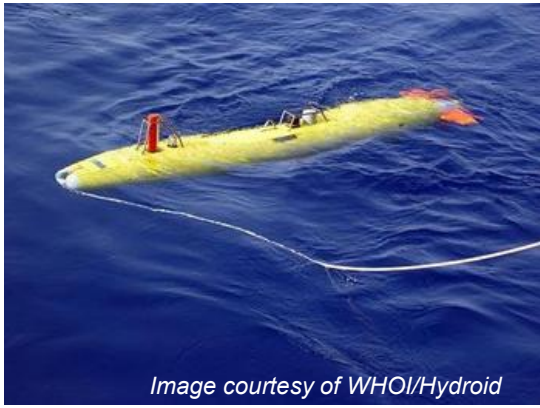
- Dedicated ship, or Fly-Away
- Most control and safest for AUV
- Most expensive



NOC Autosub LARS

Detachable Nose Tagline - Pre-rigged tow-line

- Augment other solutions
- Helps when hooking is difficult
- Must manage to prevent fouling



Shipless deployment: beach launch



Interreg NEXT Black Sea Basin

Co-funded by the European Union

EfxINNOs

AUV Technology and Application Basics

AUV Applications – What do AUVs do?

Instrumentation Types - Benthic

Benthic and mapping

Multibeam sonar

Sub-bottom profiling sonar

Side-scan sonar

Synthetic Aperture Sonar

Digital camera

Chemical sensors: pH, O2, CO2, methane, sulfide, nitrate, etc.

Loihi Seamount example

- **Left**: hull mounted sonar
- **Right**: towfish with corrected navigation
- **Takeaway**: Closer is better: AUVs can collect much higher resolution data

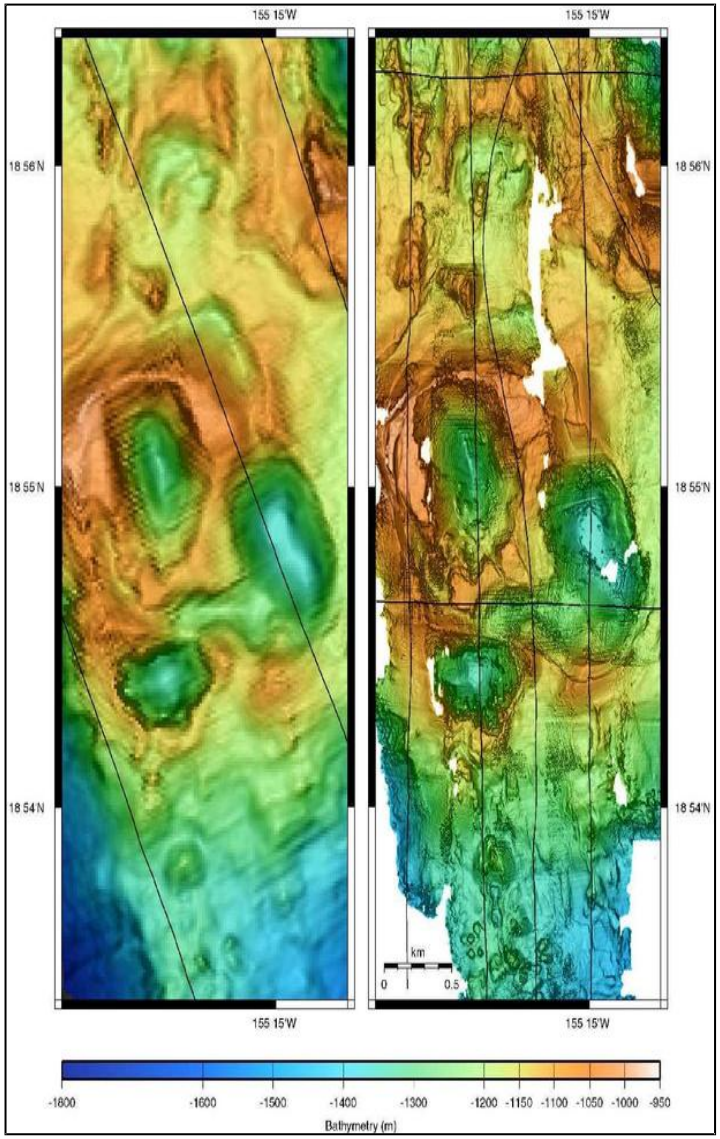
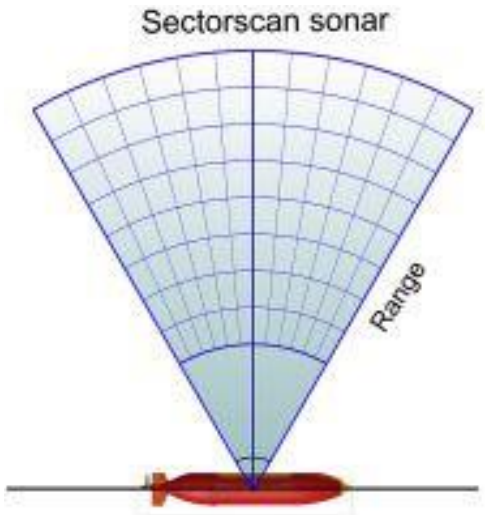
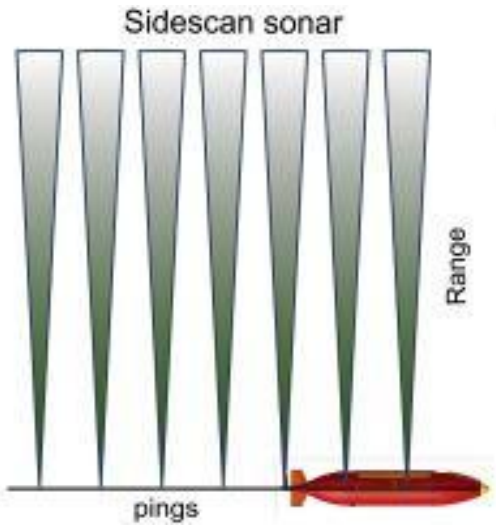
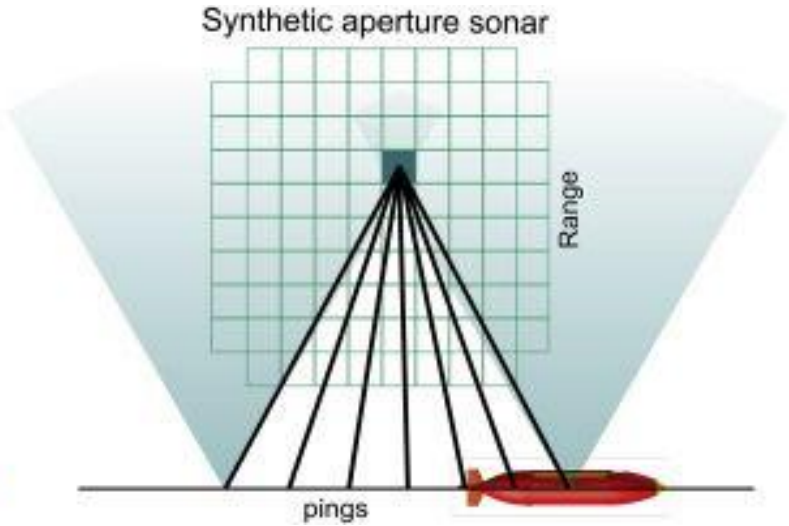


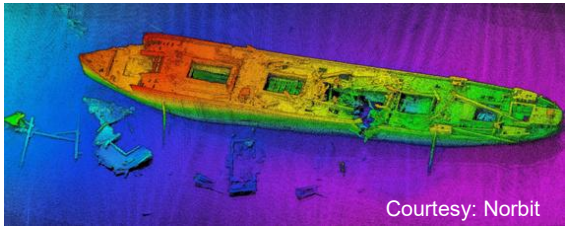
Image courtesy David Caress

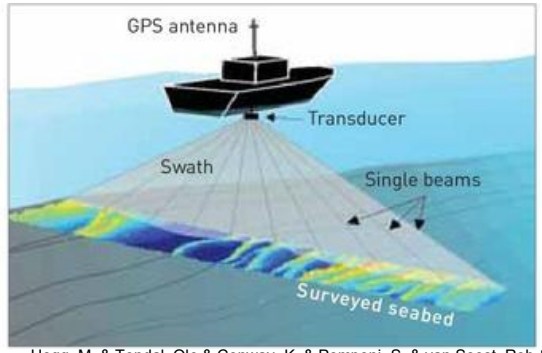
Types of Sonar



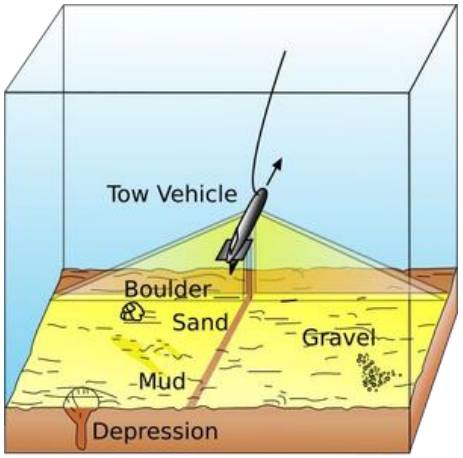


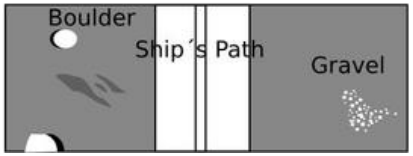






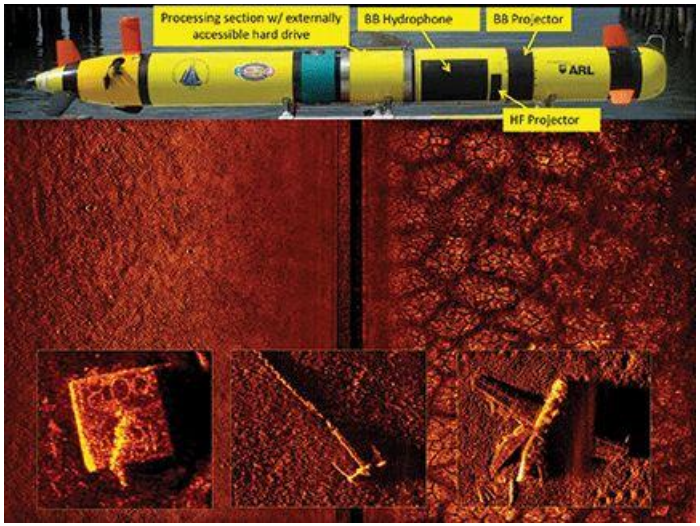
Hogg, M. & Tendal, Ole & Conway, K. & Pomponi, S. & van Soest, Rob & Gutt, J. & Krautter, Manfred & Roberts, J.. (2010). Deep-sea sponge grounds:





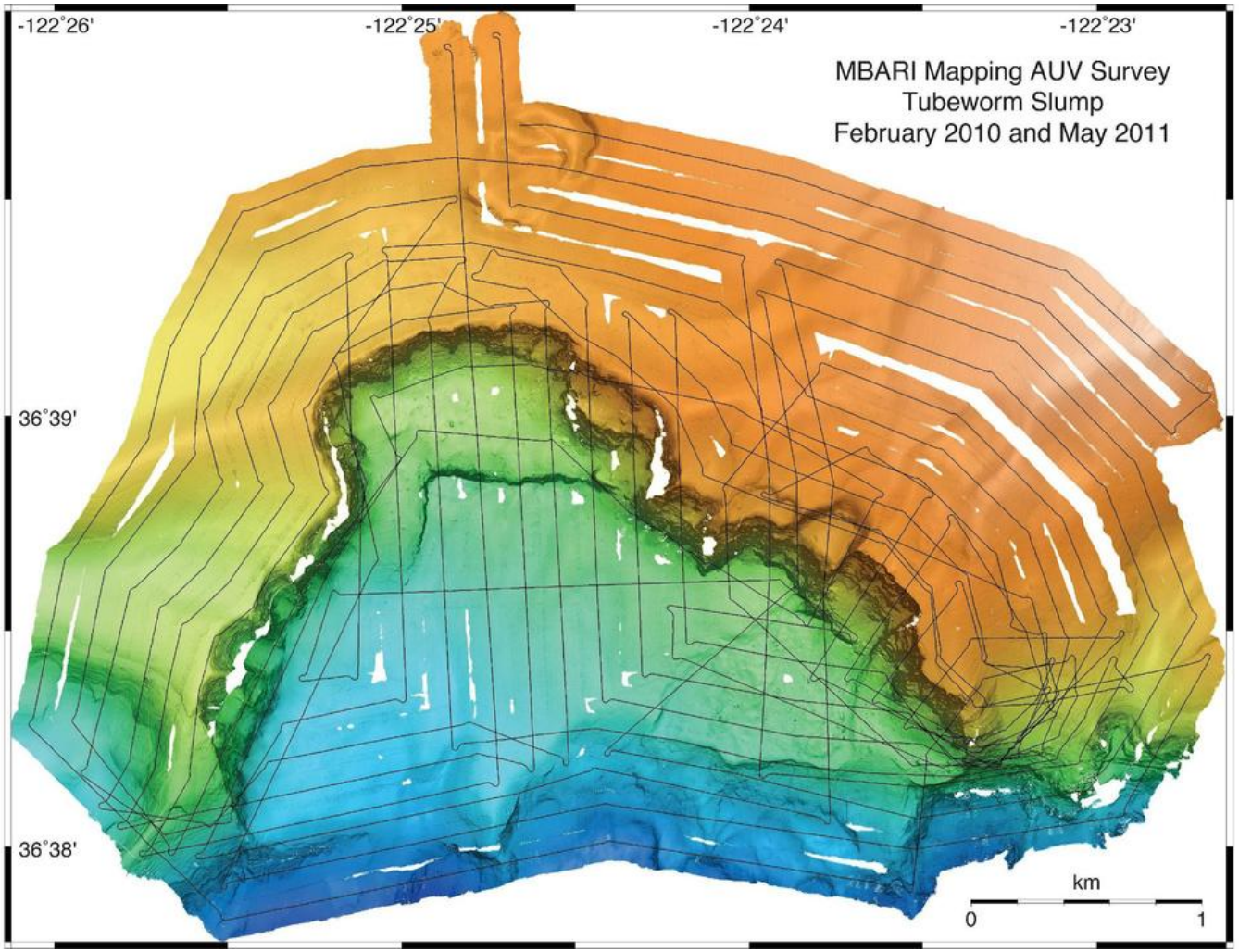
Courtesy: Wikipedia

Øyvind Ødegård, Roy E. Hansen, Hanumant Singh, Thijs J. Maarleveld, Archaeological use of Synthetic Aperture Sonar on deepwater wreck sites in Skagerrak

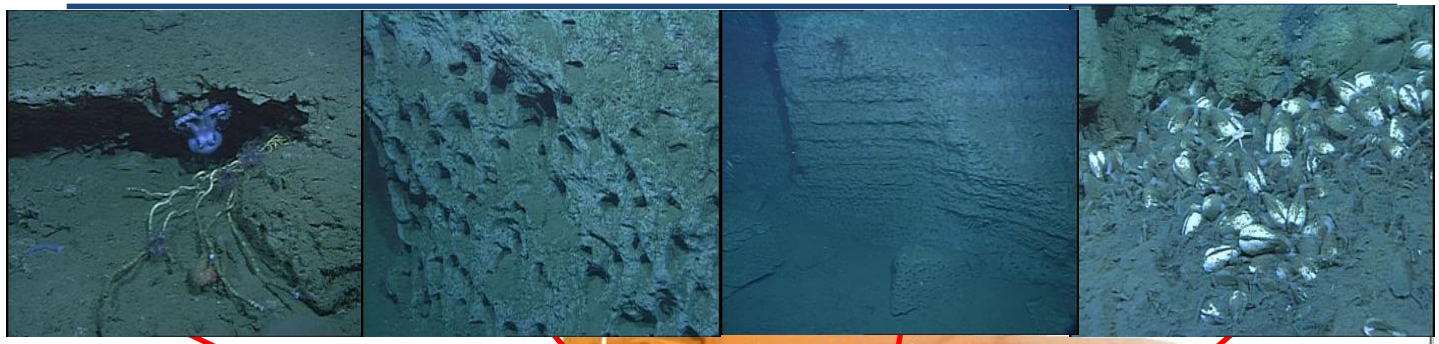


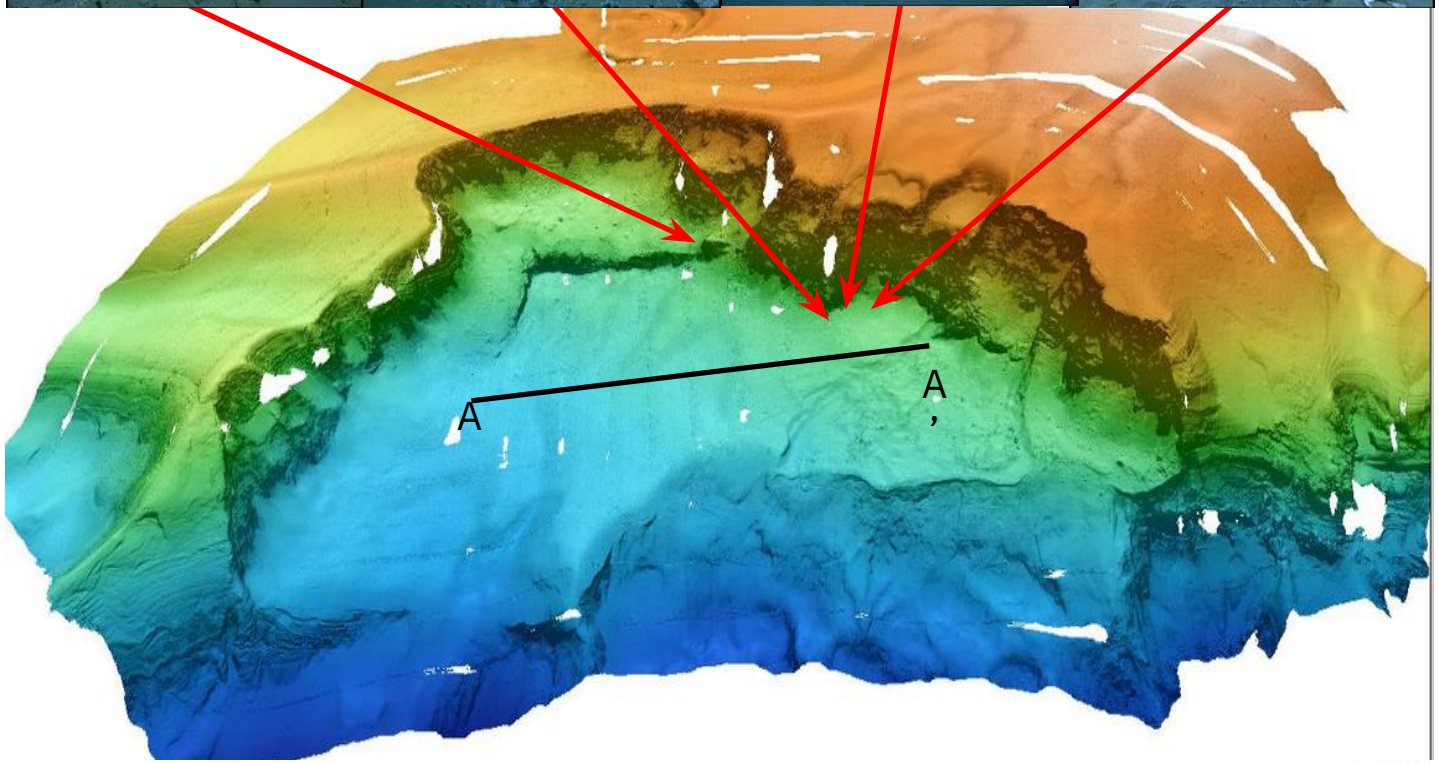
Courtesy: navy.mil

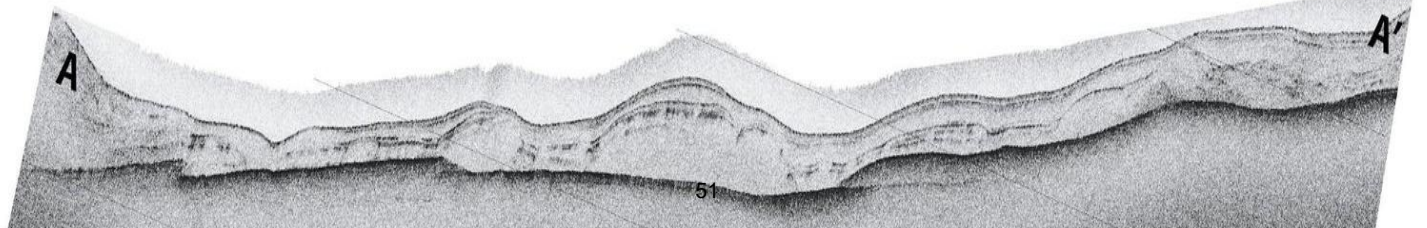
Seafloor Mapping - Planning



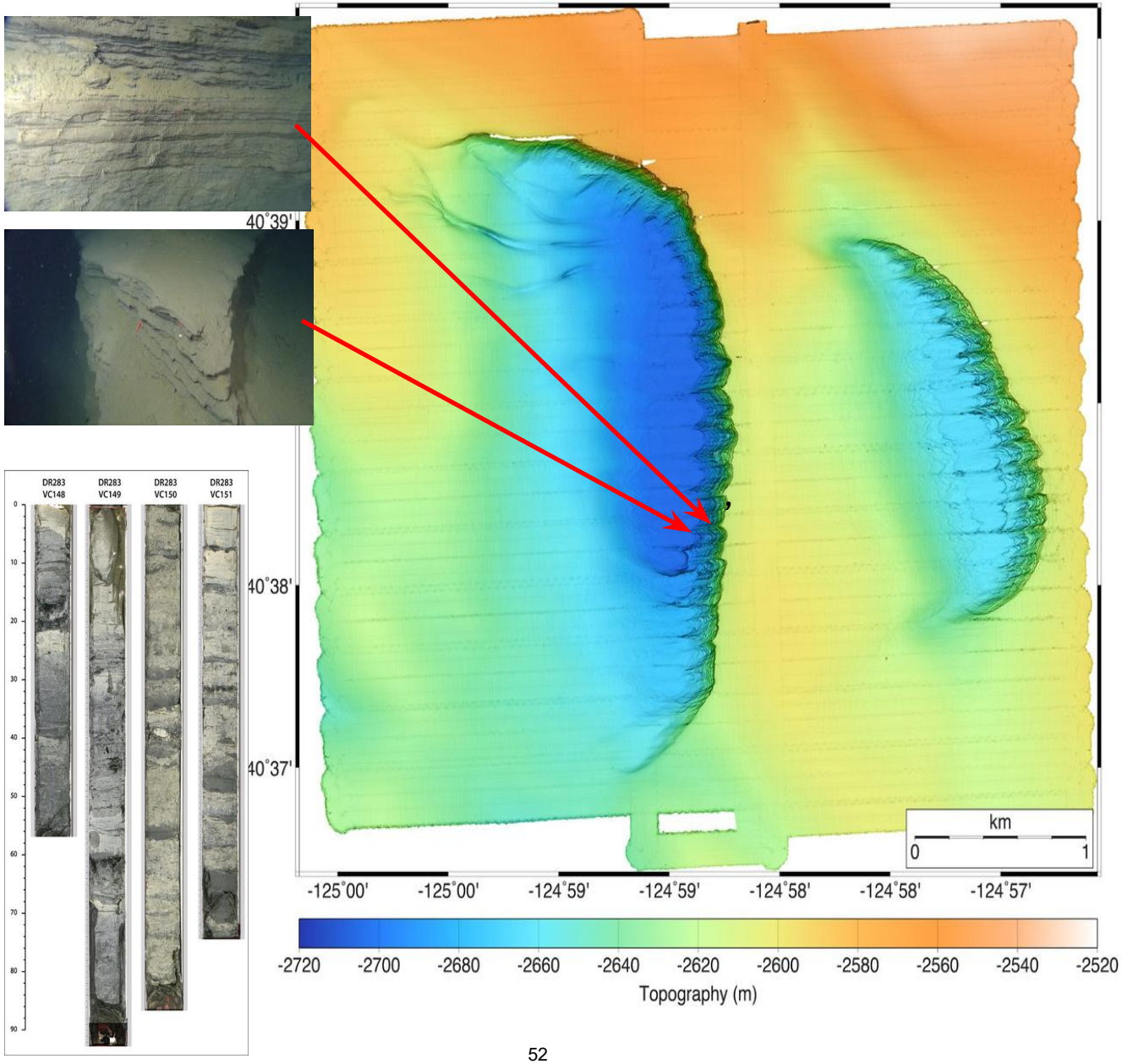
Seafloor Mapping – Ground Truth



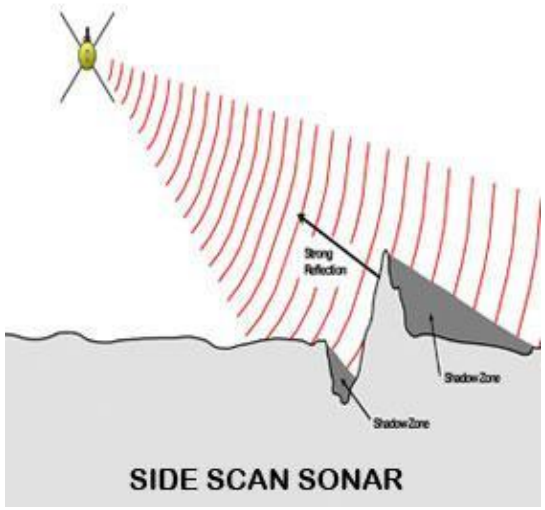




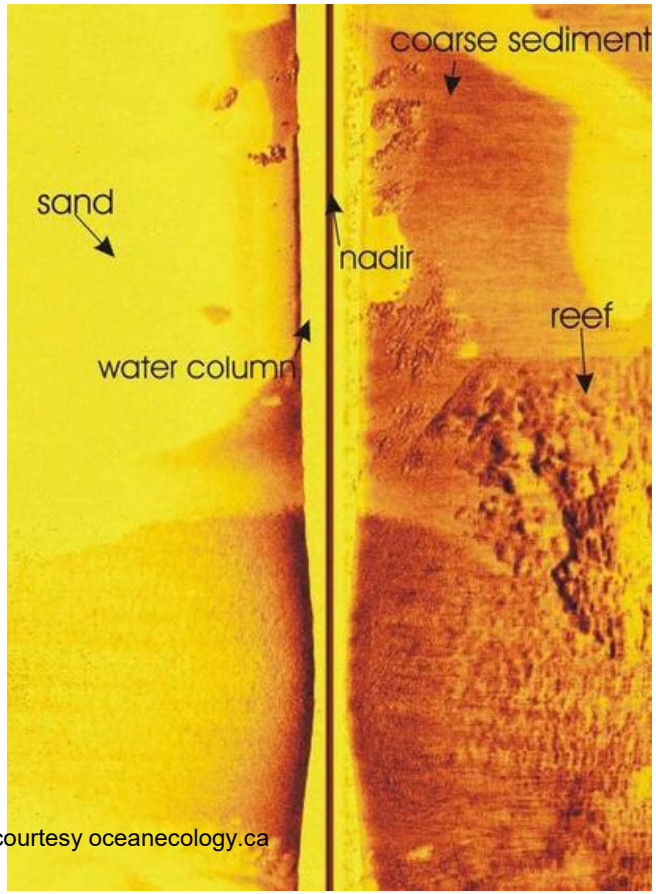
Seafloor Mapping



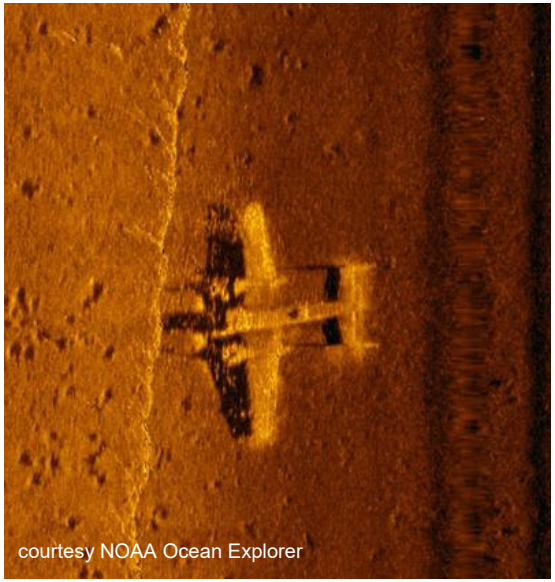
Side-Scan Sonar Data Example



NOAA Coast Survey



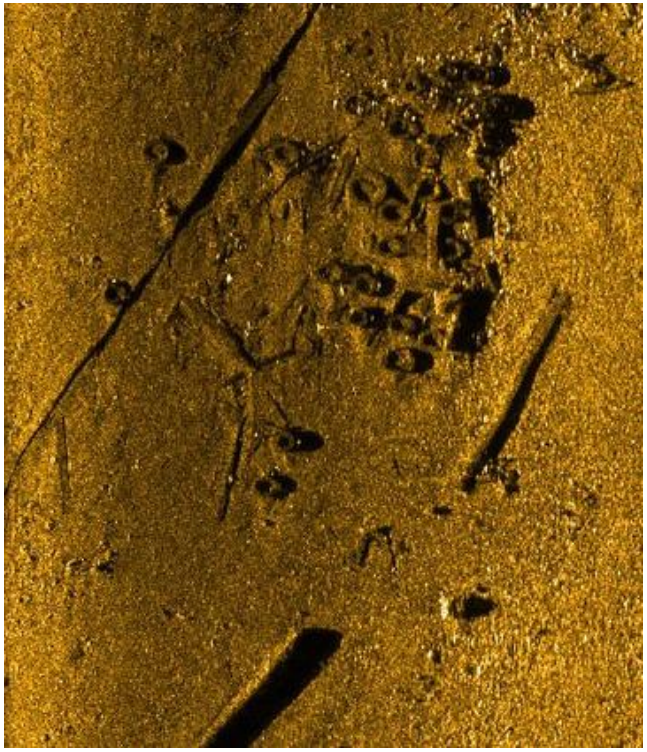
courtesy oceanecology.ca



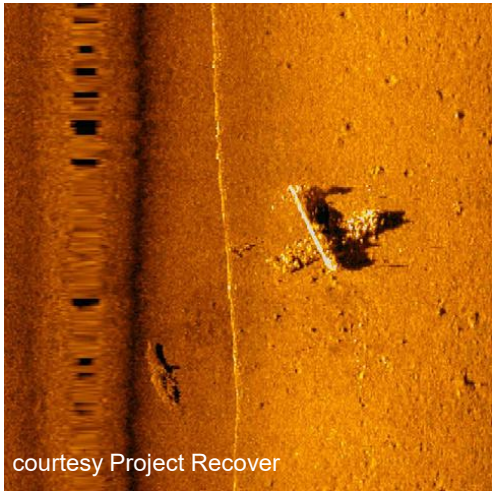
courtesy NOAA Ocean Explorer

Side-Scan Sonar Data Example

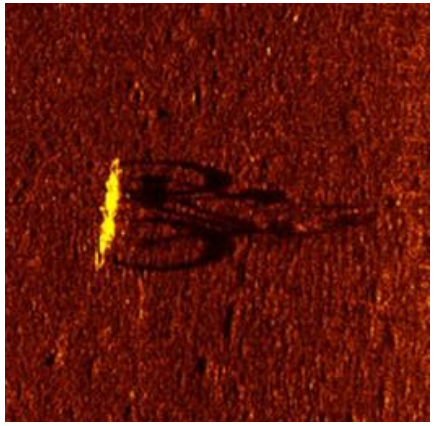




Can you guess the debris field?

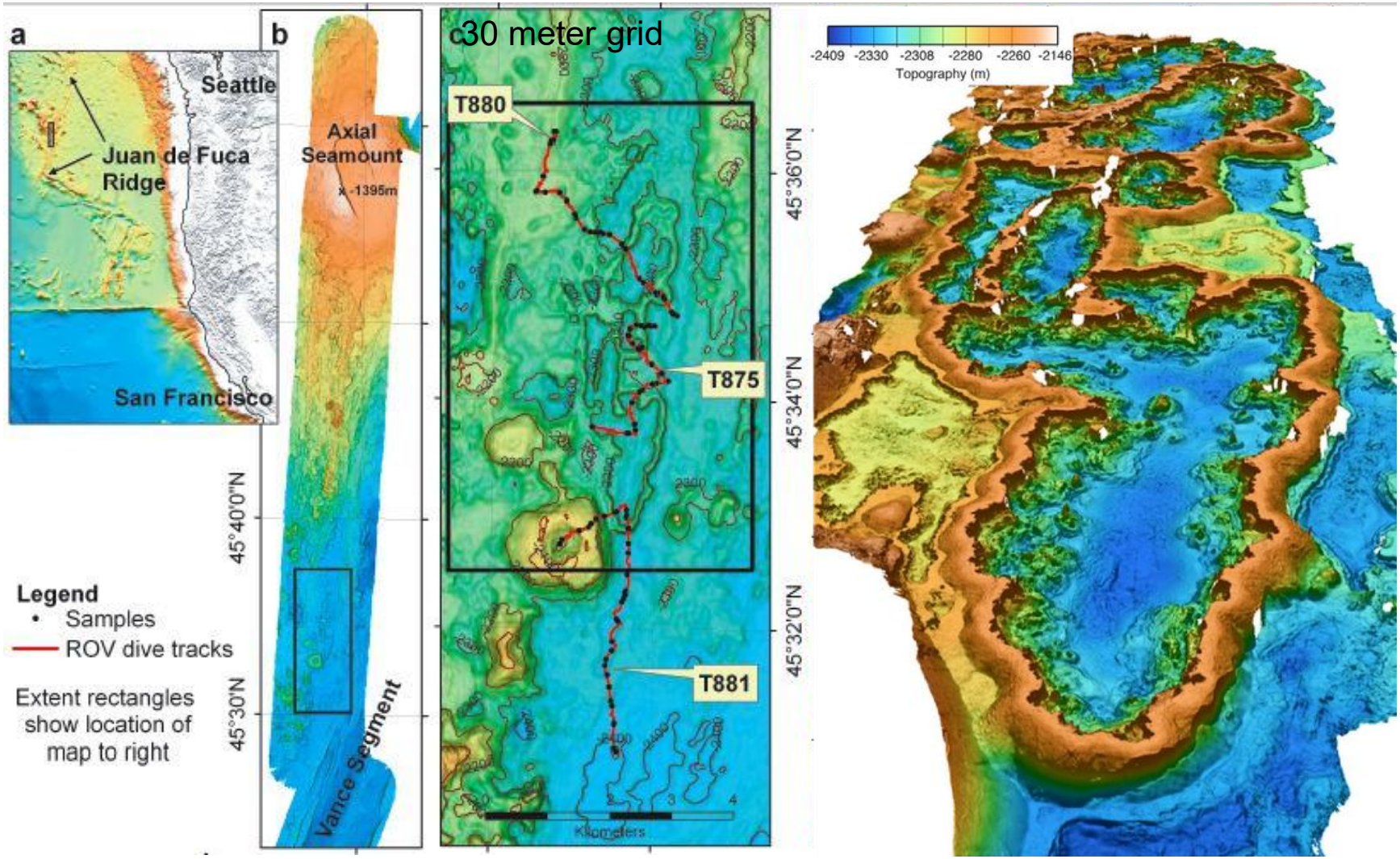


Use the shadow to interpret this target:



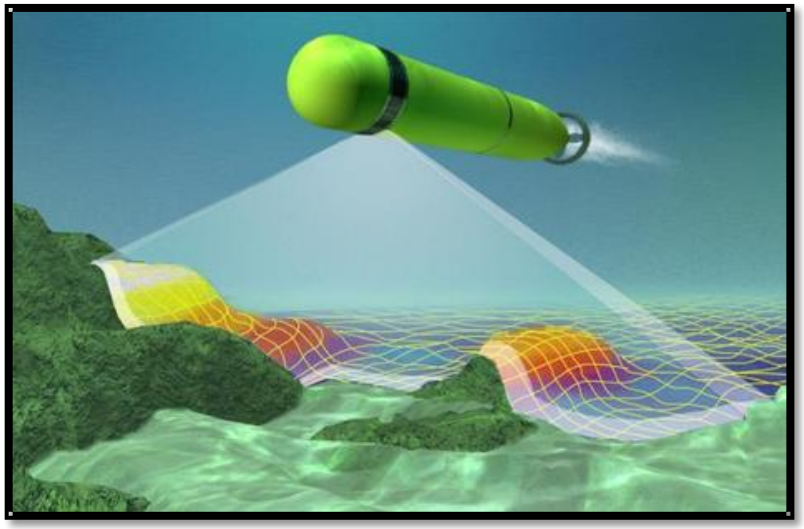
Multibeam Sonar Example

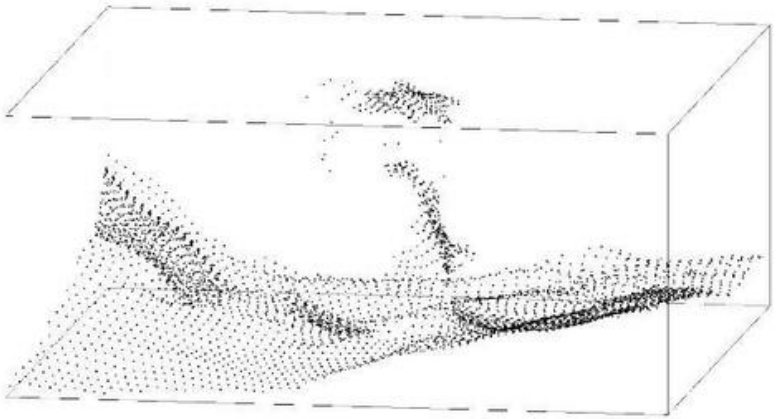
Drained Lava Ponds Along South Rift of Axial Seamount



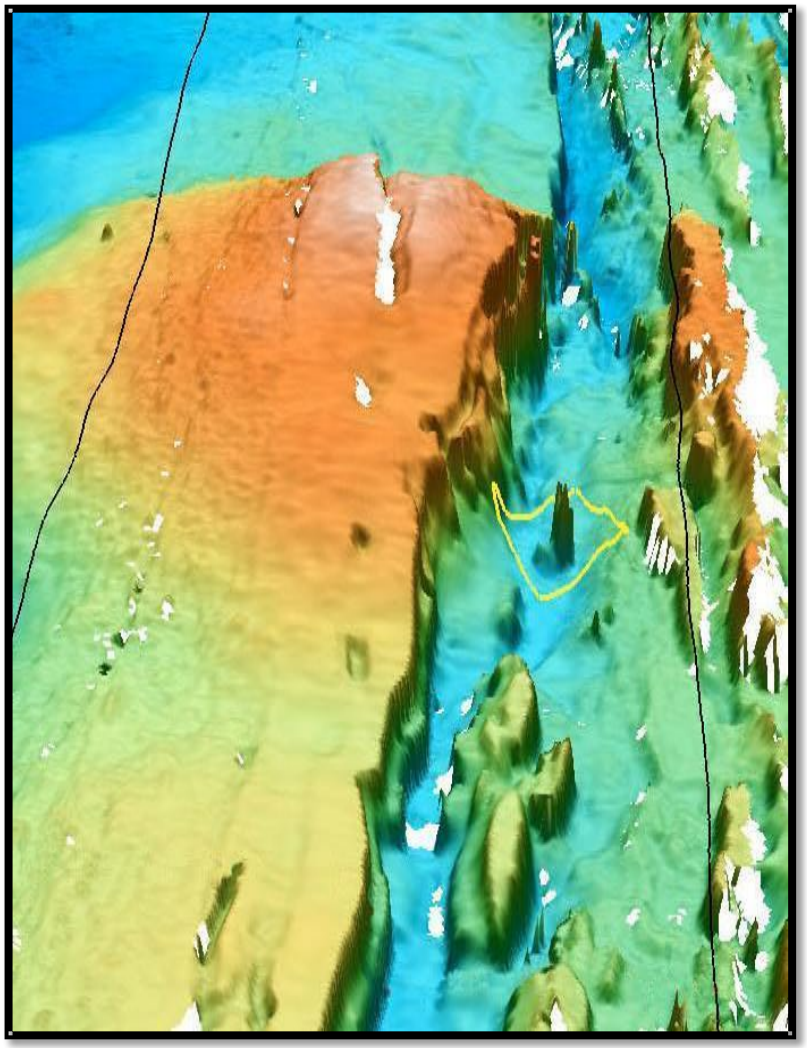
Dave Caress (MBARI), et. al. 2017

Finding active vents along the Alarcon Rise
likely locations identified by high resolution mapping





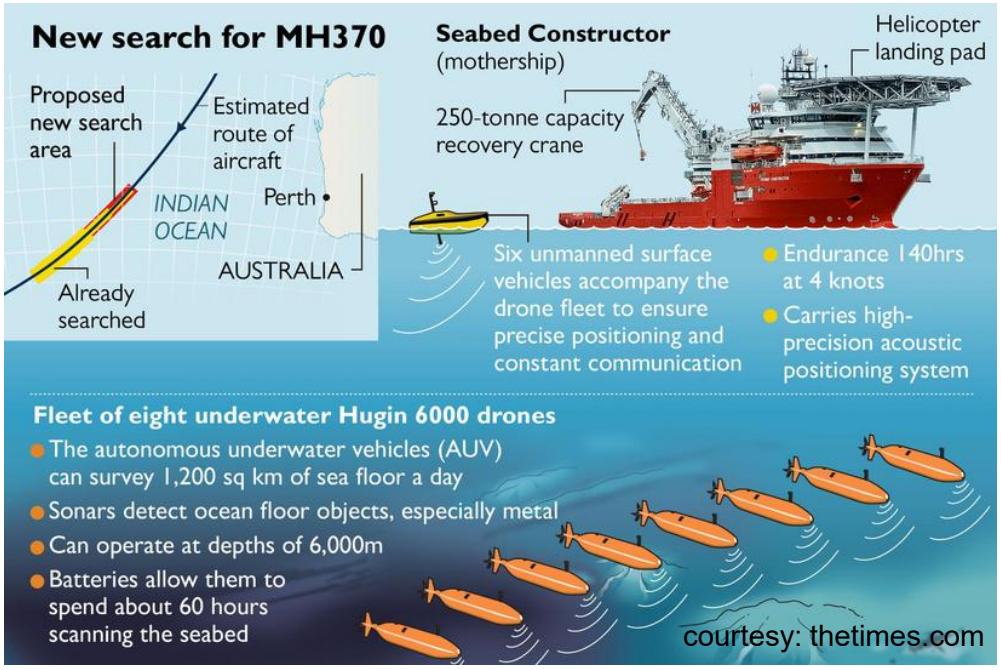
Point cloud of vent chimney in sonar soundings
(MB-System used for data processing)



AUV map: oblique view of chimneys in fault valley, part of the Meyibó field.

Jennifer Paduan (MBARI), et. al. 2017

Search and Salvage



MH370 - Hugin AUVs
And USV Global (now L3) USVs

Titanic digital twin
Remus AUVs



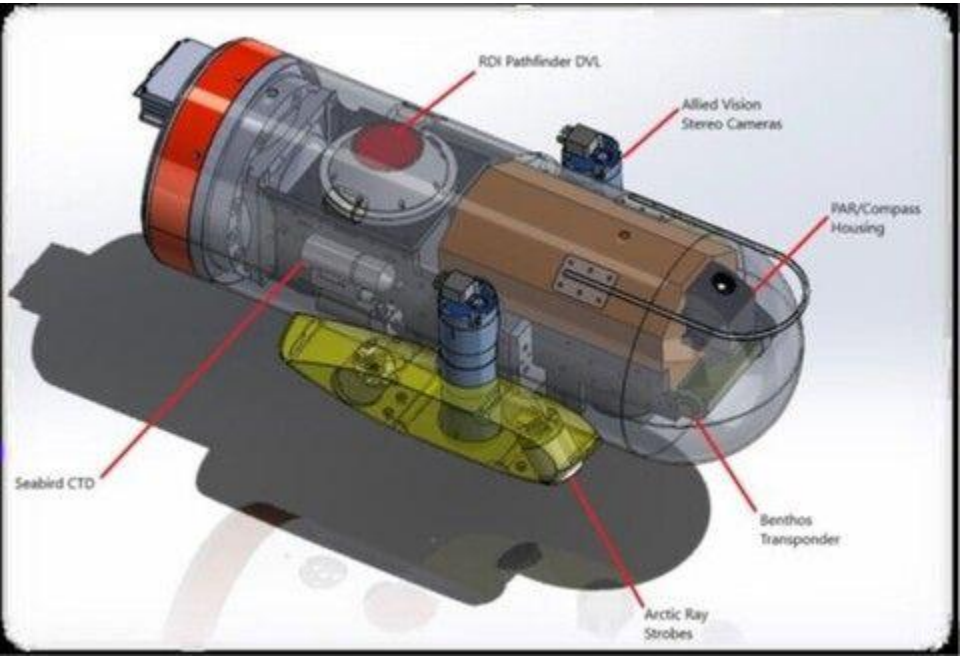
Frontier: 6-DOF hovering for mapping

Requires: precision navigation, control, and planning
Map at high resolution places traditional AUVs, ROVs, and other systems can't go



Macroimaging

(img WHOI)



(img WHOI)

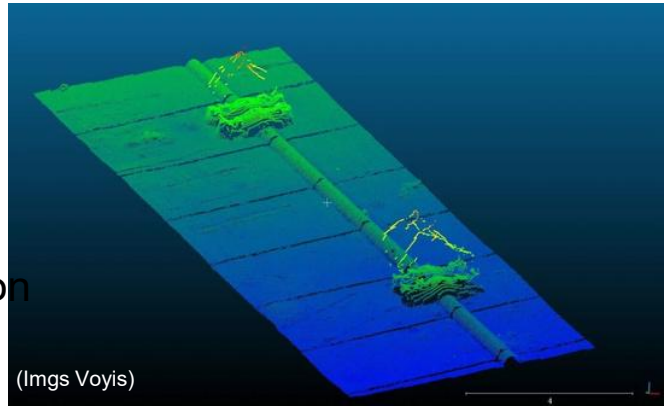


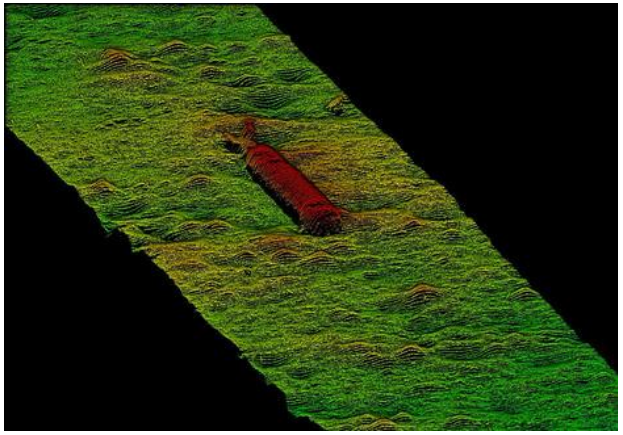
Technologies

- Conventional (low-res ←→ 4k)
- 3D/stereo/structured light
- Laser
- Hyperspectral/multispectral

Use cases examples:

- Behavioral ecology
- Habitat mapping
- Change detection
- Infrastructure inspection



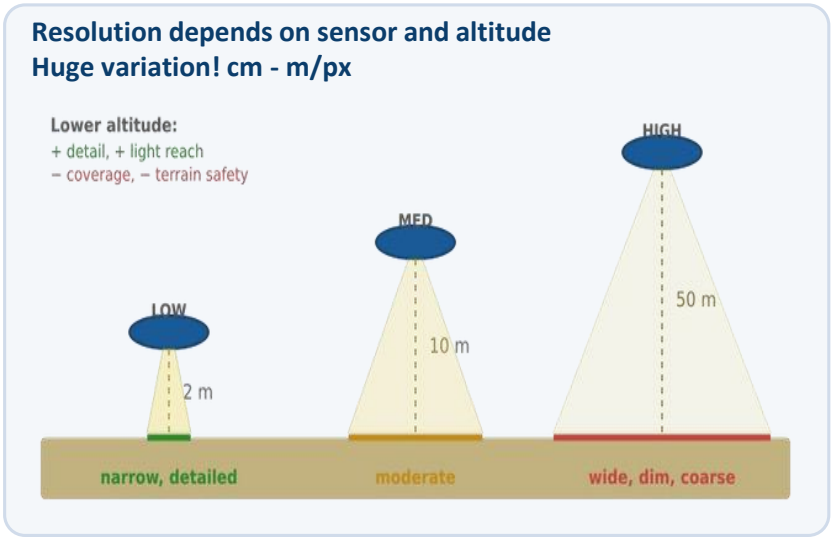


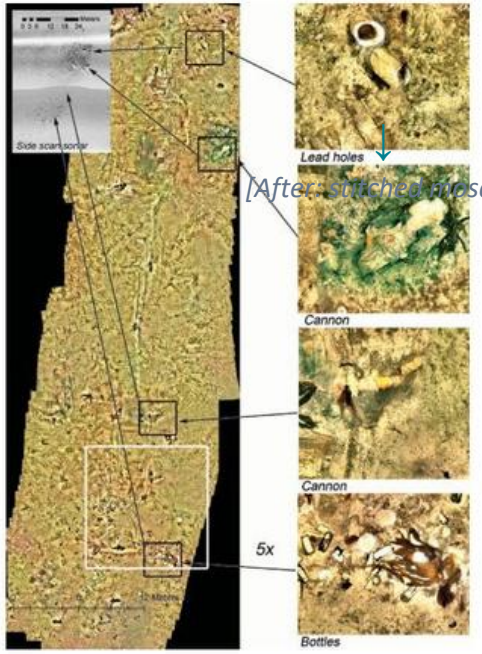
Voyis laser scanner mine detection and pipeline inspection on Kongsberg Hugin

Photomosiacing

Stitching together overlappingimagestocreateasingle, seamless composite image

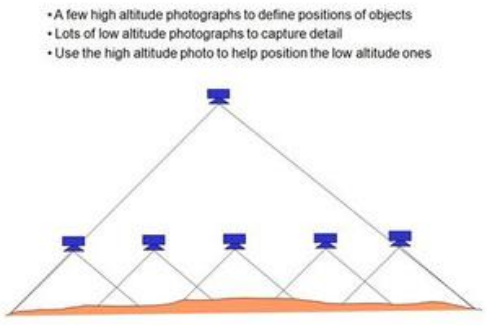
- Can be seafloor, vertical walls, structures, organisms
- May or may not be georeferenced
- 2D panorama or input to 3D reconstruction (SfM)
- Often merged with sonar or other data

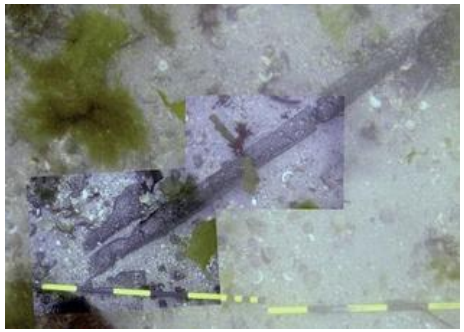




[After: stitched mosaic]

Img Ludvigsen et. al, https://tos.org/oceanography/assets/docs/20-4_ludvigsen.pdf





Imgs 3HConsultion, https://www.3hconsulting.com/techniques/TechPhotomosaics.html



Photomosiacing: why's it hard?

Corechallenge:Findinghowimagesrelateto each otherspatially

Main problem

- No absolutepositioningunderwater
- Nav drift accumulatesover time
- Need to determine relative positions from image content
- Must visually match features between overlapping images

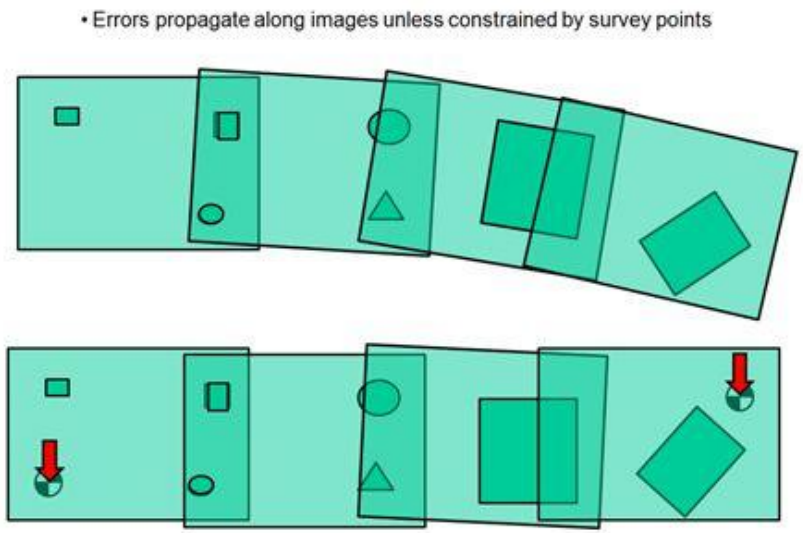
Vehicle and water properties complicate process

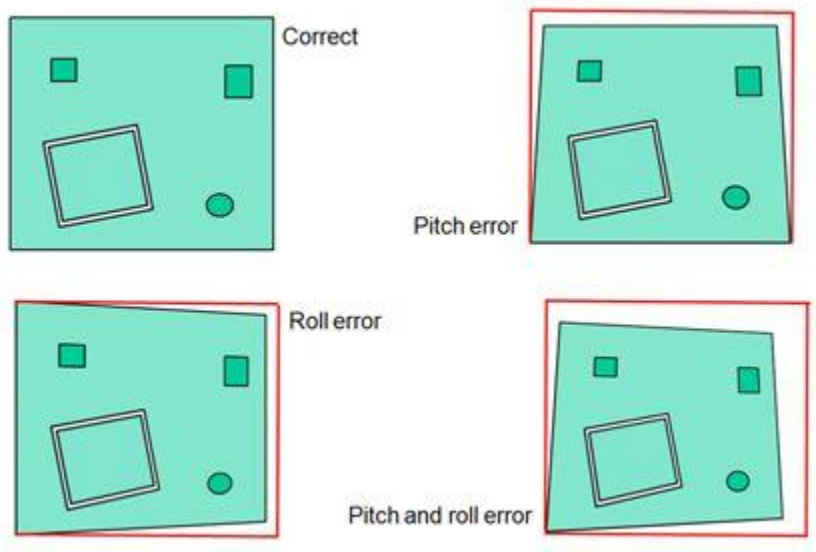
E.g.

- Camera lenses and water cause refraction, absorption, scattering
- Lights cause brightness variation
- Vehicle orientation and motion distorts image

Requirements

- Survey planning for resolution and overlap
- Vehicle telemetry and substantial postprocessing





Imgs 3HConsultion, https://www.3hconsulting.com/techniques/TechPhotomosaics.html

Data management

Ask:

How much data will we collect?
Where will it live?
What processing is needed before analysis?
Who does that processing?

Low-Volume

MB to low GB

Sources:

- CTD sensors
- Basic biogeochem
- Vehicle telemetry

Formats:
Timeseries formats:
NetCDF, CSV, Matlab, etc

Requirements:
Standard analysis tools

Medium-Volume

10s-100s GB

Sources:

- Multibeam
- Sidescan
- Still imagery

Formats:
Often proprietary

Requirements:
Processing software, storage plan

High-Volume

100s GB to TB

Sources:

- Video
- High-res imaging
- Acoustic backscatter

Formats:
Video, image, raw binary

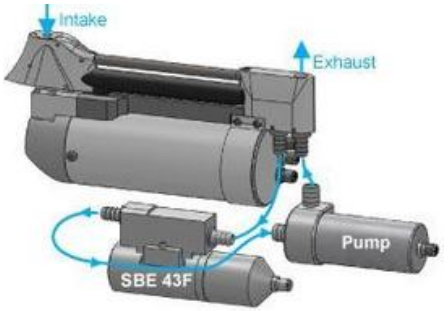
Requirements:
Storage infrastructure, processing pipeline
Consider subset strategy

Hi res video can easily approach TBs/day! Determined by bitrate, framerate, resolution,

Upper and Mid Water Instruments

Upper and mid water columns

- CTD (Conductivity, Temperature, Depth) ADCP
- (Acoustic Doppler Current Profiler) LISST -
- particle size analyzer
- Fluorometer
- Nitrate ISUS (In-Situ Ultraviolet Spectrometer)
- Optical backscatter
- Bathyphotometer
- Hydrocarbons, methane
- pH and O2

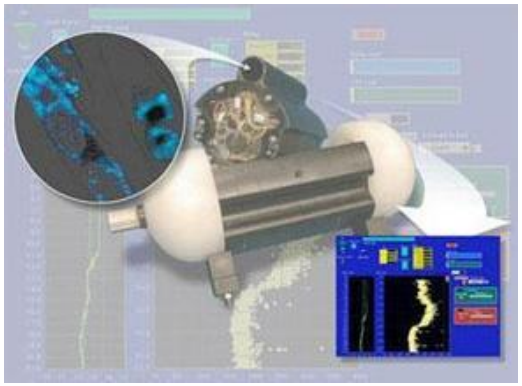


SeaBird GPCTD

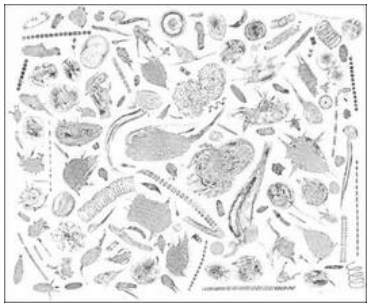


WetLabs SeaOWL





Bathyphotometer



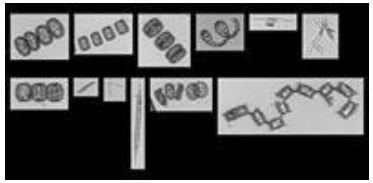
LISST-Holo68



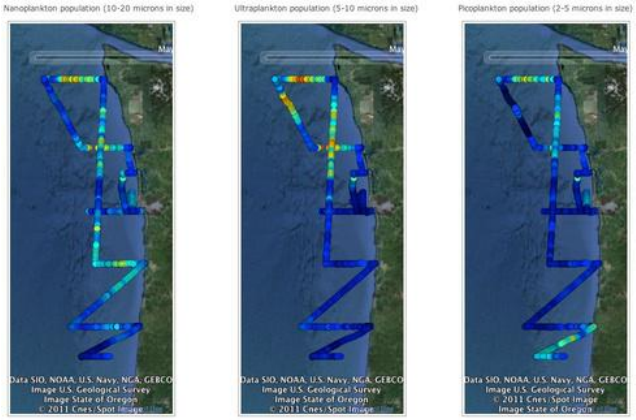
WetLabs Flourometer

Other Sensors

Insitu Microbe Identification
- Flow Cytometer
  - SeaFlow: 0.5 - 20 Micron • FlowCam 10 - 60 Micron

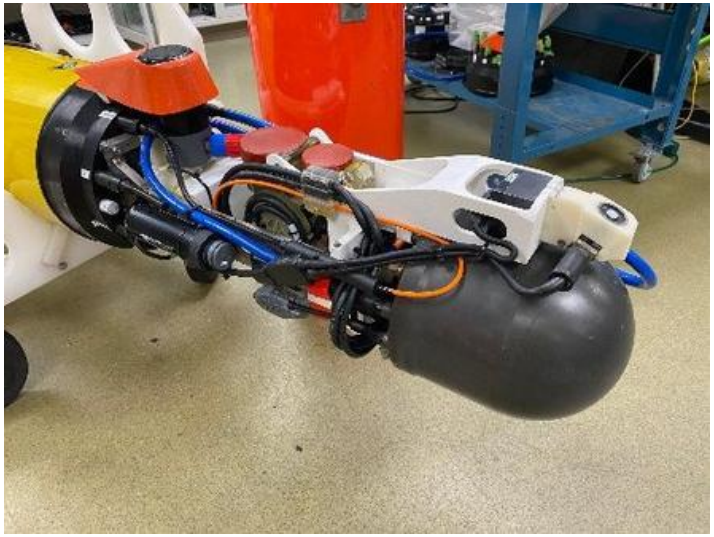


Fluid Imaging FlowCam

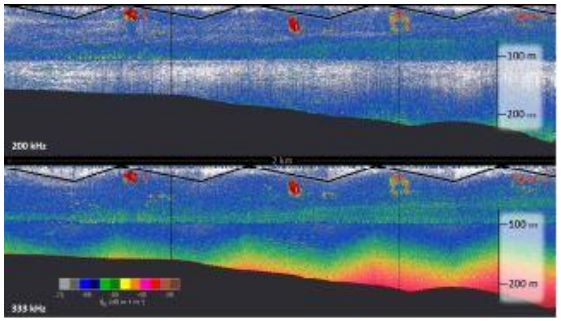


UW SeaFlow

Active bioacoustics



Kongsberg mini EK-80 Echosounder
200 and 333 kHz





Passive acoustic monitoring PAM



OceanInstruments NZ
SoundTrap recorder

Physical Sample Collection

Water sampling

- Highvolume vs low volume
  - Balancing sample size with vehicle buoyancy
  - Power requirements for sample processing
  - Storage constraints during long missions
- “Sipping” vs “gulping” – continuous or “smear” sampling



Pressure Management challenges

- Maintaining sample integrityduring ascent
- Preventing contamination from pressure changes
- Sealing mechanisms that function at depth

Other sampling

- Organisms (e.g. Sentry PlankZooka)
- Sediment (frontier: push cores moving to AUVs)





Payload Considerations for AUV Applications

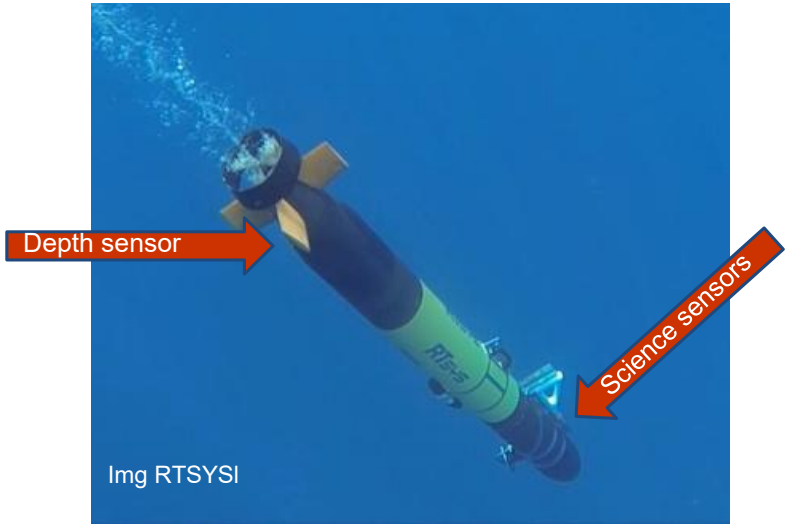
Geometry and motion affect when and where measurements are taken
:

When

- Delays create spatial smearing
- Flow paths, sensor settling, high-volume data transmission
- **Matters for:** Pumped flows, optodes, etc
- **Example**:
  - CTD data with 1s flow path
  - Vehicle travelling at 1 m/s = 1 m smear

Where:

- Sensor locations matter relative to navigation reference
- Vehicle attitude affects true sensor position
- **Example**: 30° pitch with sensors 2m apart = **1m vertical error**

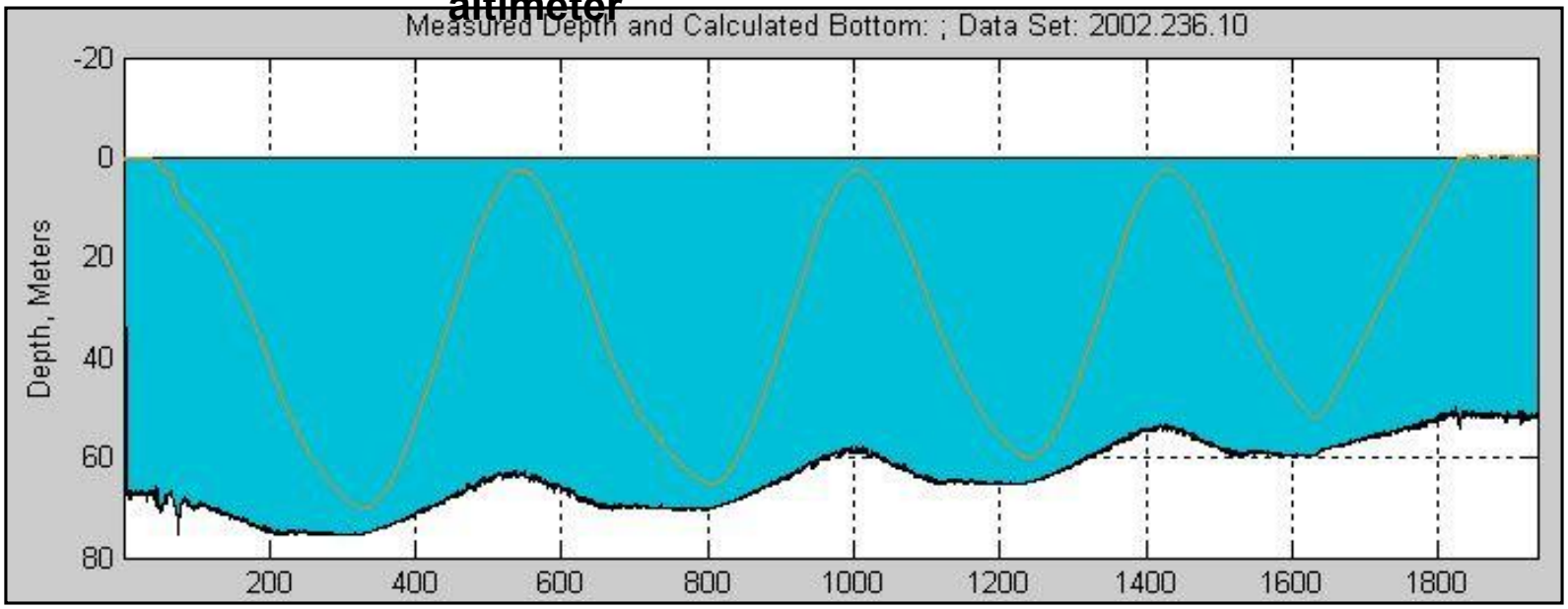


Payload Considerations for AUV Applications

Vehicle kinematics matter

- Vehicles skid and drift in turns
- Sensor orientation changes with vehicle attitude

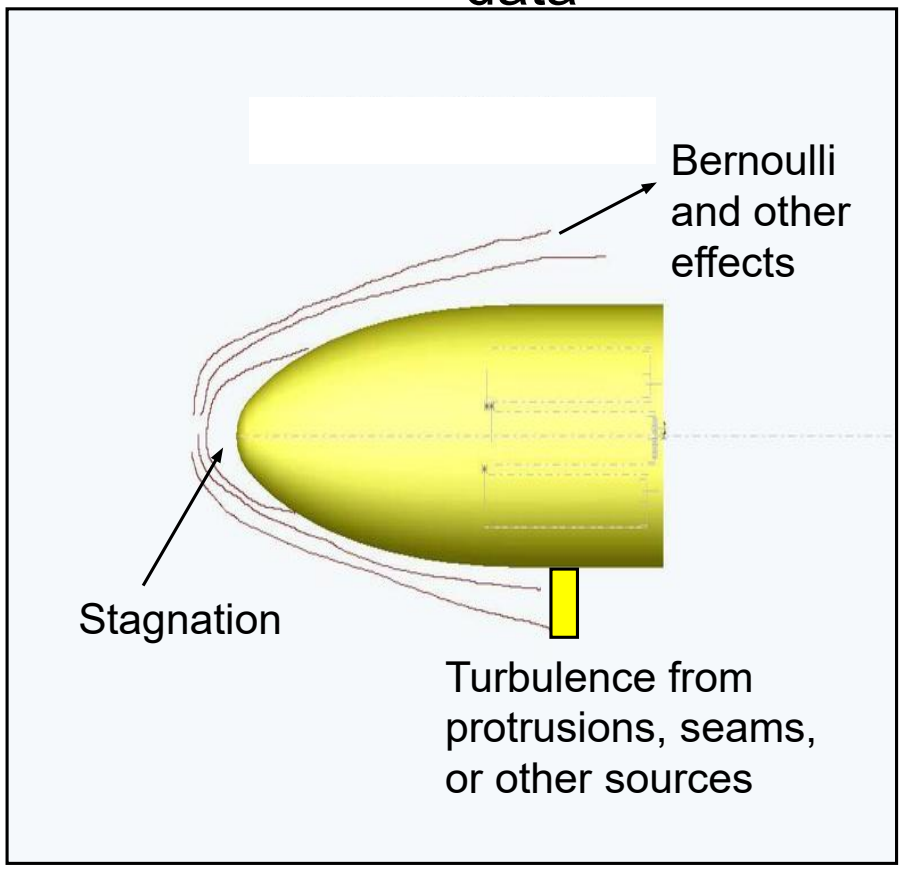
Example: bathymetry from altimeter



- When vehicle pitches down, altimeter reads closer; when pitching up, reads farther
- Smooth, sloped seafloor appears to have artificial "ripples"
- **Collect all raw vehicle and raw science data for post processing and analysis**.

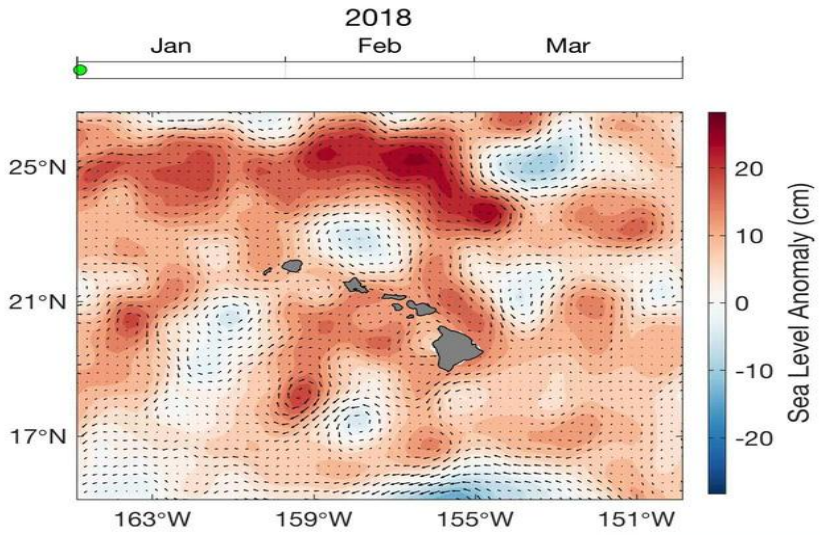
Payload Considerations for AUV Applications

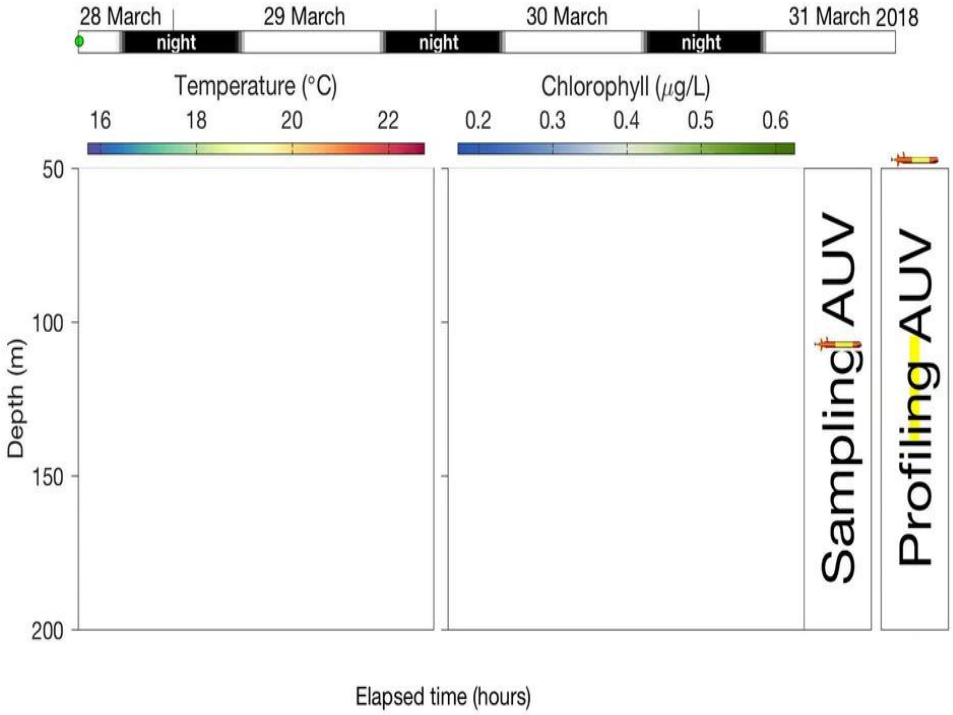
Flow around vehicle can affect the data





Coordinated ops





What's your reference?



GPS on the surface

- Easy, inexpensive, accurate
- Interrupts mission
- Surface is dangerous
- Weather/sea state dependent

Short missions, long-distance missions, shallow water



Acoustic beacons or ship

- Accurate (cm to meters)
- Requires infrastructure or ship
- Complex, expensive, affected by site specifics

Fixed sites, ship-supported ops, very deep water



Features of known terrain (TRN)

- Match sensors to known maps
- No infrastructure needed
- Very accurate, continuous reference
- Requires maps, distinctive terrain, good view of bottom, lots of computation



Features of unknown terrain (SLAM)

- Create map as you navigate
- Requires distinctive terrain, but no prior maps
- High sensing/compute requirement
- Emerging technology

Nav comparison

Method	Error Rate	Power	Cost	Notes
Dead Reckoning Compass + depth + speed estimate	~5-10% of distance	<~2W	$	
DVL-aided Dead Reckoning Addspeed-over-groundfrom seafloor	~0.1-1% of distance	~10W	$$	DVL needs altitude <~300m
INS (Inertial Navigation) "SmartDR":fusewithaccelerometers + gyros	~0.05-0.1% of distance	~15-20W	$$$	Best when combined with DVL
TRN / SLAM Continuous terrain/feature matching	Not determined by distance	Varies	Varies	Computation/terrain requirements



- Fast, high-quality fix at the surface
- Surfacing frequency drives mission design



- Frequent positioning without surfacing
- Infrastructure cost is high

Interreg NEXT Black Sea Basin

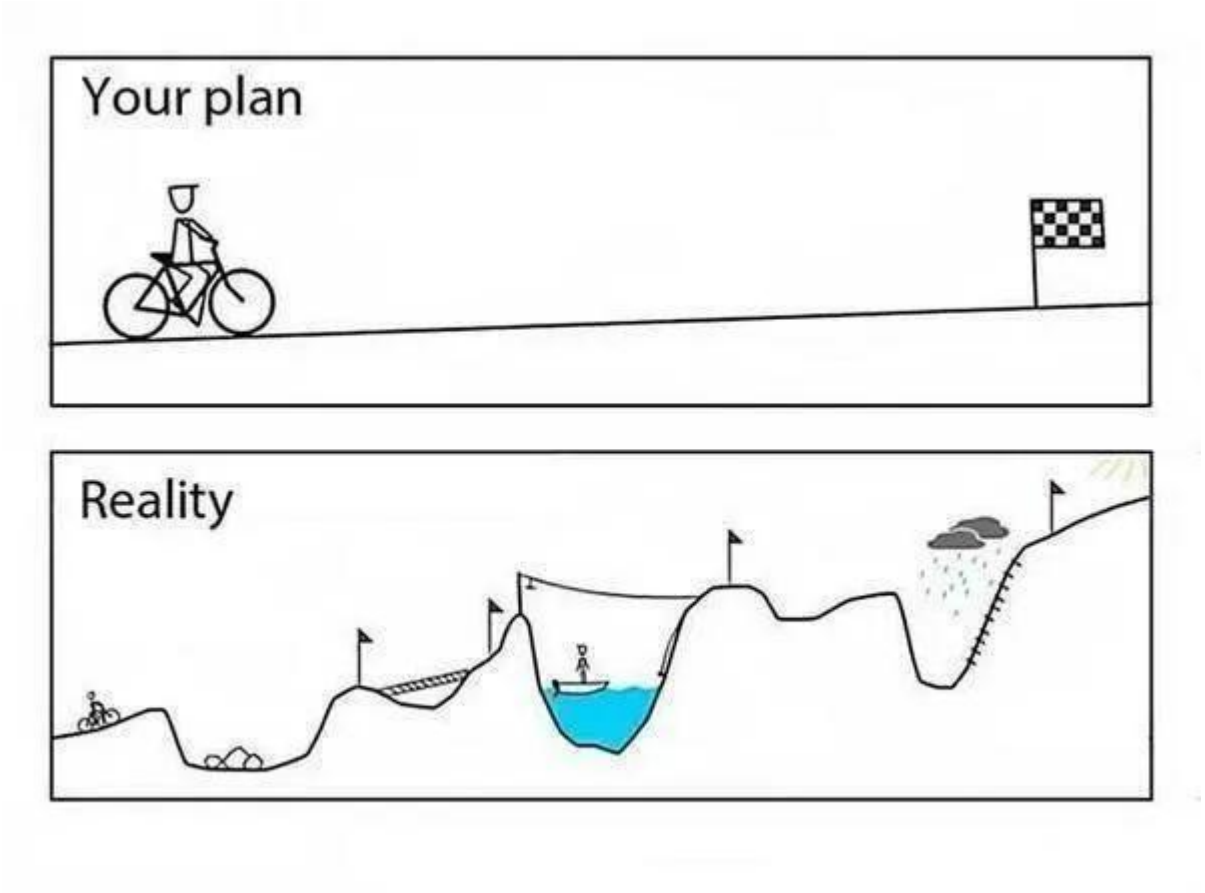
Co-funded by the European Union

EfxINNOs

What navigation method is most appropriate for your application?

Path planning and obstacle avoidance

How to do things → what to do



Manual control → Waypoint following → Path planning → Adaptive autonomy

- Obstacle avoidance Multi-
- objective optimization

- Dynamic replanning
- Collaborative planning

AUV Hazards



At sea

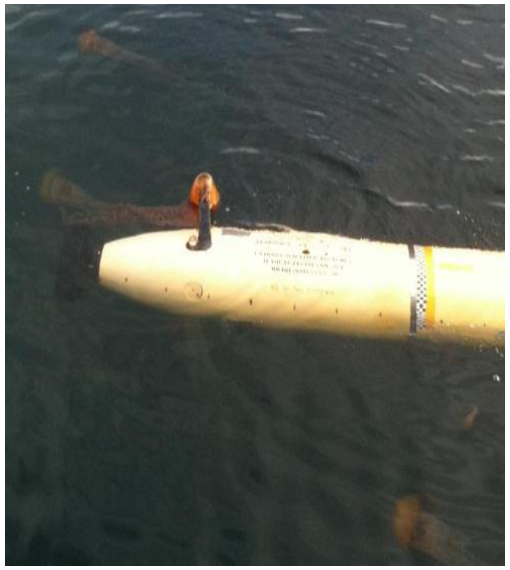
- Entrapment
  - Fishing nets
  - Under rocksor ledges
- Entanglement
  - Kelp
- Flooding
  -

  Seals
- Implosion
  - GPS position updatesand radio communications
  - Rendezvous for recovery
  - Antenna damage, or worse
  - Liability – was the boat or people injured?
  - Stolen
- Communications Failure

Vulnerable on the Surface







Prevention

- Stay off the surface!
- Situational awareness (yours and others)
- Notice to mariners
- Labelling
- Contact info and resources
- Be visible
- Redundancy and mission planning
- Response: be prepared and practice





Insurance

- Premiums dependent on history
  - Nohistory? Rate reflectshistory of all AUVs and is very expensive!
  - Good option to “piggyback” on group who knows what they’re doing to establish history
- Having an ROV available reduces insurance cost considerably
- AUVs have liability coverage but not much
  - Mostof thecostisfor vehiclereplacement versus human injury or environmental damage

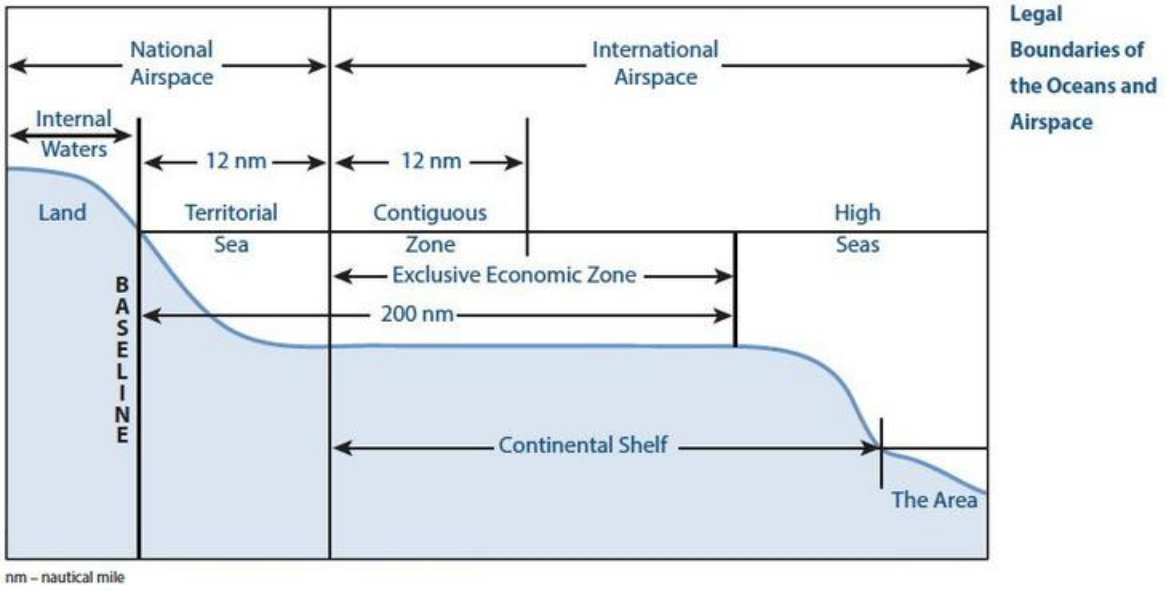


Regulation

- Evolving - everyone's making it up
- Farther along with ASVs
- Guidelines for ROVs
- UNCLOS application fuzzy
- Are AUVs vessels?
- Marine protected areas
- Export control
- AIS

What todo?

- Identify stakeholders
- Cite similar operations



(img Tufts University)

Selective Sensor Operation

Running high-power payloads only when necessary increases range and duration





Example: Harmful Algae Bloom Detection

- Transit mode: Prop+ CTD +Fluorometer only
- Look for bloom signatures
- Detection mode: Add flow cytometer + imaging (3x power)
- Only when fluorescence threshold exceeded
- Precise species identification and counting
- Candidate blooms 10% of mission? 1%?



Power Impact:

- 10% detection time: **3× range improvement** vs always-on
- 1% detection time: **4× range improvement** vs always-on

Sensor Selection

Your mission:Find aircraft wreckage

Parameters:
Area:200km²
Duration:72hours
Battery: 20 kWh

Available sensors:

- Navigation suite: 35W (required)
- Sidescan sonar: 45W
- Camera system: 40W
- Magnetometer: 8W
- Chemical sensors: 15W
- Acoustic transponder and modem: 15W

What sensors do you choose and why?

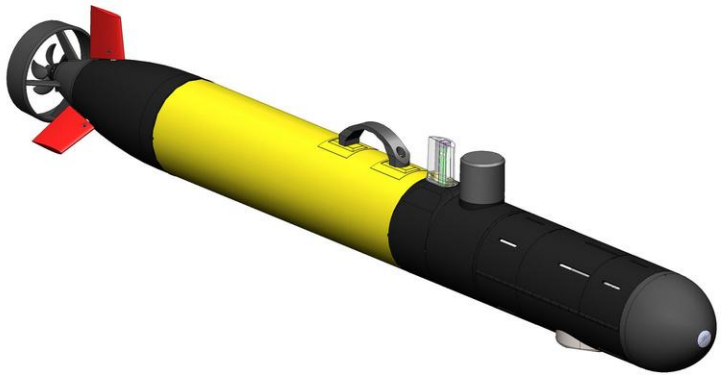


mAUV – Nemosense (RTSys)





AUV Description



Camera Configuration:

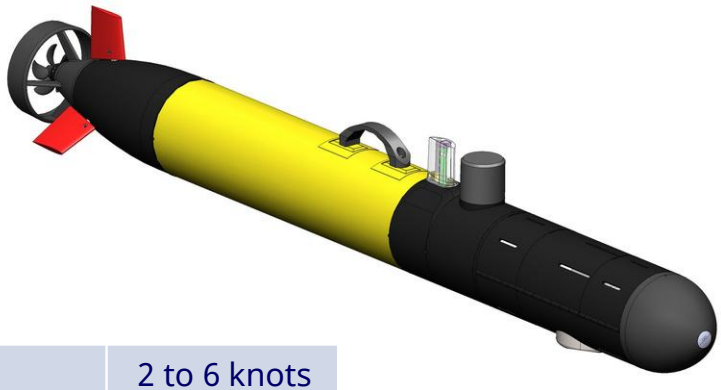
Total Length	1540 mm
⌀ Hull	124 mm
⌀ Fins	222 mm
Weight	≈ 14 kg
Battery capacity	600 Wh
Buoyancy	Positive
Max Depth	300 m

CTD Configuration:

Total Length	1550 mm
⌀ Hull	124 mm
⌀ Fins	222 mm
Weight	≈ 14 kg
Battery capacity	600 Wh
Buoyancy	Positive
Max Depth	300 m

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Dynamic performances



Speed	2 to 6 knots
Speed accuracy	± 0.5 knots
Heading change rate	± 5°/s
Heading accuracy	± 3°
Depth (1 meter step)	0 to 300 m
Depth accuracy	± 0.5 m
Sea Conditions limits (expert)	Sea State 4
Memory Capacity	128 GB

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Navigation Safety

In case of safety issue detection, the mission is ended.
Propulsion is stopped and the AUV surfaces due to its positive buoyancy.
The flashing light, the UHF, the safety alarm and the red LED are activated.



Safety Activation

Mean Pitch control	max 30° during 3s
Mean Roll control	max 40° during 5s
Roll control	max 120°
Maximal depth	300m
Altitude	1m step
Error on critical sensors	INS, pressure sensor, battery …
Internal pressure	More than 850 mbar

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NemoSens Radius Turns

When you plan a mission take care about the radius of the turn, the potential current.

Velocity (knots)	Radius (m)
02	12
03	18
04	24
05	30
06	36
07	42
08	48
09	54
10	59
11	65
12	71

Speed turning : 6°/s
20% margin

NemoSens Radius Turns

If the AUV miss the WayPoint it will turn around until it reach the WayPoint. If not the AUV will stop the mission at the timeout set.

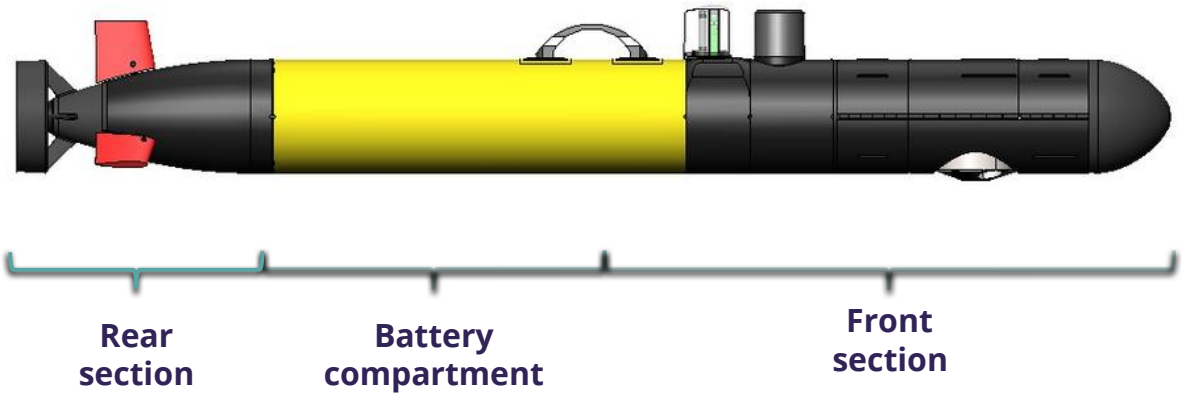
If need, you can :

- Decrease the velocity between before the turn
- Pan larger rails

•Increase the radius fot the validation of the WayPoint

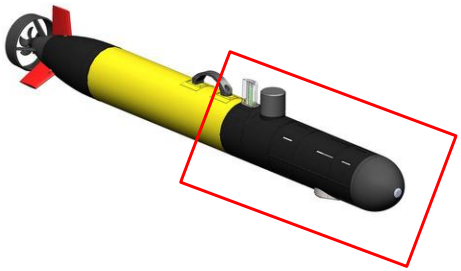
•Create two family rails who can crossed.

AUV Description



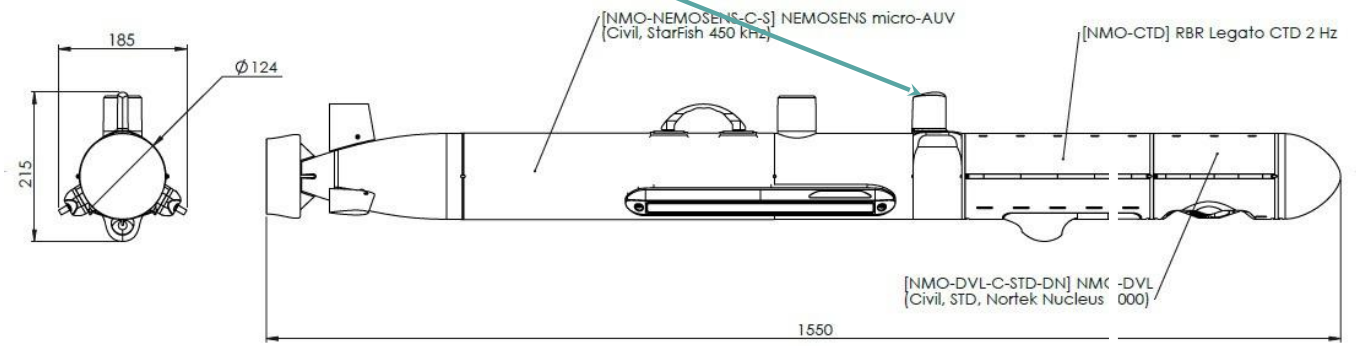
IATA Certified

The front section in CTD configuration



Mast:

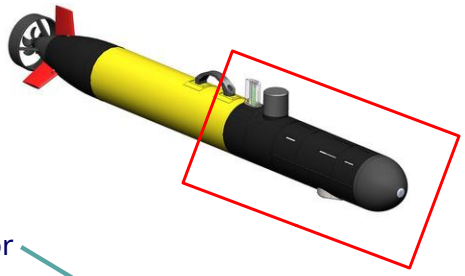
- GPS antenna (1575 MHz)
- Wi-Fi antenna (2.4 GHz)
- UHF antenna (868MHz)
- Status LED
- Flashing LED
- ON / OFF with magnet sensor

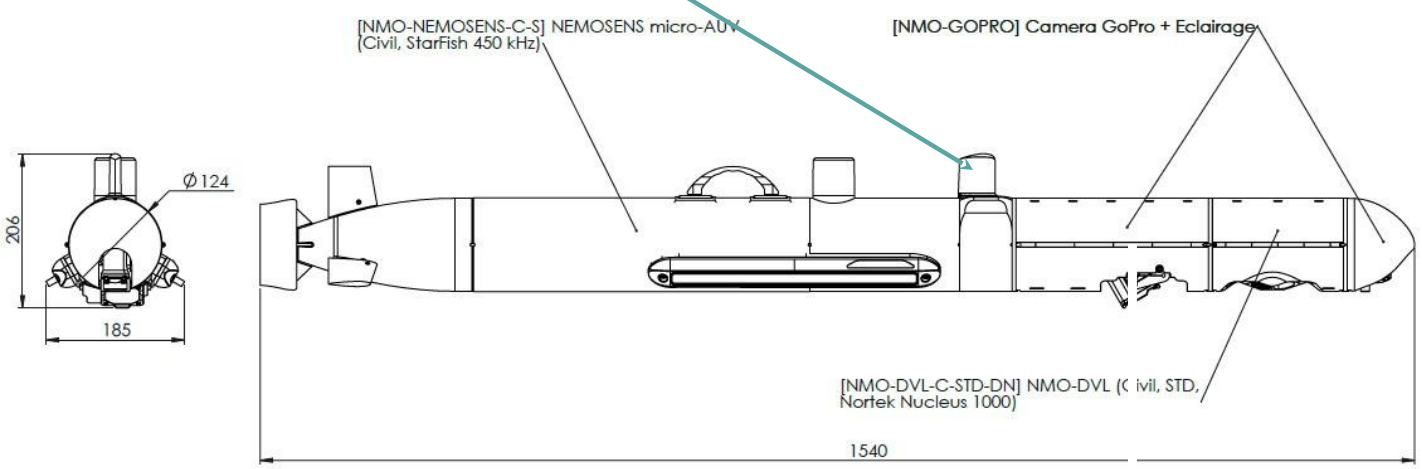


The front section in Camera configuration

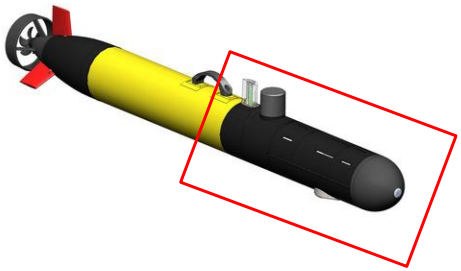
Mast:

- GPS antenna (1575 MHz)
- Wi-Fi antenna (2.4 GHz)
- UHF antenna (868MHz)
- Status LED
- Flashing LED
- ON / OFF with magnet sensor





Front Section : Payloads (DVL)





Foam

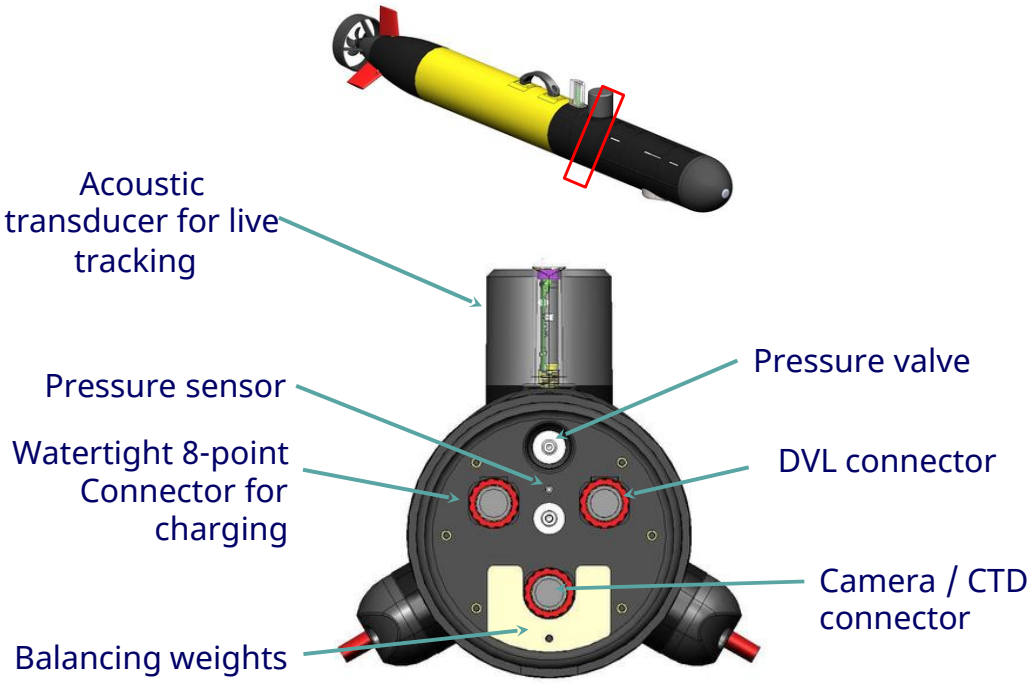


Deepler **V**elocity
Logger
Nortek Nucleus

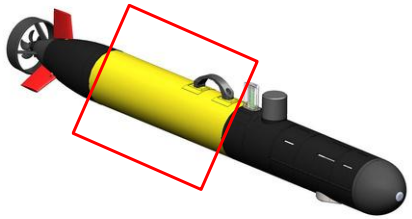


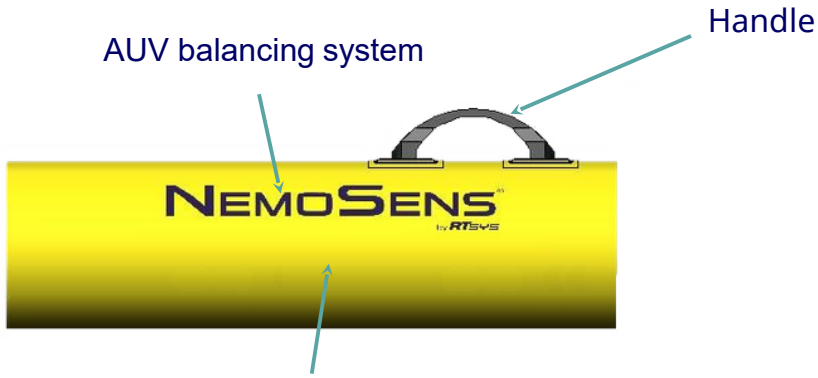
Protective
housing

Bulkhead of the Nemosens

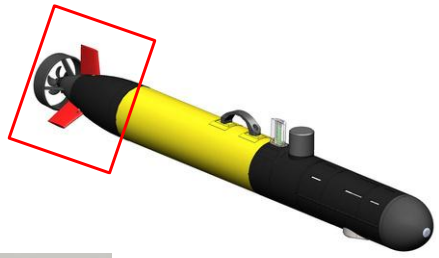


The battery section

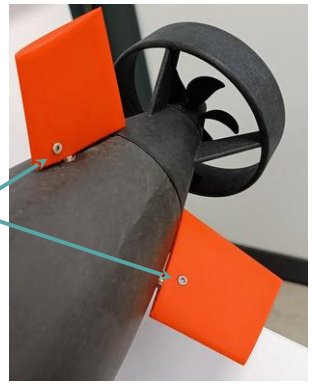




The rear section



2 screws per fins



Nozzle

Propeller with 2 opposite screws



Do not handle the propeller when the AUV is on. Do not run the engine in the air.

Product environmental characteristics

The AUV can navigate by either cold or warm water temperature. Once launched, the AUV's internal temperature remains the same and the battery life will not be impacted either.
Storage conditions (especially temperature) might impact the autonomy of the robot. Storage advice is provided to minimize the impact.

	Min	Max
Seawater temperature	-5° C	40° C
Air temperature	-20° C	54° C

Long Storage

For long storage (more than one month) and standard transport, the AUV shall be kept in a dry and climatized environment. Temperature Range [0 / 30]°C. The storage location shall be ventilated.



The AUV shall be stored far from heat sources, open flames, food and drinks. The AUV shall not be stacked. If the temperature of the battery section increase do not stand in front of behind the AUV !

	Min	Max
Storage temperature	-20° C	54°C
Room Humidity	45%	85%
Battery must be maintained between	30%	50%

The discharge rate is about :
AUV On: 1% every 60 minutes
AUV Off: 5% per month

Power management

NemoSens battery has a capacity of 600Wh.
The charger supplied with the NemoSens shall be used.

The complete charge lasts up to **6** hours.



*The LED is **red** when it's charging*



*The LED is **green** when the charge is over*

The charging rate is about 15% every 60 minutes

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Registration Booklet

*A **registration booklet*** is delivered with every AUV to register:

- Control of the hours of operation
- Control of battery loading cycles
- Event tracking
- Follow-up on technical fact sheets
- Monitoring of the evolution of the configuration

Tracking hours of operation				
Date	Time On	Time Off	Total Hour	Remarks

CHARGE CYCLE CONTROL					
Cycle	Date	Serial number	Operator	Default	Remarks

EVENT TRACKING			
Date	Subsystem	Modification / evolution / dysfunction	Remarks

FOLLOW UP ON TECHNICAL FACT SHEETS		
Date	Sheet number	Remarks

MONITORING OF THE EVOLUTION OF THE CONFIGURATION			
Date	Subsystem	Reference	New S/N

Backup Safety

The AUV is equipped with a safety valve avoiding any internal overpressure accident.

The AUV is NOT equiped with any leak sensor. The user shall ALWAYS check the internal pressure before any trial in water.

In case the internal pressure is not within [700-850] mbar, do NOT launch the AUV.





Be aware lithium is a very flammable product.
If the safety valve triggers, put the AUV outside of the building or in a water tank. The battery will keep consuming until the hot spot remains.

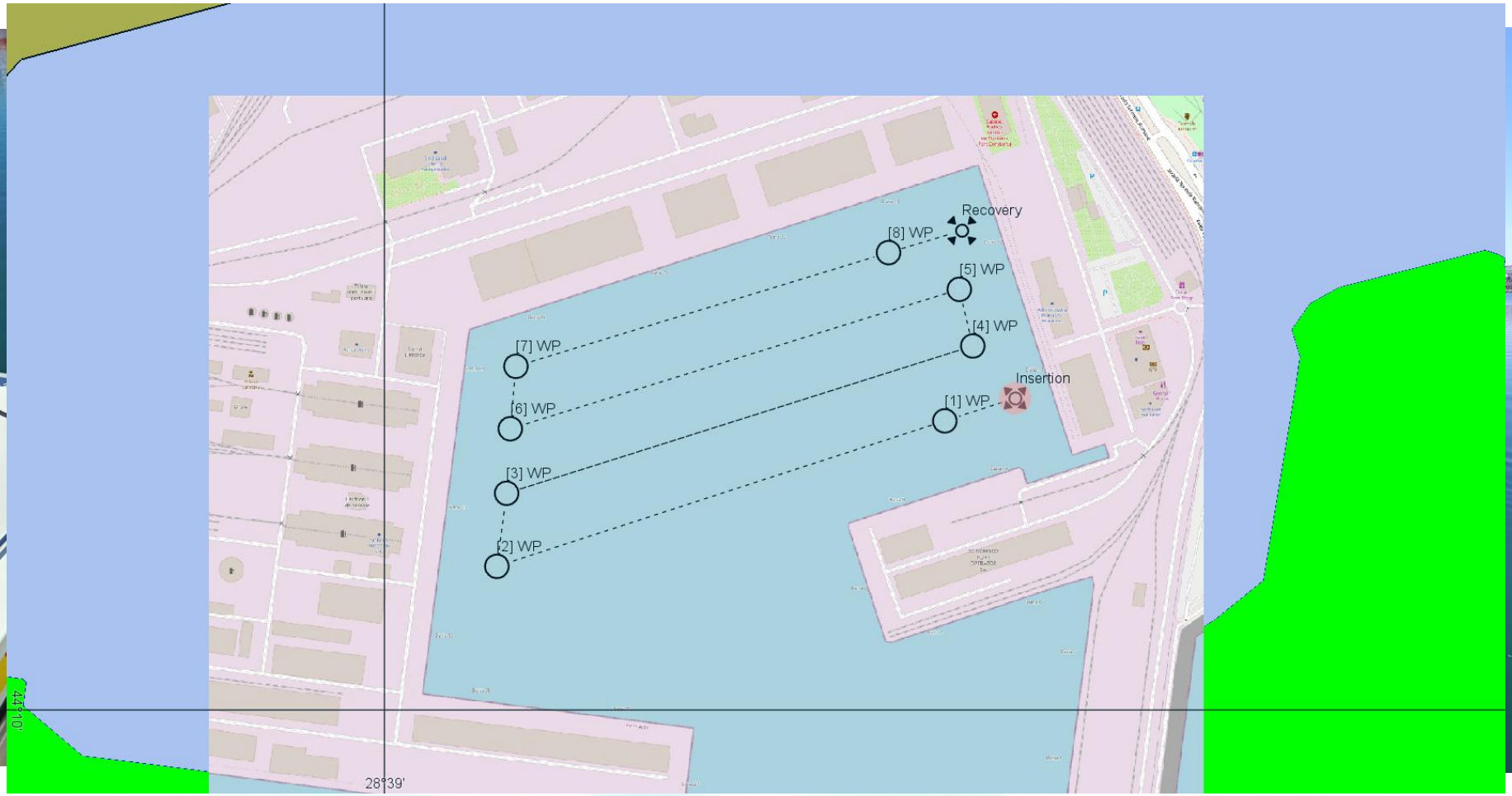
Navigation

The AUV is equipped with several navigation sensors:

- An INS (Inertial Navigation System), which measures the AUV’s attitude, pitch, roll and yaw.
- A GPS, for locating the AUV when it rises to the surface.
- A pressure sensor to measure the immersion (depth).
- A DVL (Doppler Velocity Log), which measures:
  - A velocity estimation relative to the water.
  - The absolute velocity (according to the seabed), if the AUV is navigating at less than 50 m from the seabed.
  - The relative position (altitude) from the seabed through the sounder function (if the AUV is navigating between 1 and 80 m from the seabed).

The INS centralizes all the information from the different sensors in order to get an estimation of the AUV's position. It is paired with the GPS which is able to locate the AUV when it rises to the surface.

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Recovery
[8] WP
[5] WP
[4] WP
[7] WP
Insertion
[6] WP
[1] WP
[3] WP
[2] WP
44°10'
28°39'

Interreg

Co-funded by the European Union

NEXT Black Sea Basin

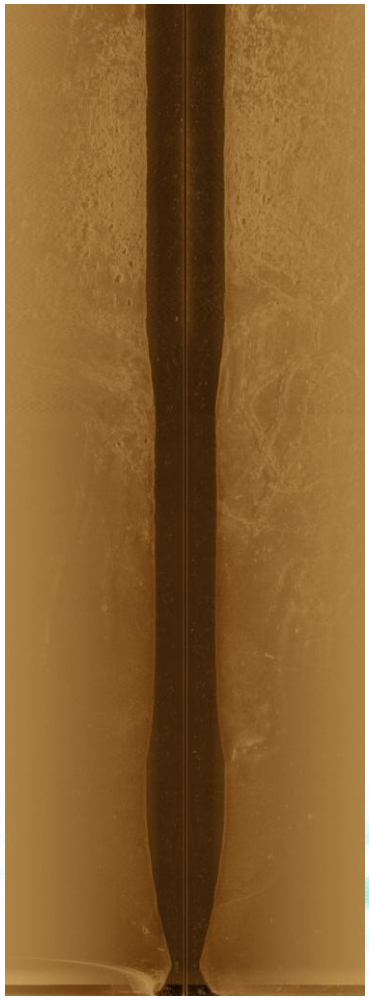
EfxINNOs

Launching from Constanta Port Key



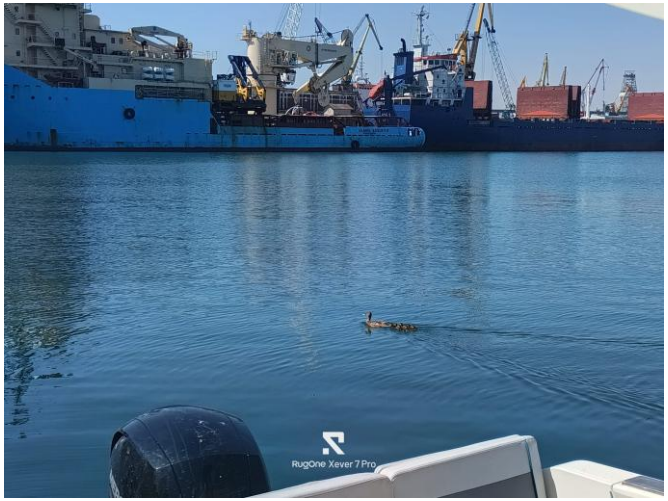
BSB00193 – EfxINNOs

Side Scan from Constanta Port
- terminal basin -











Interreg

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NEXT Black Sea Basin

EfxINNOs

Requirements for an Integrated Black Sea Ocean Observing Network – EfxINNOs experience



- to address existing gaps in the spatial and temporal coverage of oceanographic observations
- to strengthen regional capacities for marine environmental monitoring, and operational forecasting
- to integrate existing national and regional monitoring infrastructures with complementary autonomous observing technologies, including multiparameter buoys, underwater gliders, autonomous profiling floats, acoustic current profilers, surface drifters and **autonomous underwater vehicles**.
- to attain continuous observations of essential physical and biogeochemical variables, especially in coastal and shelf areas exposed to significant environmental and anthropogenic pressures.
- to harmonize the measurement protocols, quality assurance procedures, metadata standards and data management practices to ensure interoperability with European and international marine data infrastructures, including Copernicus Marine, EMODnet, SeaDataNet and GOOS.
- to support the integration of in situ observations, satellite remote sensing and numerical modelling, contributing to improved oceanographic forecasting, marine pollution tracking, coastal hazard assessment and evidence-based marine management.
- to follow the long-term sustainability will require coordinated regional governance, technical capacity building, maintenance arrangements and stable operational funding.
- to maximize synergies between established infrastructures and new autonomous technologies, providing a scalable and cost-effective framework for sustained Black Sea observations.

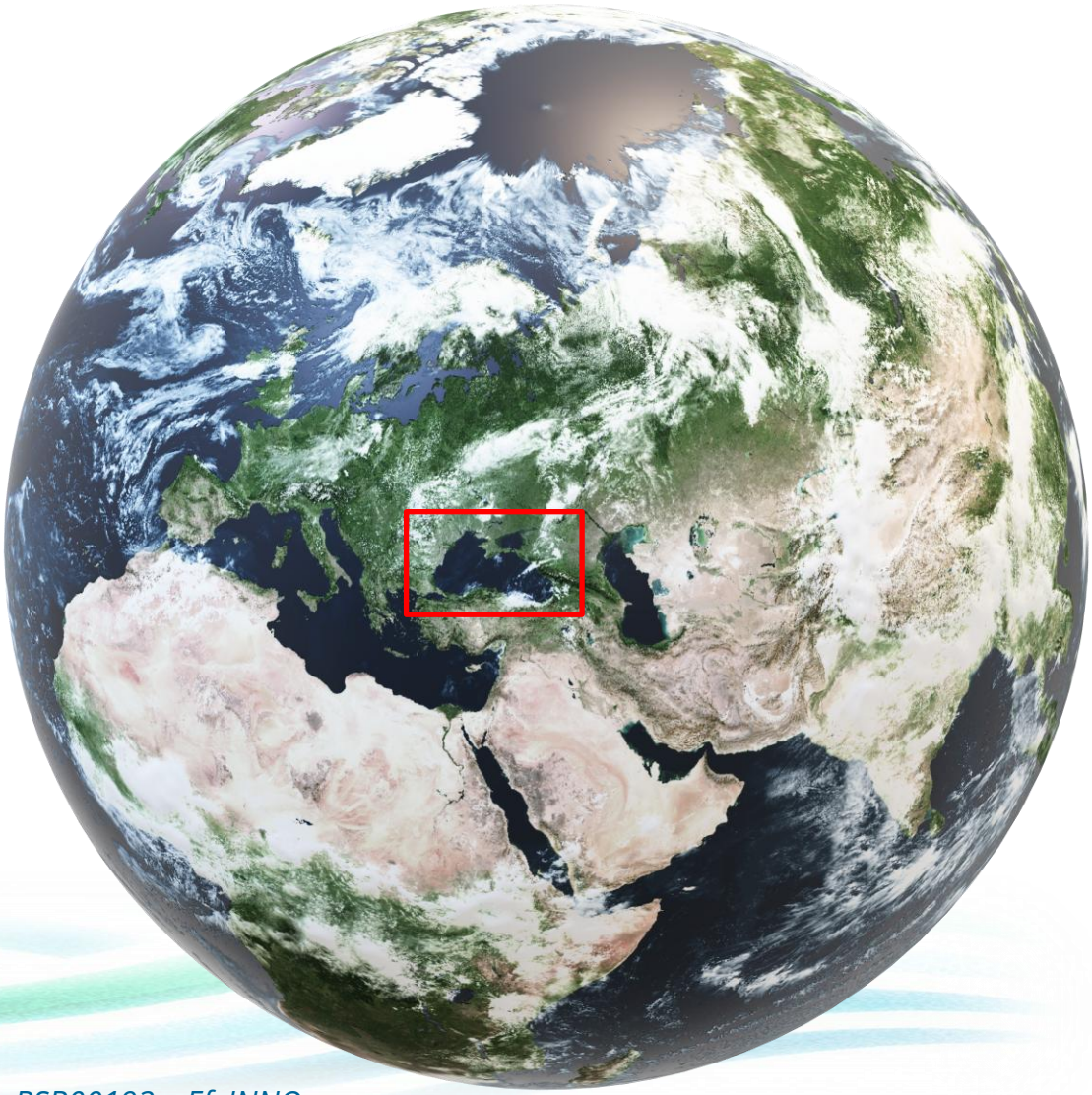
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NEXT Black Sea Basin

EfxINNOs

Thanks for your attention!



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NEXT Black Sea Basin

EfxINNOs

Intelligent Underwater Survey System

PROJECT CONCEPT, OBJECTIVES AND METHODOLOGY

Synchronized sonar, camera, navigation and trainable AI

assoc. prof. Hristo Nenov

TU - Varna

Romania, Constanta 28 October 2026

Background: Current Data Reality



REAL CAMERA FRAME FROM THE SOZOPOL SURVEY

CAMERA

4K H.264 video provides visual seabed evidence.

SONAR

XTF records provide acoustic returns and timing.

NAVIGATION

Position, depth and attitude provide the spatial reference.

The proposed system links the three records on one timeline.

Objectives: Synchronized Observation



Objective: create one observation record for the same place and time across camera, sonar and navigation.

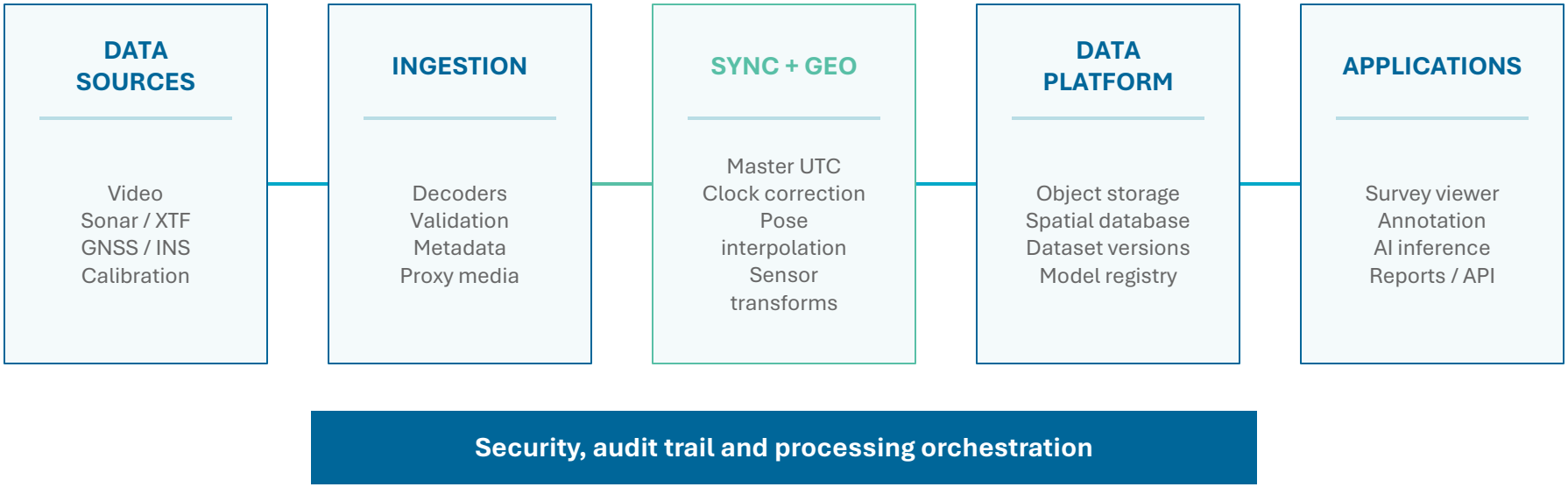
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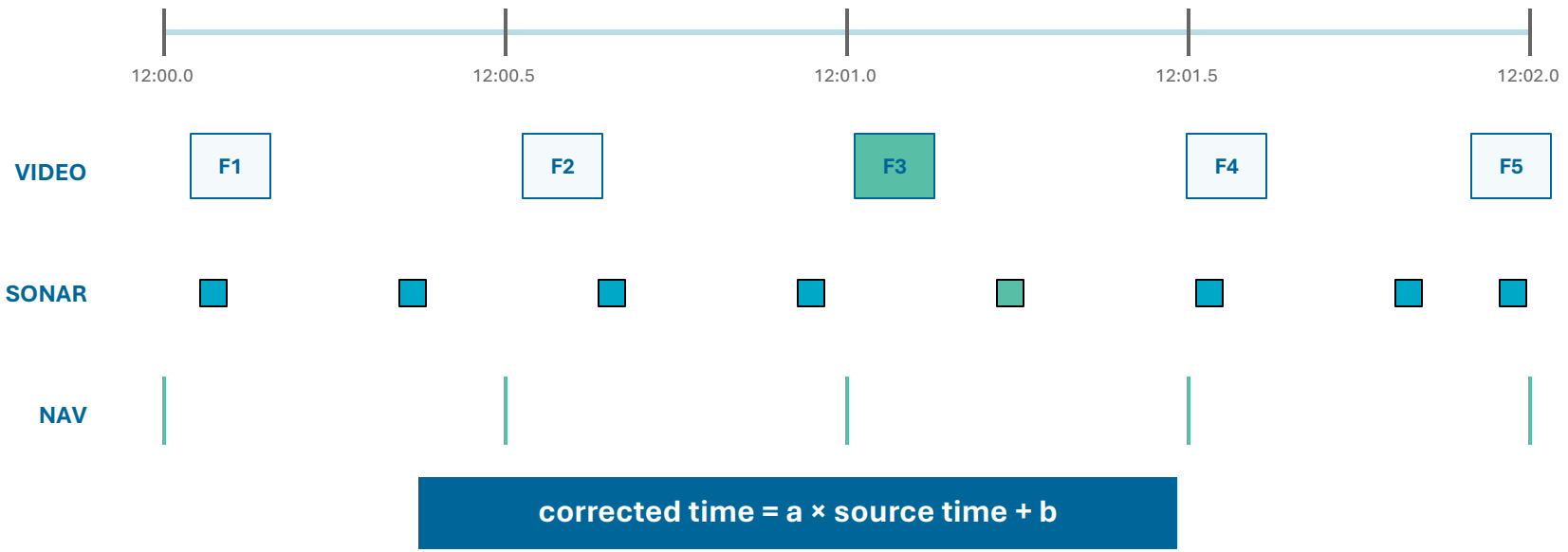
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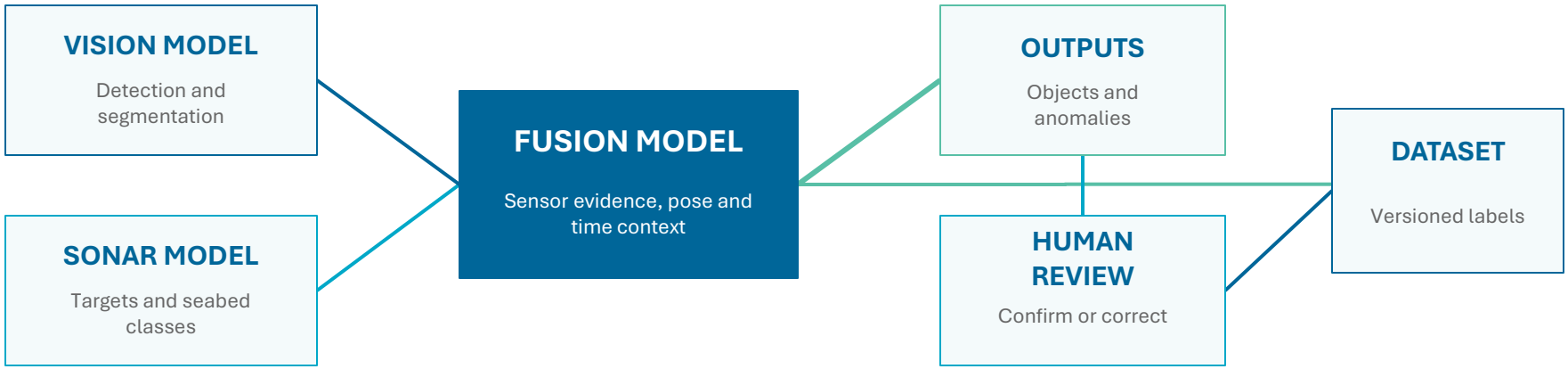
Methodology: System Architecture



Methodology: Time and Spatial Synchronization



Methodology: Trainable AI Module



Confirmed corrections become training data for the next model version.

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Methodology: Operator Workflow

01	02	03	04	05
SELECT	**COMPARE**	**REVIEW**	**ANNOTATE**	**EXPORT**
Map or timeline	Camera and sonar	AI confidence	Confirm or correct	Dataset or report

The same workspace supports survey review, annotation and quality control.

Methodology: Phased Delivery

PHASE 1

Data foundation

Decode inputs
Extract time and position
Define the common record

PHASE 2

Survey viewer

Linked camera, sonar and map
Timeline navigation

PHASE 3

AI baseline

Annotation workflow
Separate sensor models

PHASE 4

Multimodal system

Fusion model
Automated processing
Integration API

First milestone: synchronized review of one representative survey dataset.

Expected Outcomes and Next Step

MVP acceptance criteria

DATA INGESTION
Video, sonar and navigation load without manual conversion.

SYNCHRONIZED REVIEW
The operator opens the same moment in camera, sonar and map.

TRAINING OUTPUT
Confirmed observations export as a versioned dataset.

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Use of mAUVs in the monitoring of benthic habitats & marine litter

ΔΗΜΟΚΡΙΤΕΙΟ ΠΑΝΕΠΙΣΤΗΜΙΟ ΘΡΑΚΗΣ
DEMOCRITUS UNIVERSITY OF THRACE

Vasiliki Myrintzou, DUTH
Nikolaos Kokkos, DOMI Dev. P.C.

DOMI Development P.C

28 October 2026, Constanța

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micro-AUVs – What are they?

Autonomous Underwater Vehicles (AUVs)

are self-propelled, untethered robots that navigate underwater without real-time human control.

micro-AUVs (mAUVs) are a compact sub-class — typically **< 1 m in length and < 10 kg** — designed for shallow-water and coastal operations where larger AUVs cannot access.

They carry integrated sensor payloads and follow pre-programmed mission plans, enabling **repeatable, high-resolution surveys** with minimal ship time.

Small & Lightweight

< 1 m long, < 10 kg — deployable by hand from a small boat or shore

Fully Autonomous

Pre-programmed waypoint missions; no tether or constant operator input

Modular Payload Bay

Swappable sensors: side-scan sonar, camera, CTD, water sampler

Cost-Effective

10–50× cheaper to operate than crewed survey vessels

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micro-AUVs – Key Advantages for Marine Monitoring

Access to Shallow & Complex Areas

Operate in water depths of 1–300 m, including rocky reefs, seagrass beds and confined areas inaccessible to survey vessels or towfish.

Proximity to the Seabed

Flying at 1–3 m altitude above the bottom, mAUVs dramatically improve the resolution of sonar imagery and optical data compared to surface-towed systems.

Repeatable Missions

Pre-programmed waypoint plans allow identical transects to be re-run across surveys, enabling robust temporal change detection of habitats and litter accumulation.

Multi-Sensor Integration

A single dive can simultaneously collect side-scan sonar, stereo video, USBL positioning and water quality data — reducing the number of field operations required.

Minimal Environmental Impact

Electric propulsion and small hydrodynamic profile reduce noise and physical disturbance to sensitive benthic communities compared to vessels or divers.

Reduced Cost & Crew

A two-person team can operate an mAUV from an inflatable boat, replacing crewed research vessels and significantly cutting survey costs and carbon footprint.

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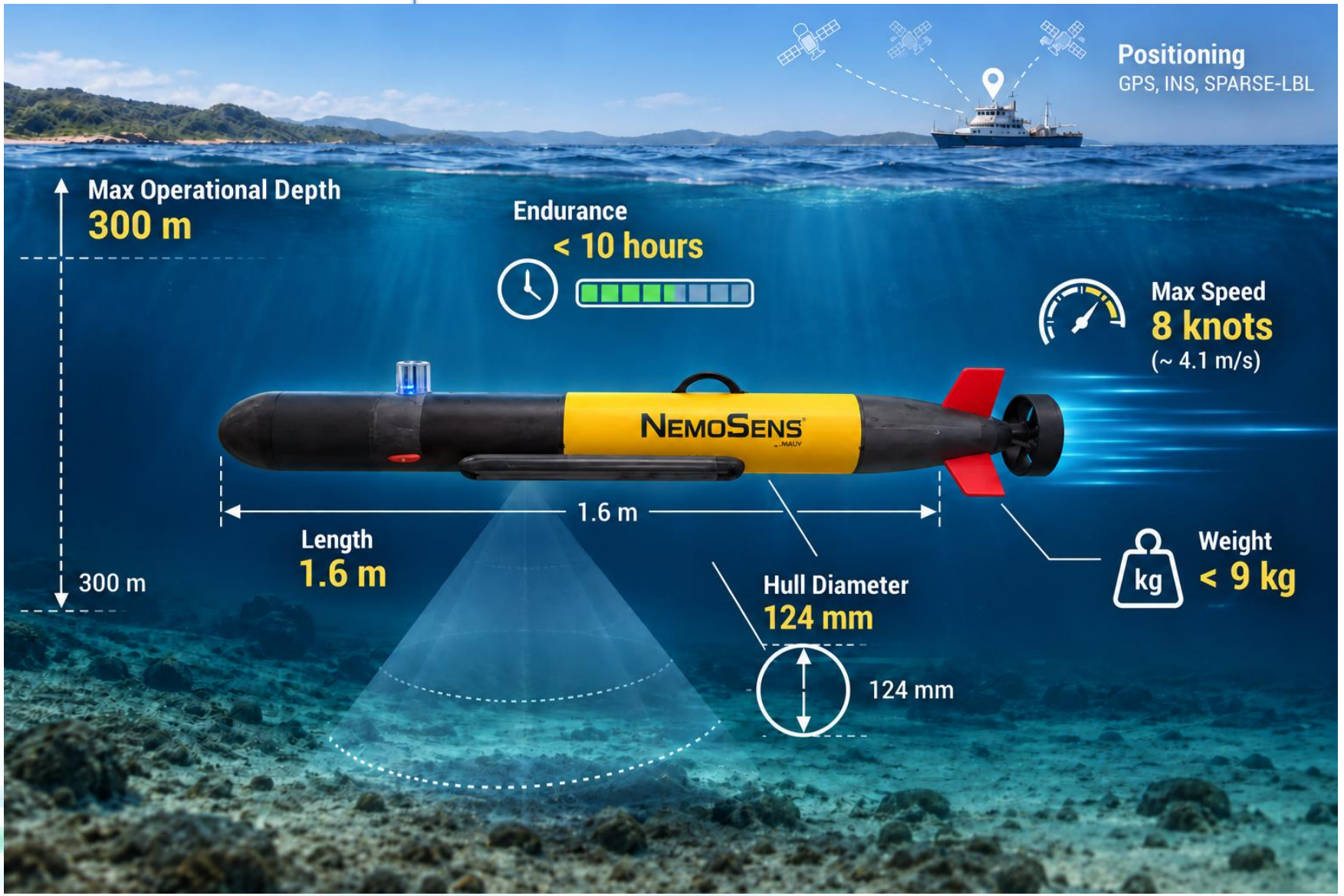
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The micro-AUV

RTSYS NemoSens

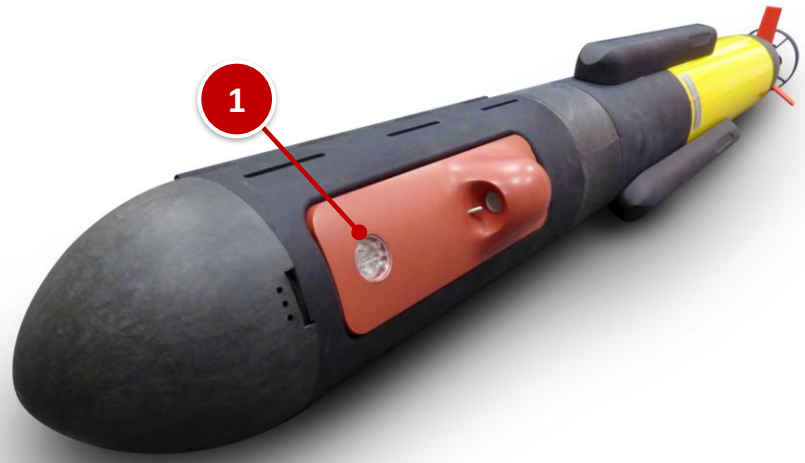
Max operational depth	300 m
Endurance	<10 hours[1]
Length	~1.6 m[1]
Hull diameter	124 mm
Weight	<9 kg
Max speed	8 knots
Positioning	GPS, INS, SPARSE-LBL



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Technology platform and data collection



RTSYS NEMOSENS mAUV equipped with:

1. **RBRlegato CTD**: salinity and temperature data
2. **GoPro Camera**: RGB videos and images
3. **StarFish 454 Side Scan Sonar**: acoustic images



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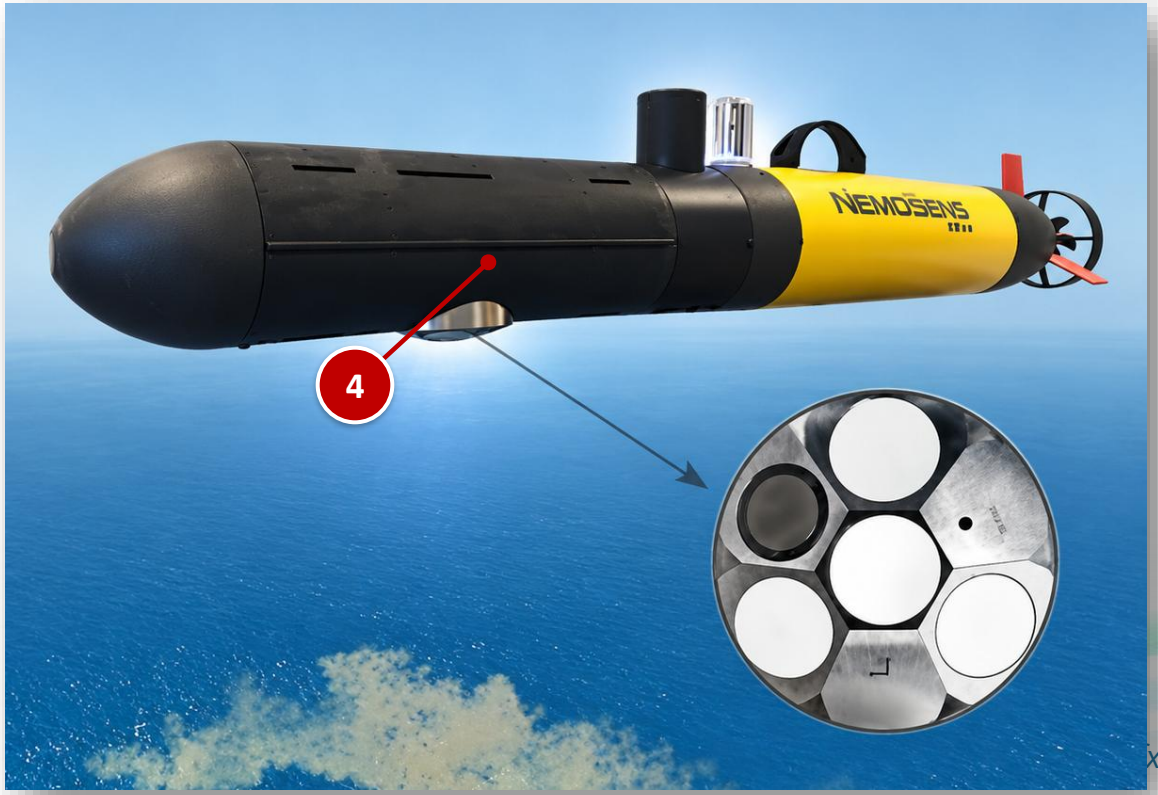
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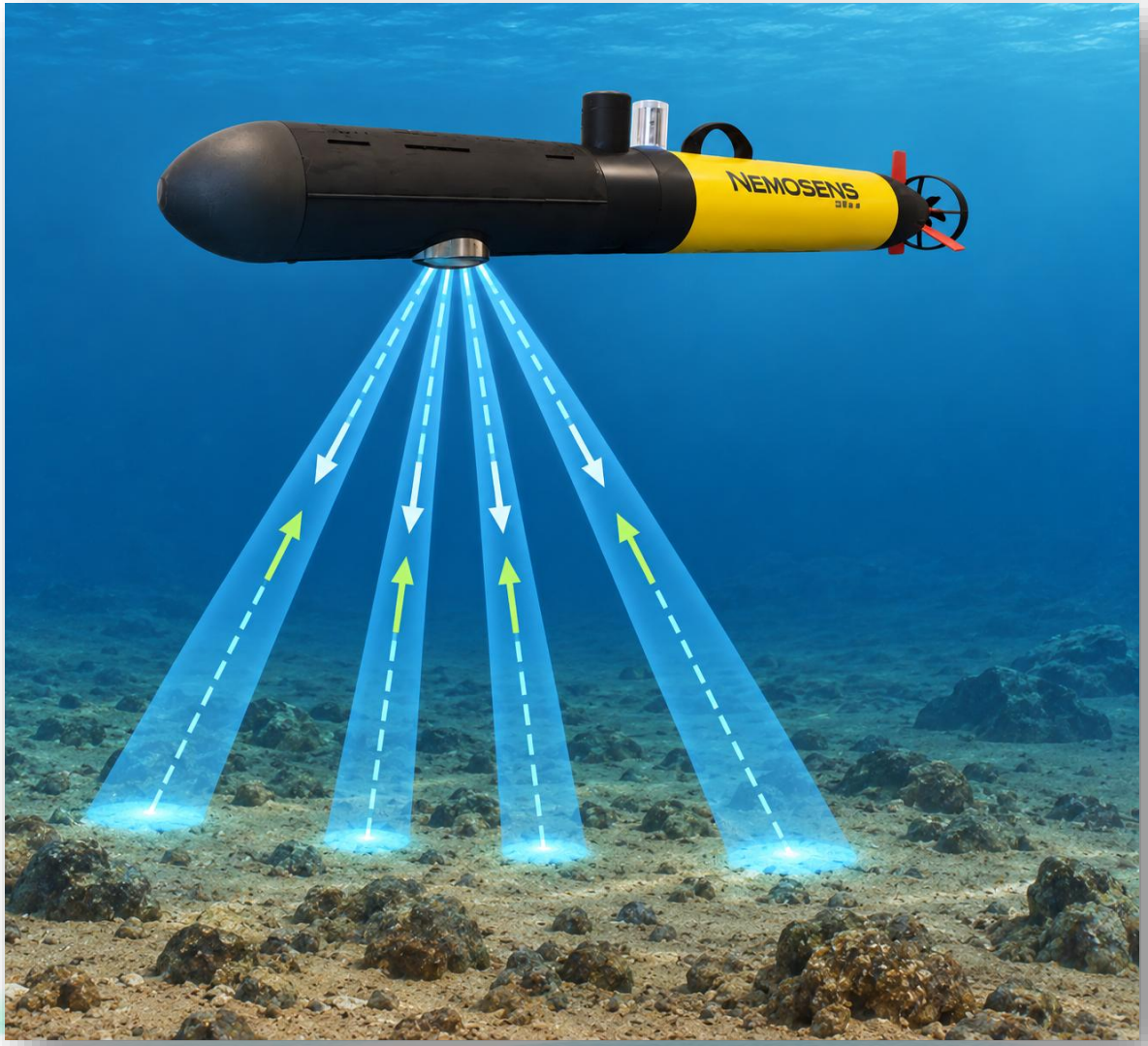
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Technology platform and data collection

RTSYS NEMOSENS mAUV equipped with:

4. **Nortek Nucleus DVL/INS**: velocity and navigation data



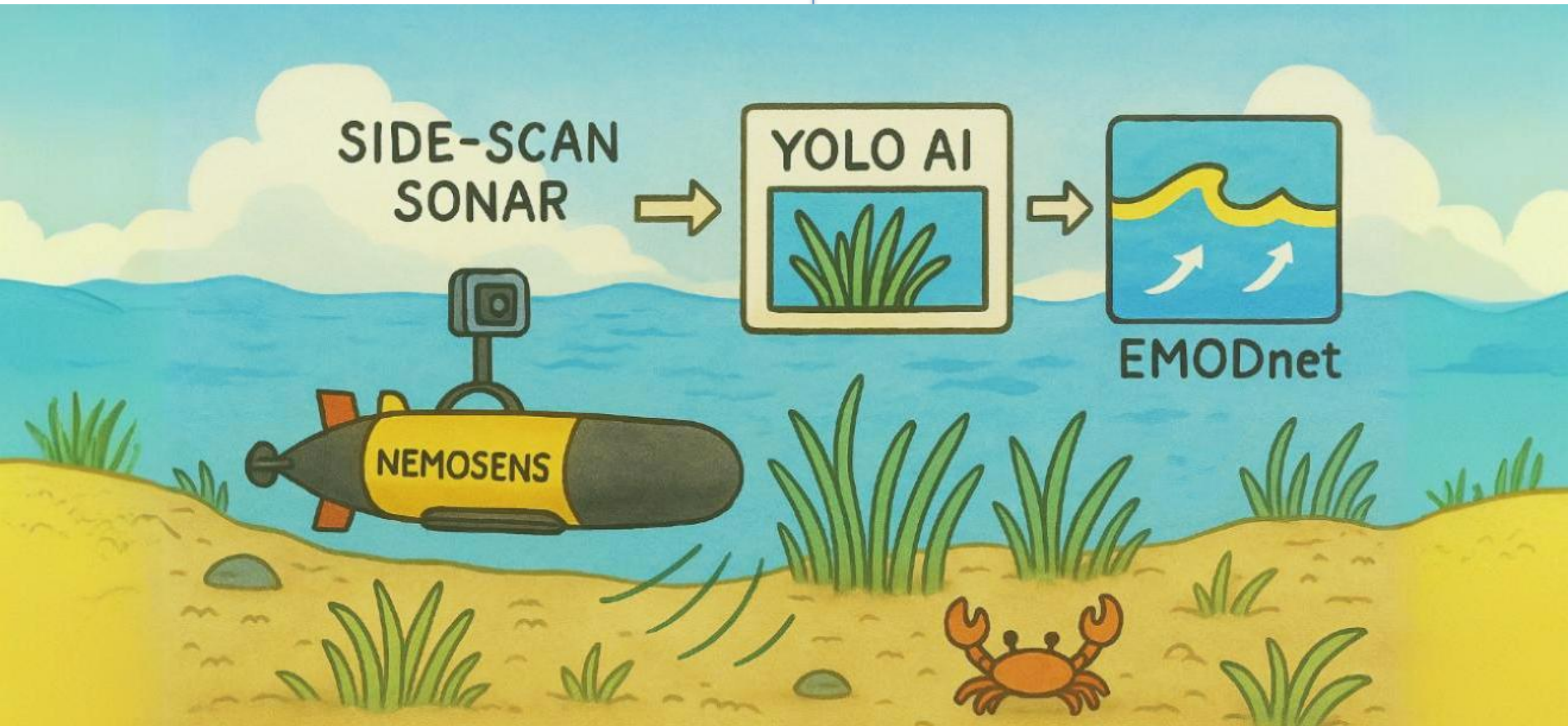


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Side-scan sonars

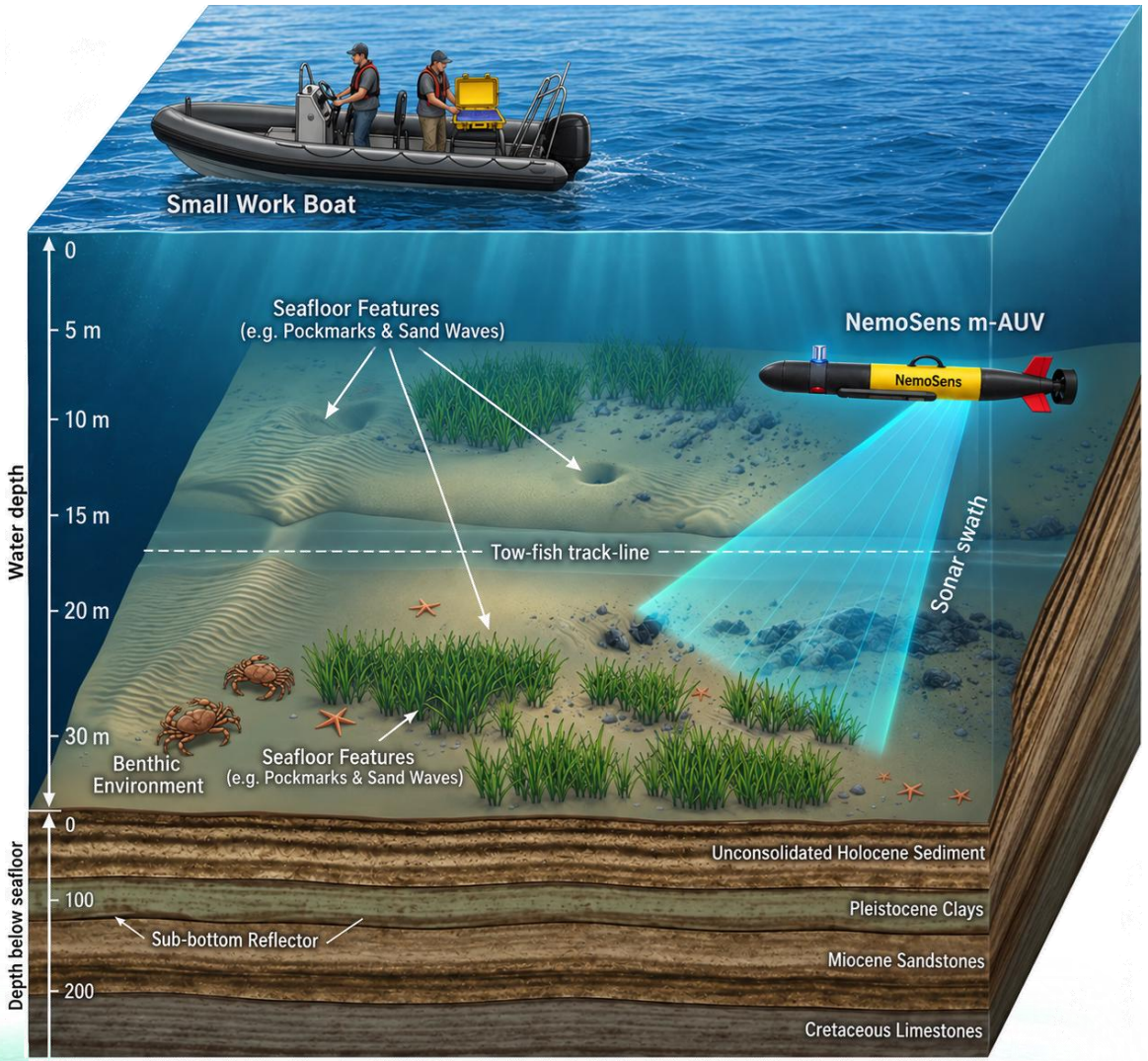
The Side Scan Sonar (SSS) is an acoustic reflection technology. **Basically, they use a swath of sound** to survey the seafloor.

Side-scan sonars **emit conical or fan-shaped pulses across a wide angle** perpendicular to the path of their towed sensors ('towfish' or 'rail') and record the echoes.

The received signals (echoes) create a detailed image of the **seafloor's reflectivity and its anomalies** ('sonograph') within the beam's swath (coverage range). The travel time and intensity of the returned pulse are recorded.

The **reflectivity** of the seafloor **depends on its roughness** and the nature of the topmost material:

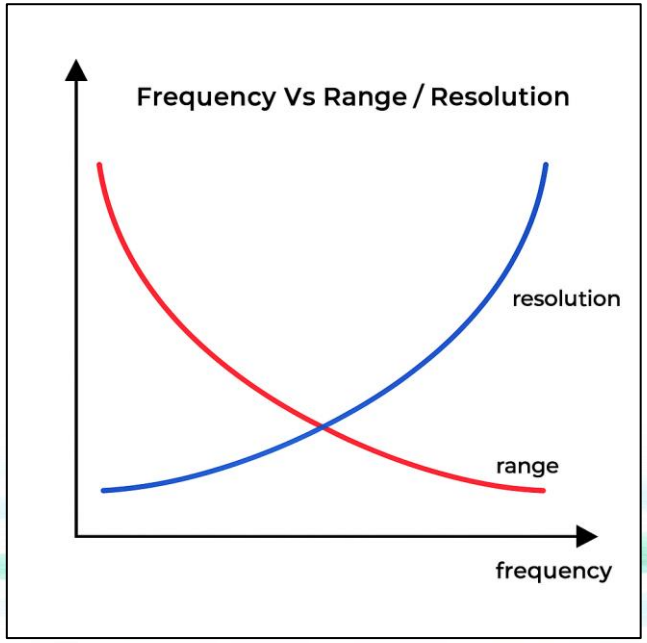
- coarse-grain sediments display higher reflectivity than fine-grain deposits,
- rocky outcrops reflect higher than sediments, etc.

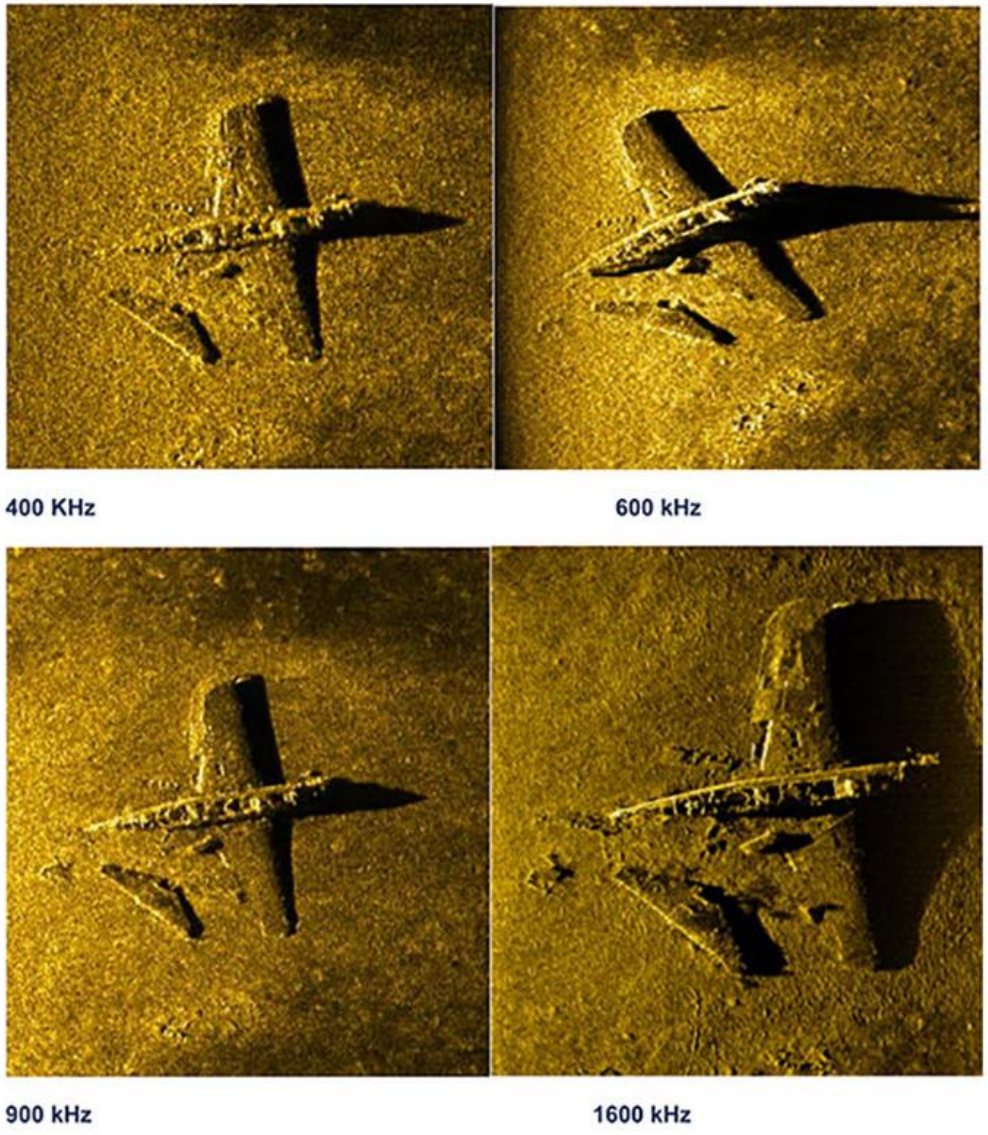


Side-scan sonars – Range of detection

The **lower 200 kHz** frequency side scan sonar is capable of detecting large targets at **ranges of 150 meters**.

The **higher 455 kHz** frequency side scan sonar **has a narrow beam** and **shorter (100m) range** for **more detailed** images of closer targets.





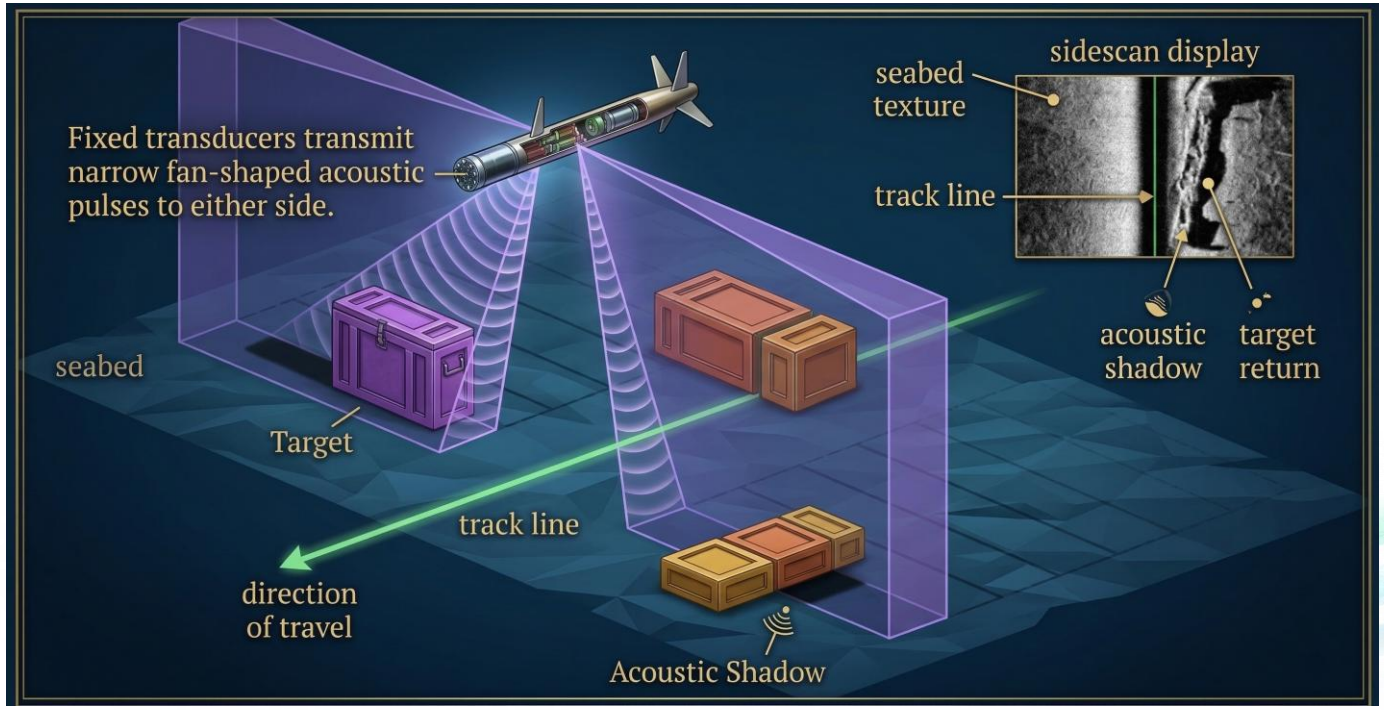
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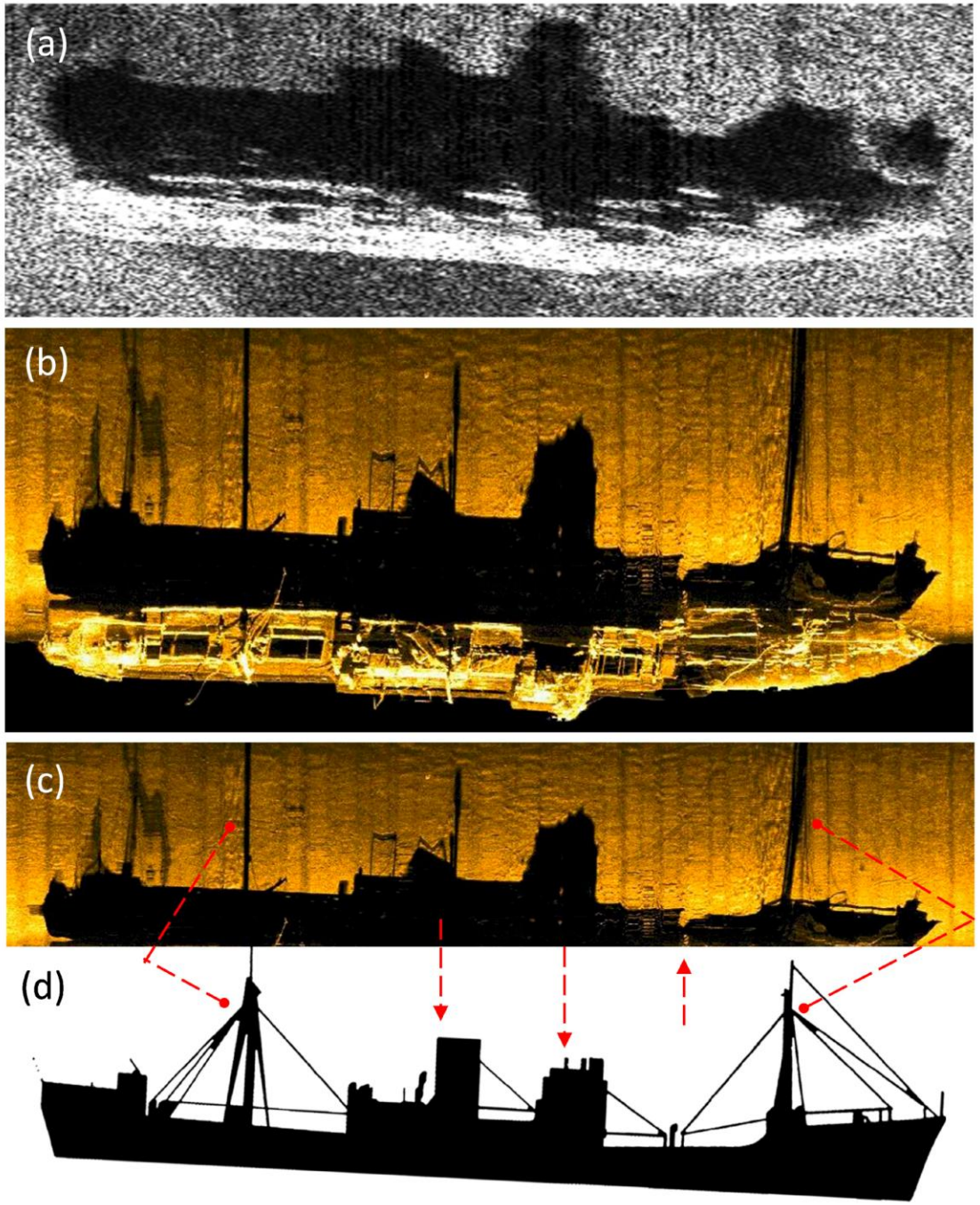
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Side-scan sonars – Acoustic shadow

Using a side scan sonar is rather like **looking at a world made of shiny black plastic, in the dark, with only a narrow torch beam** for illumination.

It can be the most important sonar imagery feature as **it provides a three-dimensional quality** to a two-dimensional survey.



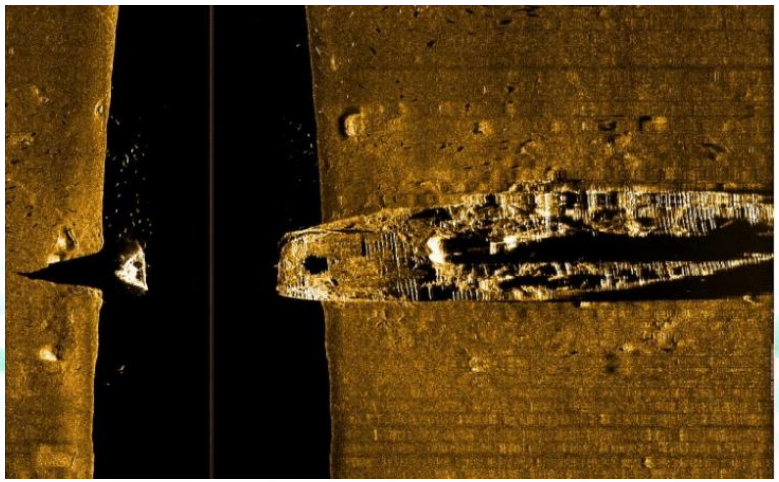


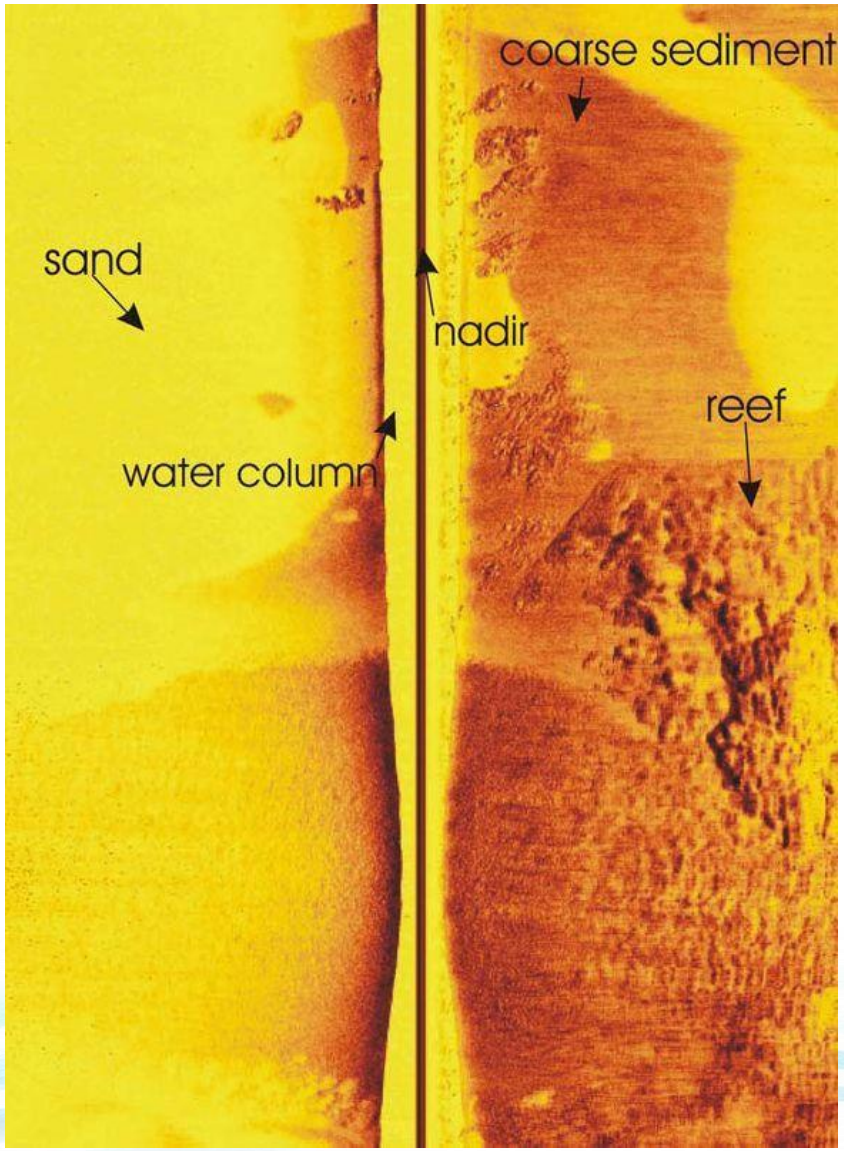
Side-scan sonars – Nadir line

Side-scan sonars **measure the time of each return to calculate the location of targets** on the seabed.

The **nadir zone** is the area on the seabed directly beneath the towfish where the beam hits at near-vertical incidence. It appears as a **bright line** in the sonar record because the strong vertical return creates ambiguity.

The **water column** is the area appearing to the left and to the right of the center line, making up approximately 5% of the range scale.





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eXtented Triton Format (XTF) files

Triton Imaging, Inc (1988)

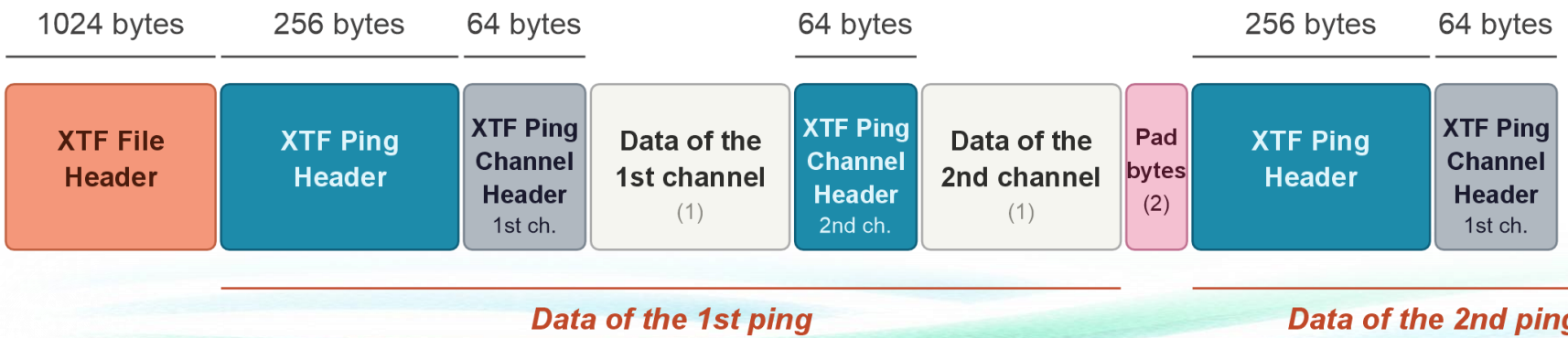


An XTF file can be thought of as a "**pool**" of data.
If you use XTF to collect data during a survey, you **can add data to the file at any time without needing to synchronize** your data packets.
For example:

- bathymetry data may be logged five times per second
- sonar data is being logged at 10 times per second.

No storage space is wasted and no "holes" are created in the saved data stream.

XTF file structure



. . .

(1) Variable length — depends on samples per ping and bit depth.
(2) Pad bytes align the next ping block to a 512-byte boundary.

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EfxINNOs

SONARWIZ

Developed by **Chesapeake Technology**, is an all-in-one software solution for geophysical, hydrographic, pipeline, and archaeological marine surveys.

- real-time data acquisition
- post-processing
  - sidescan,
  - sub-bottom,
  - bathymetry, and
  - magnetometry data

OpenSideScan



CIDCO

Developed by **CIDCO**. Open-source software for:

- processing and
- visualizing sidescan sonar data

ReefMaster



Developed by **ReefMaster Software**, is a Windows-based software.

- Track and depth log import
- Real-time mapping
- Sidescan mosaic creation
- Waypoint and route management
- Export to GPS



pyxtf

Developed by Oystein Sture (oysstu), is a Python library for reading and writing eXtended Triton Format (XTF) files.

- Read and parse XTF files (file headers & sonar/sub-bottom/bathymetry packets)
- Write or generate XTF files
- Support for reading multiple data packet types (navigation, ping, attitude, etc.)

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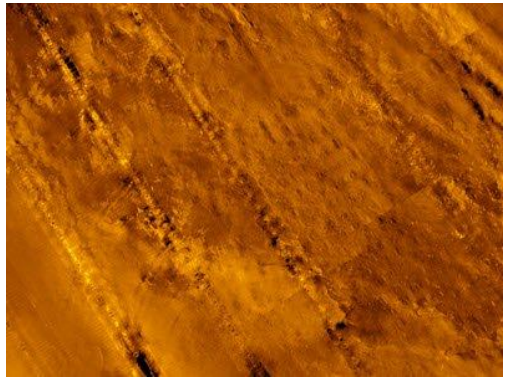
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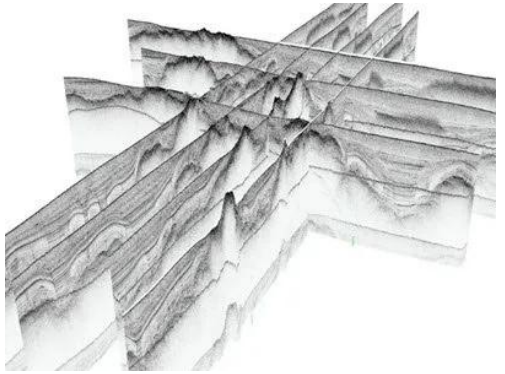
SONARWIZ

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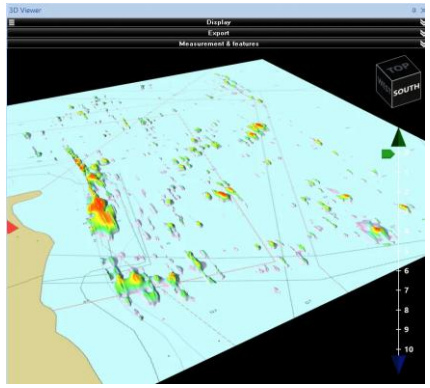
Sidescan



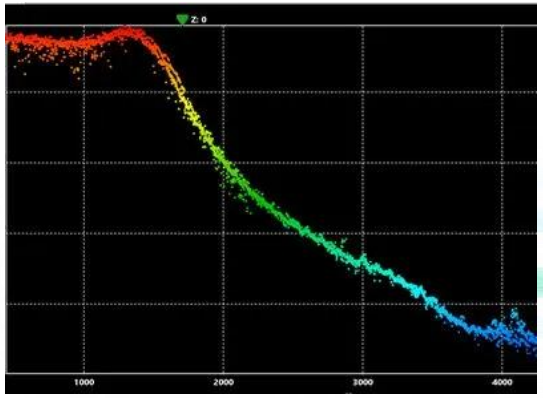
Sub-Bottom



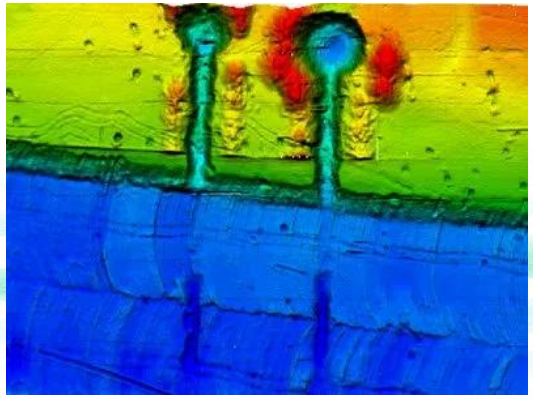
Magnetometry



Single beam



Multi-beam



https://chesapeaketech.com/products/sonarwiz-sidescan/

– *EfxINNOs*

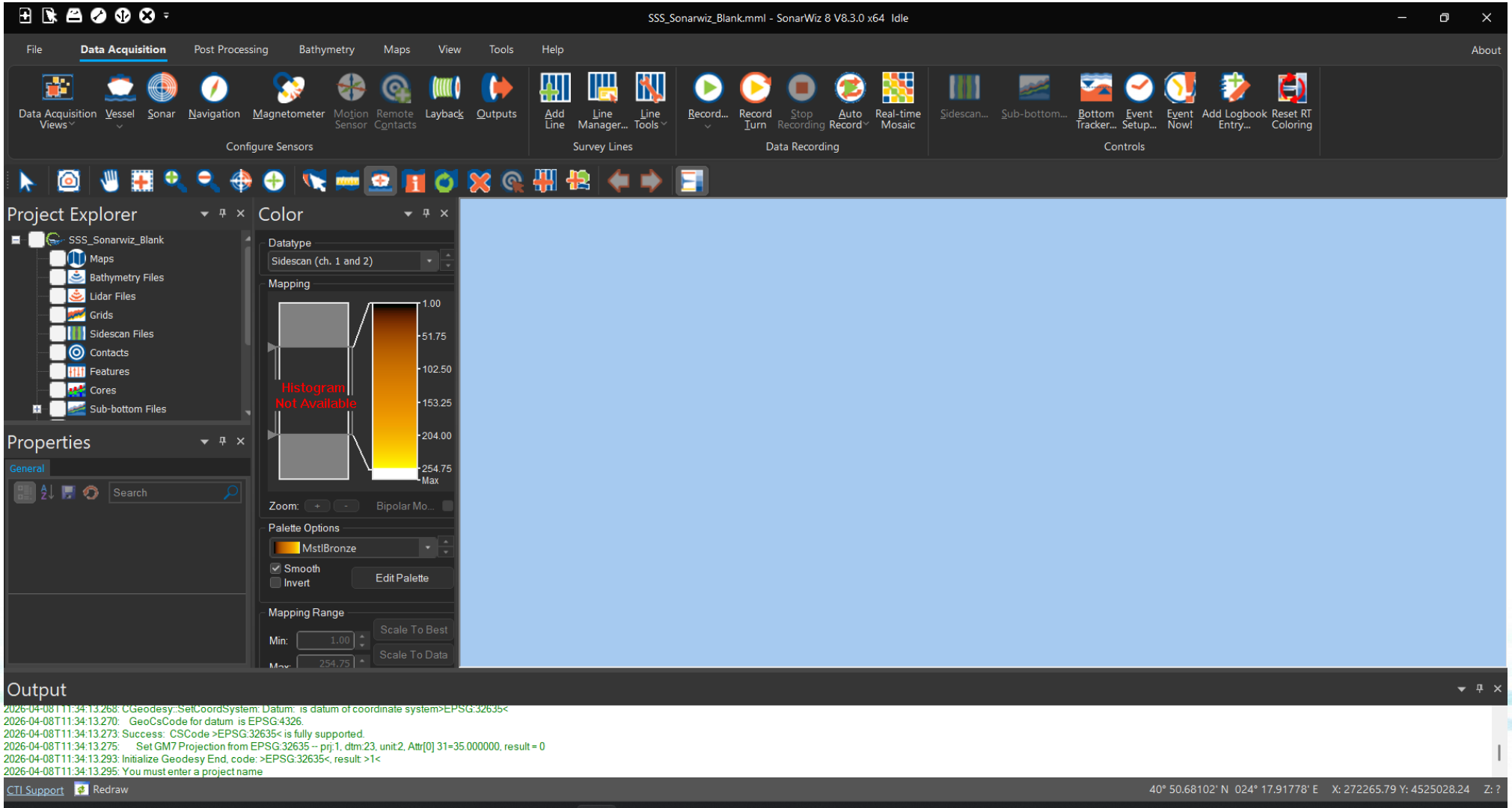
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SONARWIZ

Main view



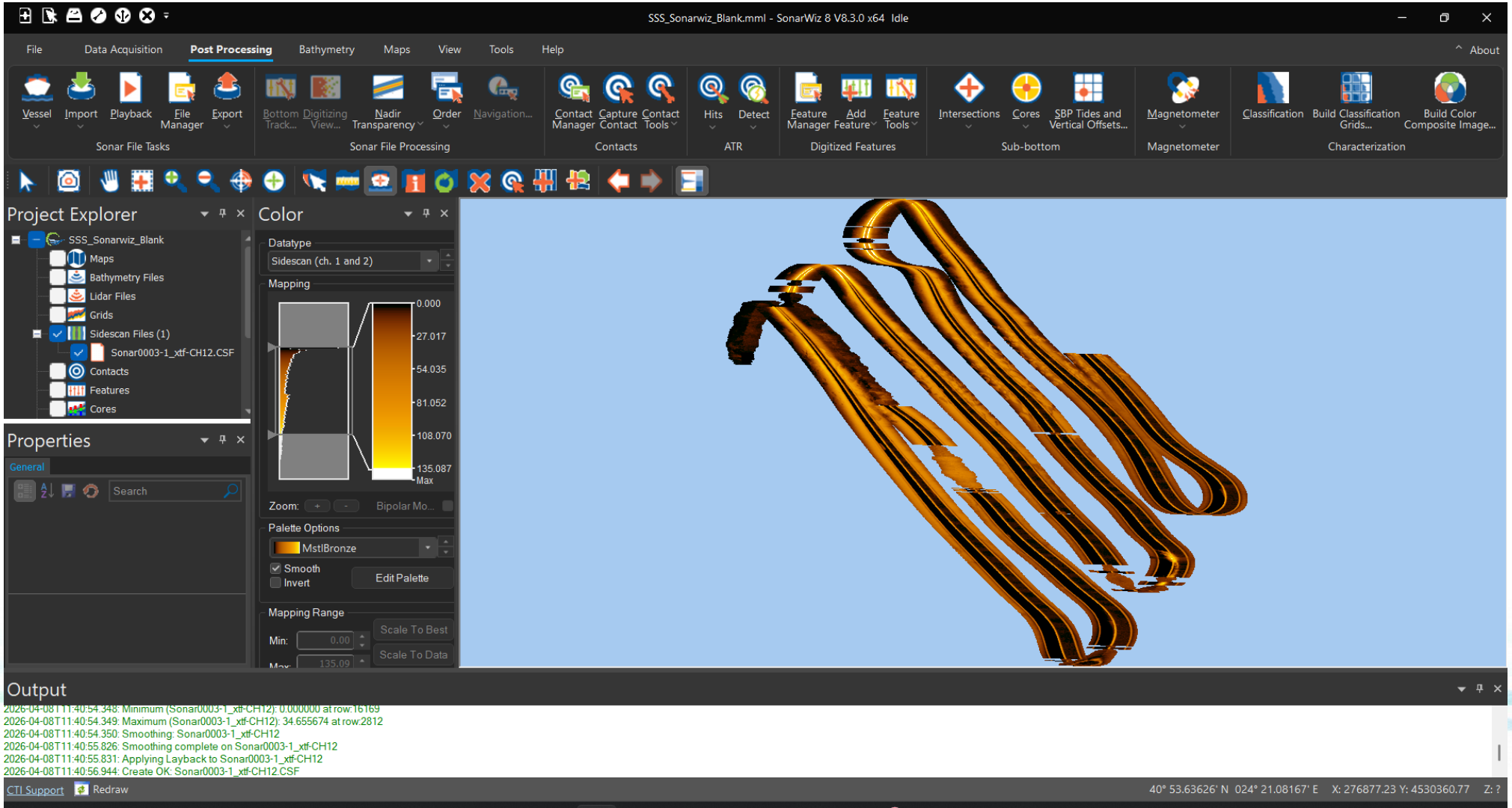
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Import files



Interreg

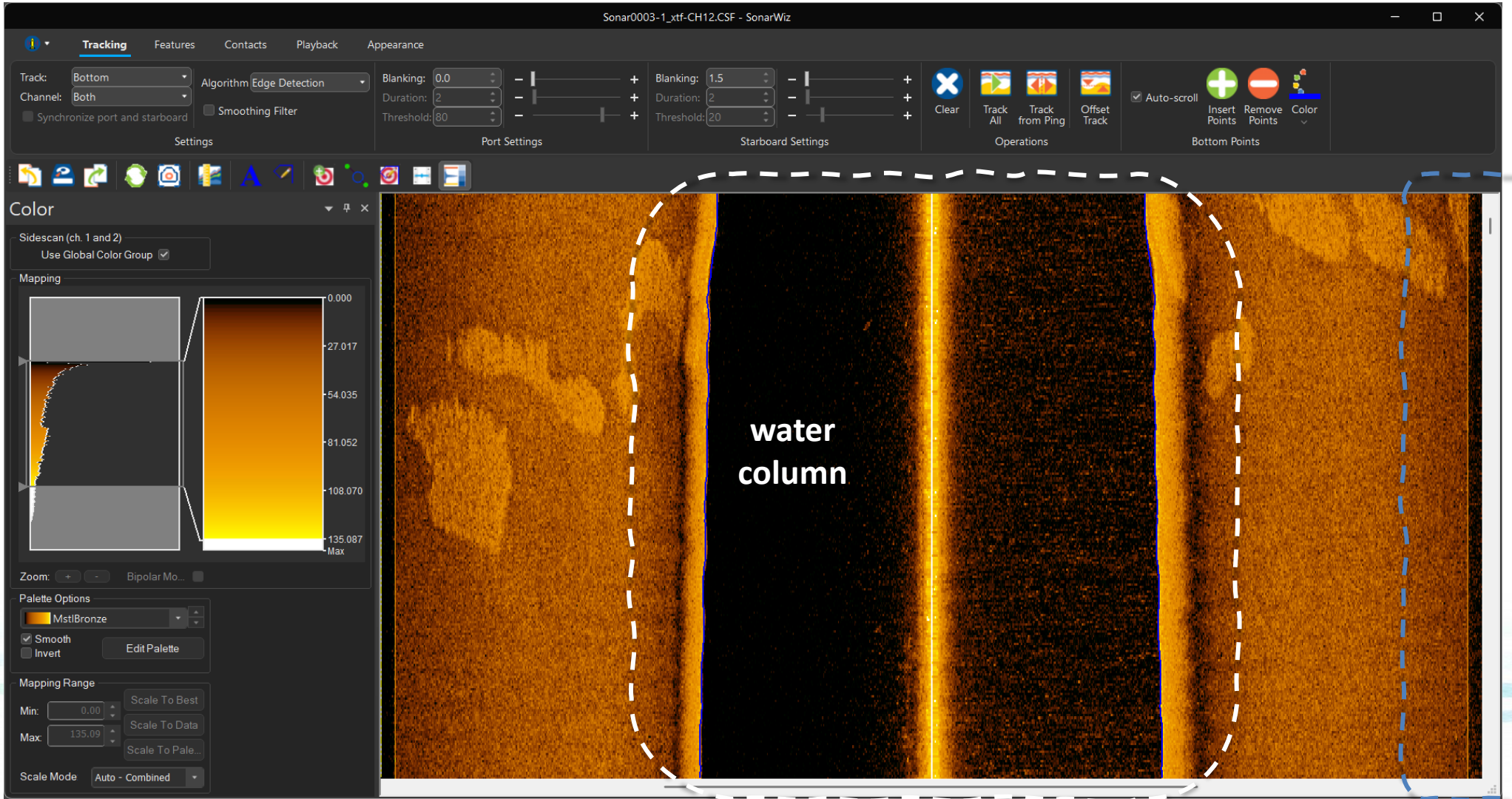
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Bottom Track



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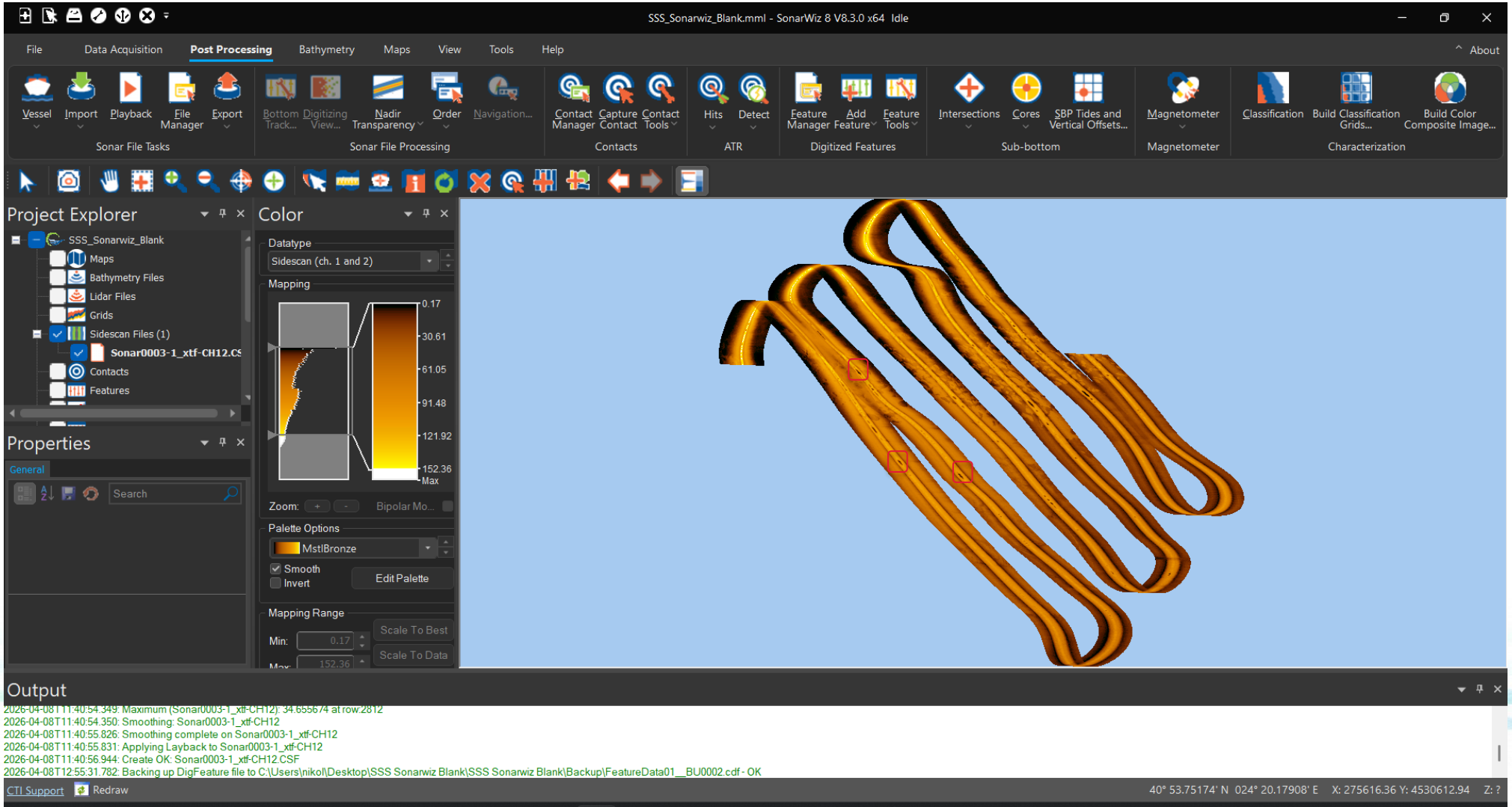
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Bottom Track

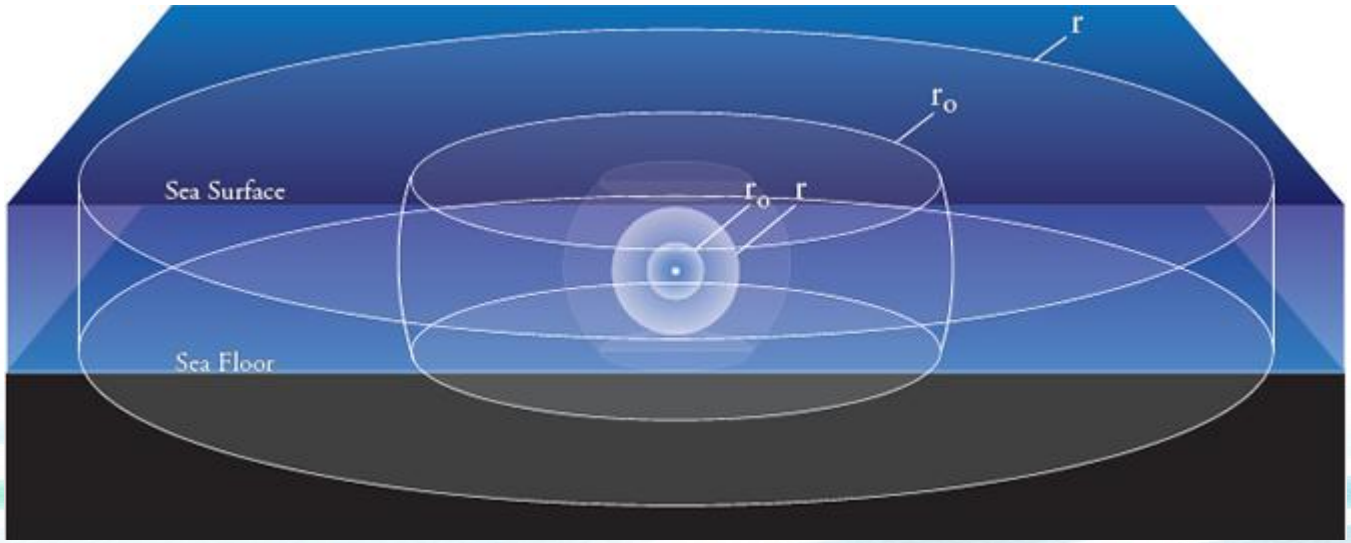


Sidescan Gain and Signal Processing

Sound **cannot propagate uniformly in all directions** from a source in the ocean forever.

Beyond some range the **sound will hit the sea surface or sea floor**.

Once the **sound is trapped between the top and bottom of the ocean it gradually begins to spread cylindrically**.

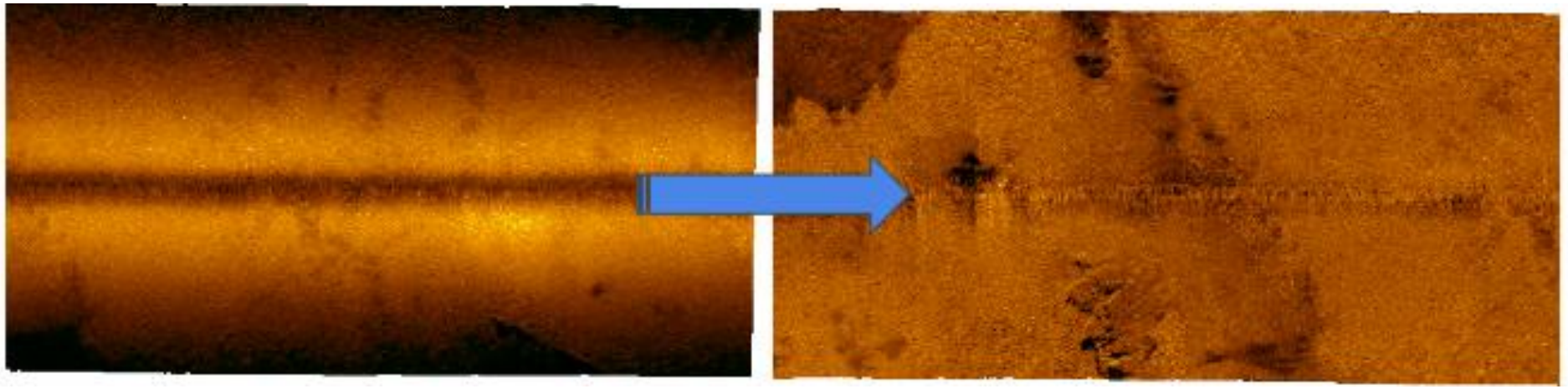


As acoustic waves propagate through the water, **they lose intensity** because of **geometric spreading** and **absorption**.

The result is an **across-track change in signal brightness** in the **waterfall** display.

Sidescan Gain and Signal Processing

SonarWiz provides algorithms for **leveling the brightness across track**.



Automatic Gain Control

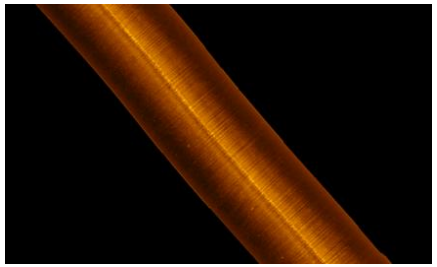
Auto TVG

Beam Angle Correction

Empirical Gain Normalization

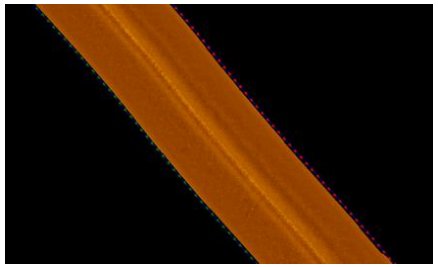
Gain Correction Methods: Before and After

Before correction



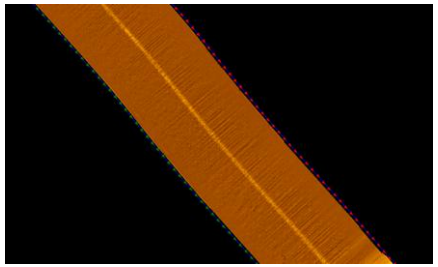
Raw sonar data with **no gain correction** applied.

Automatic Gain Control (AGC)



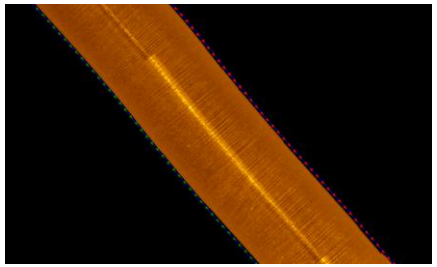
Measures the **local average signal strength** and rescales the data to a **chosen global average**.

Beam Angle Correction (BAC)



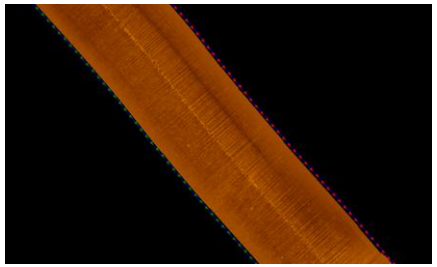
Compensates for the **non-linear response** of the sonar transducers.

Auto TVG (Time Varying Gain)



Splits the data into **parallel swaths** and adjusts each swath's gain until its **RMS power** matches a target level.

Empirical Gain Normalization (EGN)



Averages amplitudes **by altitude and range** over millions of samples to derive the beam pattern; **replaces BAC** in most cases.

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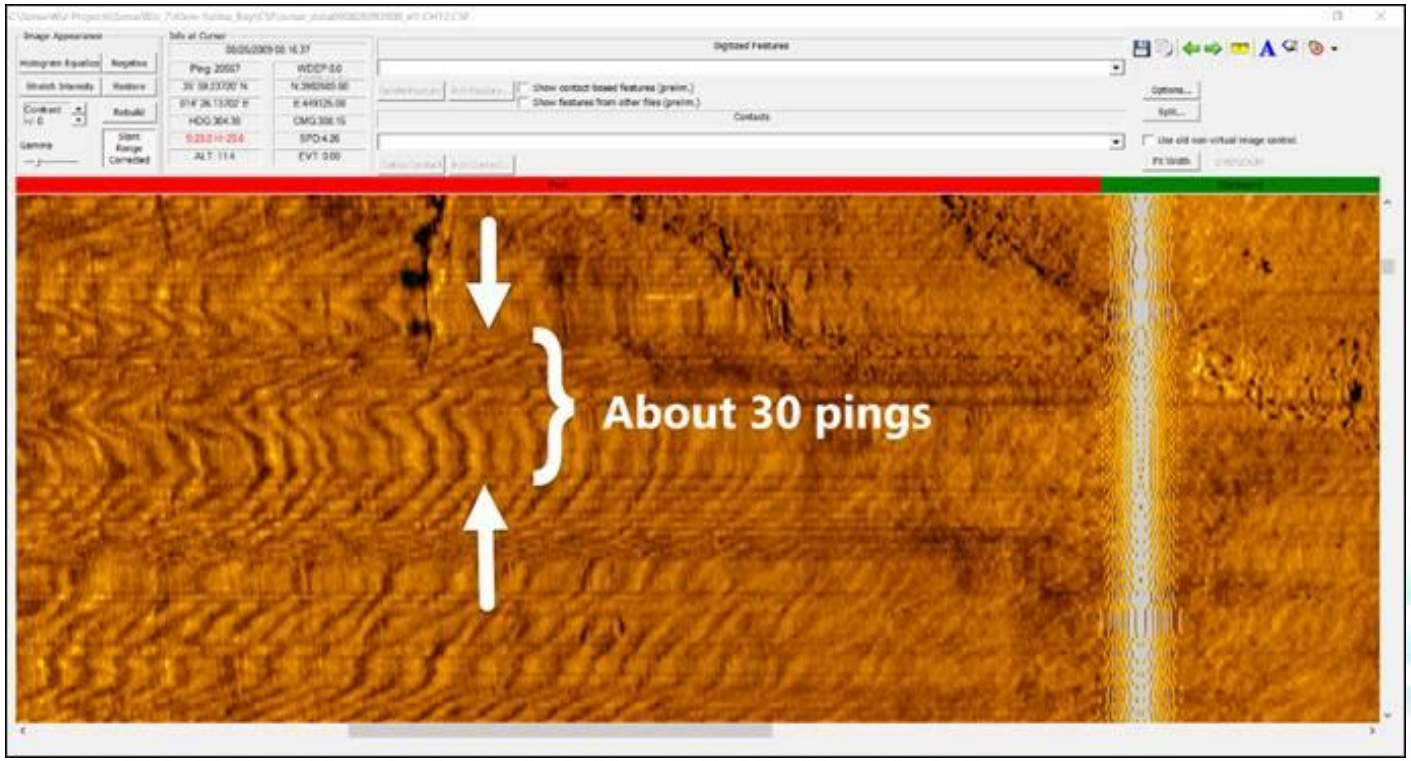
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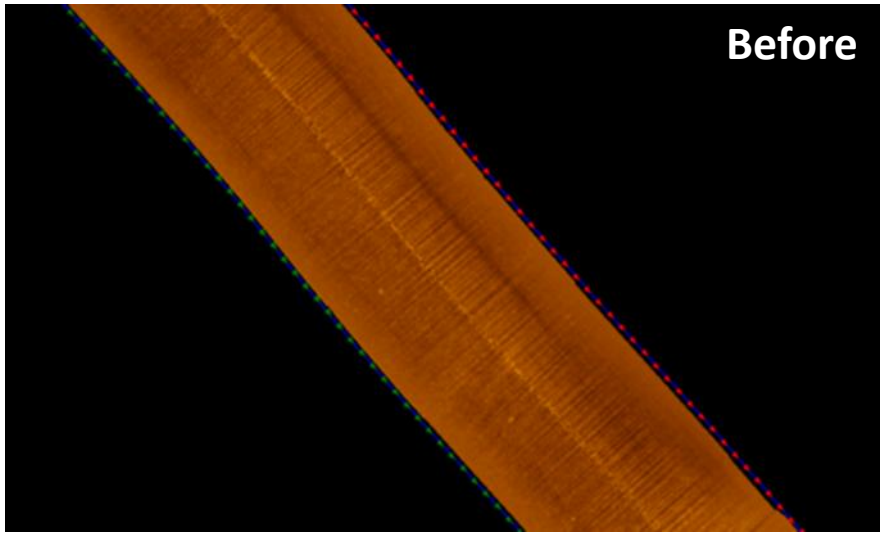
EfxINNOs

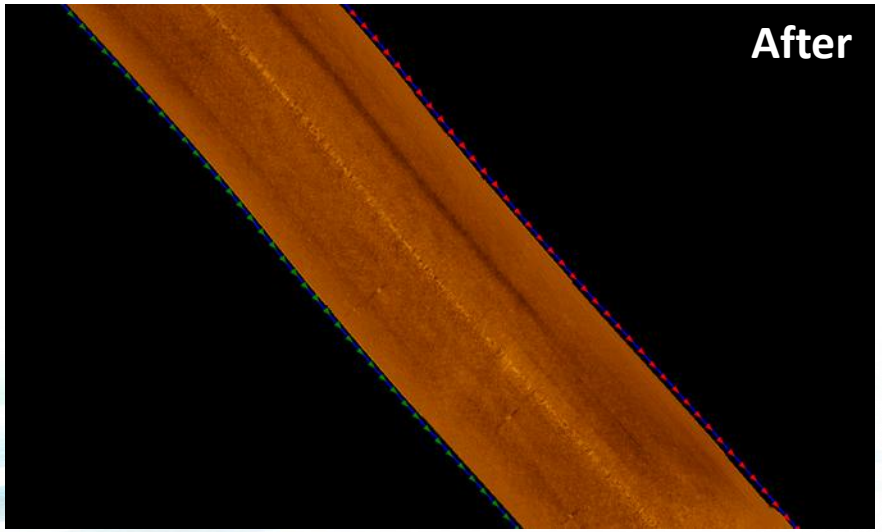
SONARWIZ

De-Striping

The De-Striping function:
Is used to reduce the effects of a '**pitching**' sonar that is characterized by a pattern perpendicular to the direction of travel.







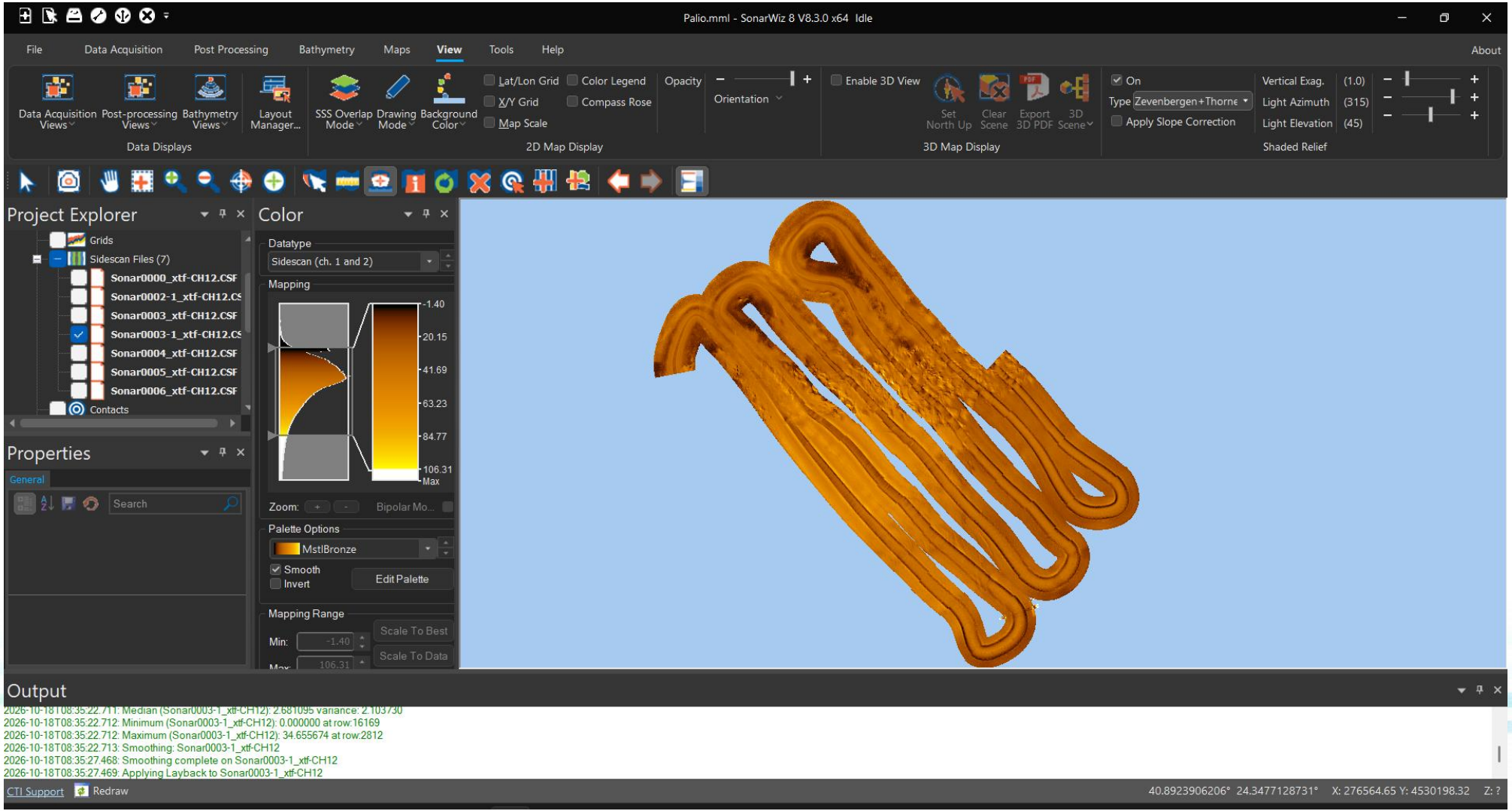
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Final result



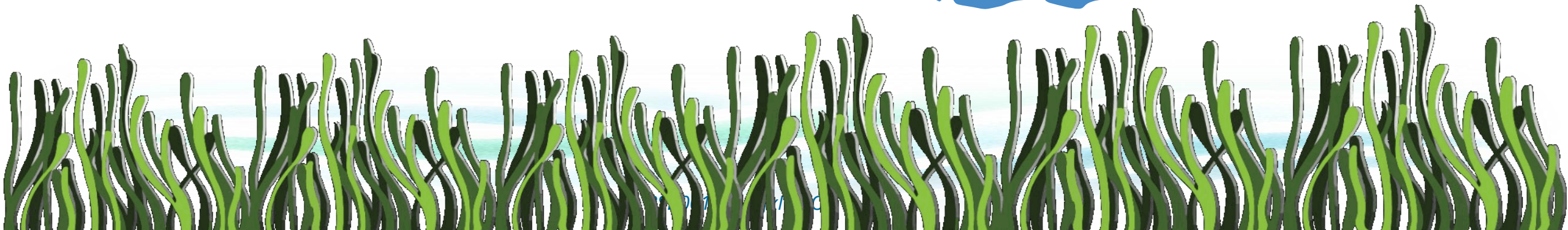
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Thank you!



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Monitoring Benthic and Seagrass Habitats with Machine Learning



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DEMOCRITUS UNIVERSITY OF THRACE

Theofani Psomouli, DUTH
Nikolaos Kokkos, DOMI Dev. P.C.

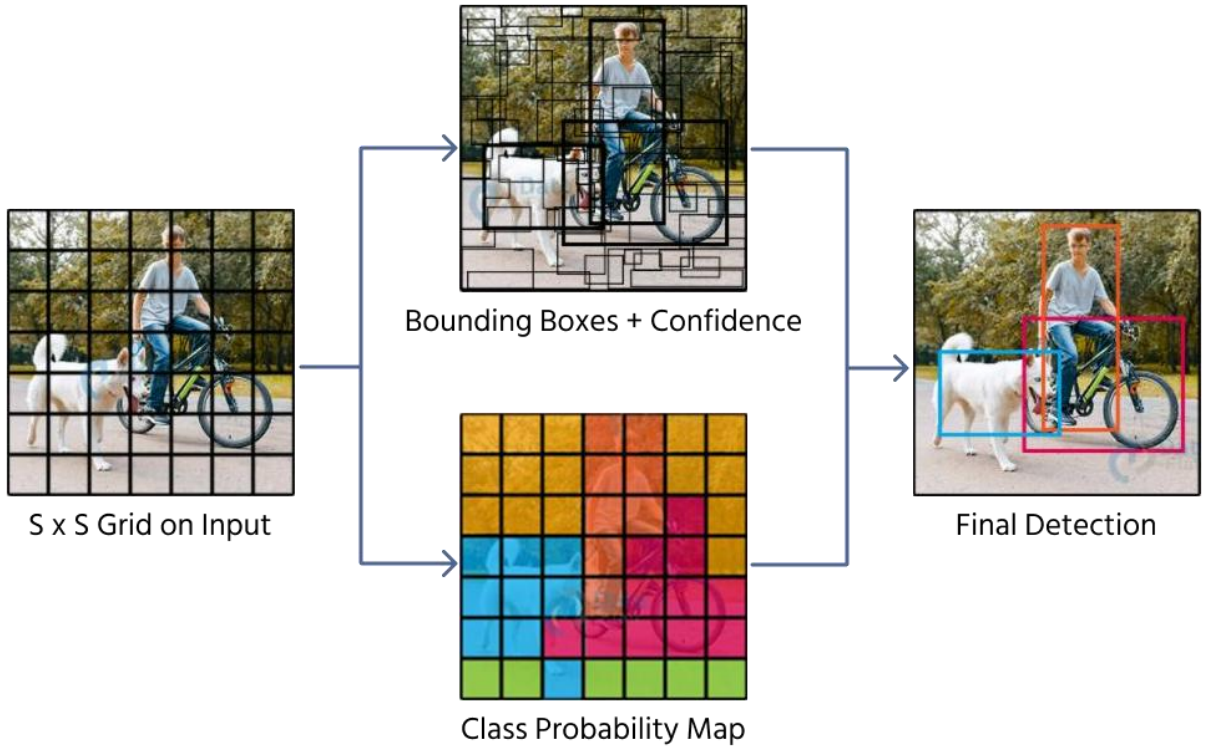


DOMI Development P.C

28 October 2026, Constanţa

What is YOLO (You Only Look Once)?

YOLO is a **single-stage instance segmentation model** built on a convolutional neural network (CNN). It looks at an image and asks:
"Where are the objects, and what shape is each one?"



How does it work?

- Input image is divided into an S x S grid
- Each grid cell predicts:
  - Bounding boxes
  - Confidence score
  - Class probabilities

Single-Pass Detection

Older methods scan an image in multiple stages. YOLO uses a **single convolutional neural network (CNN)** to look at the entire image just once. Because it runs everything in one pass, it is extremely fast.

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What is YOLO (You Only Look Once)?



ML on Videos

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Survey Footage



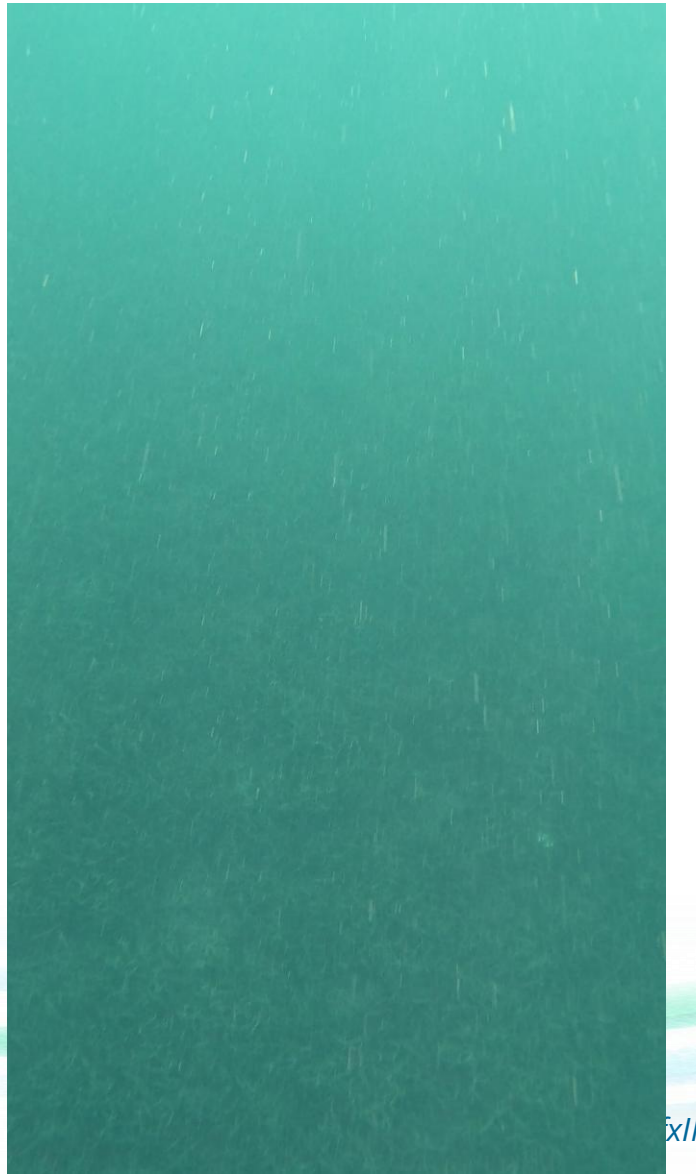
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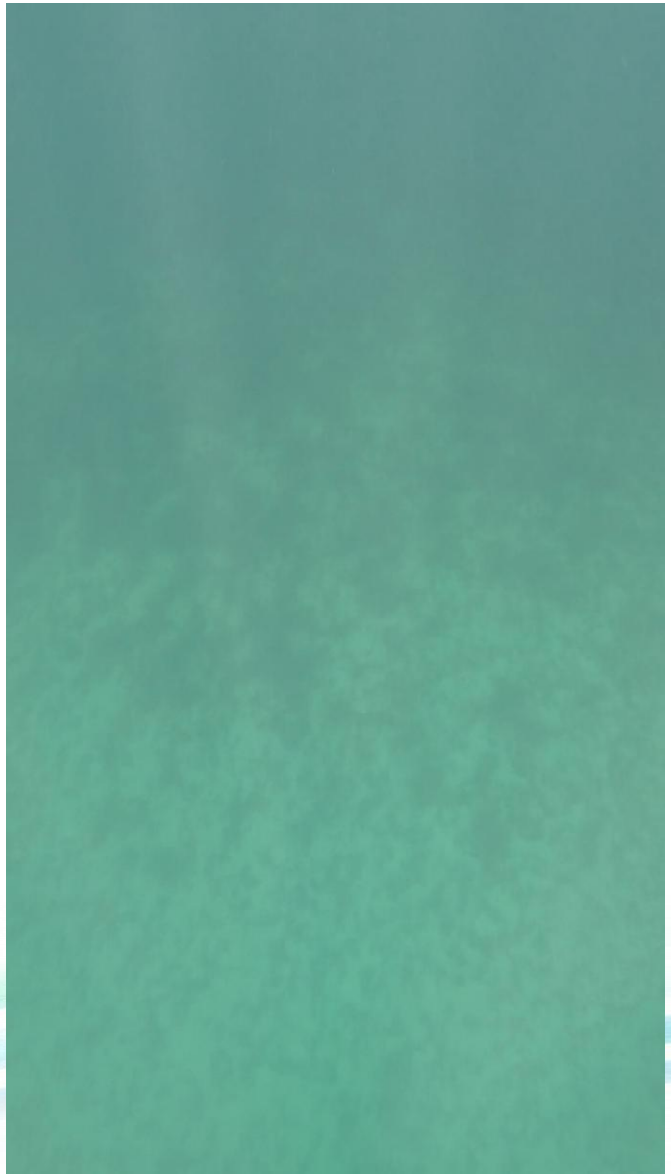
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Survey Footage





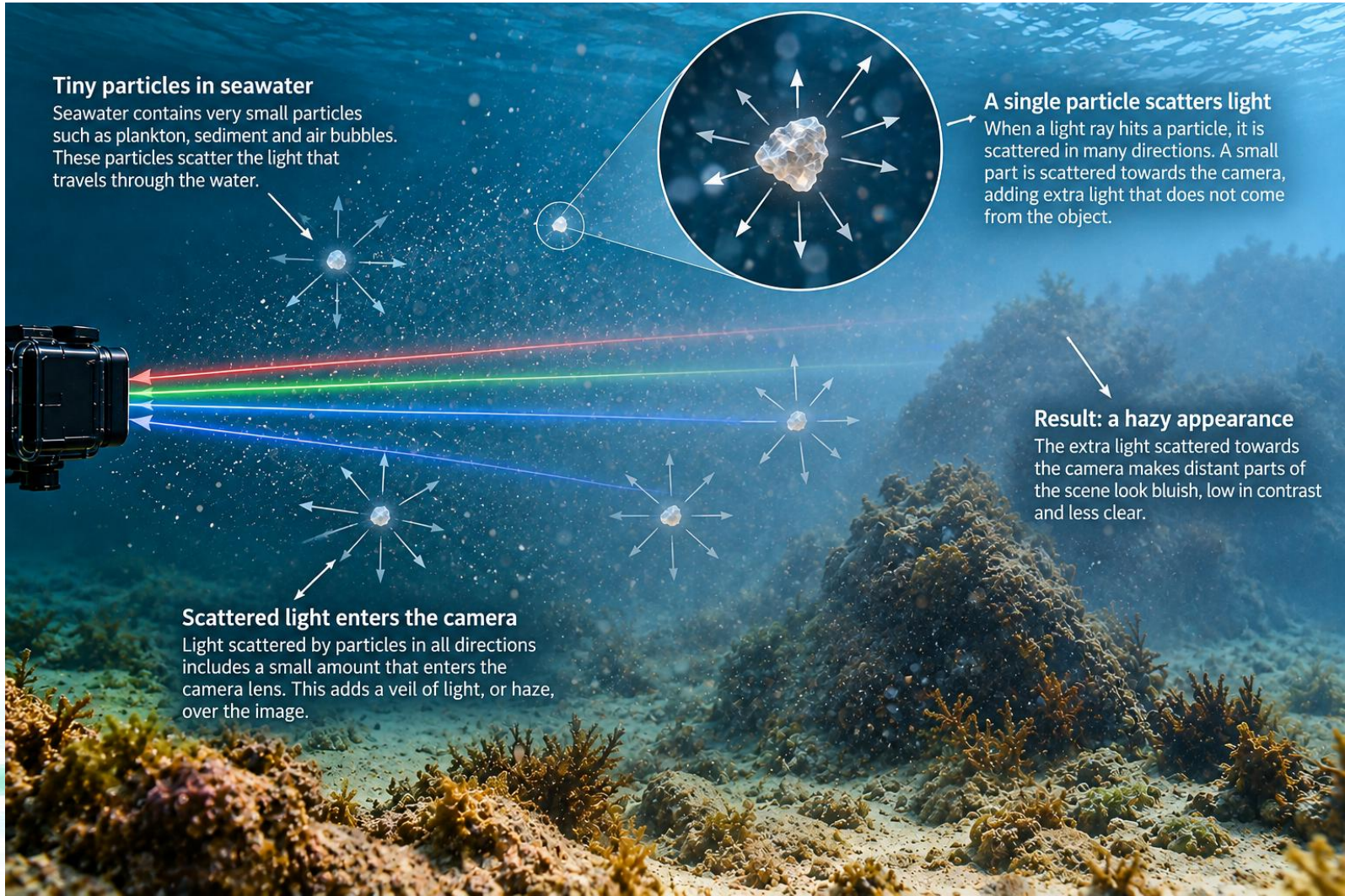
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Why Underwater Images Look Hazy

- Seawater carries **tiny particles**: plankton, sediment and air bubbles.
- Each particle **scatters light** in all directions.
- Some scattered light **reaches the camera** without coming from the object.
- This adds a **veil of haze**: distant areas look bluish, low in contrast and less clear.



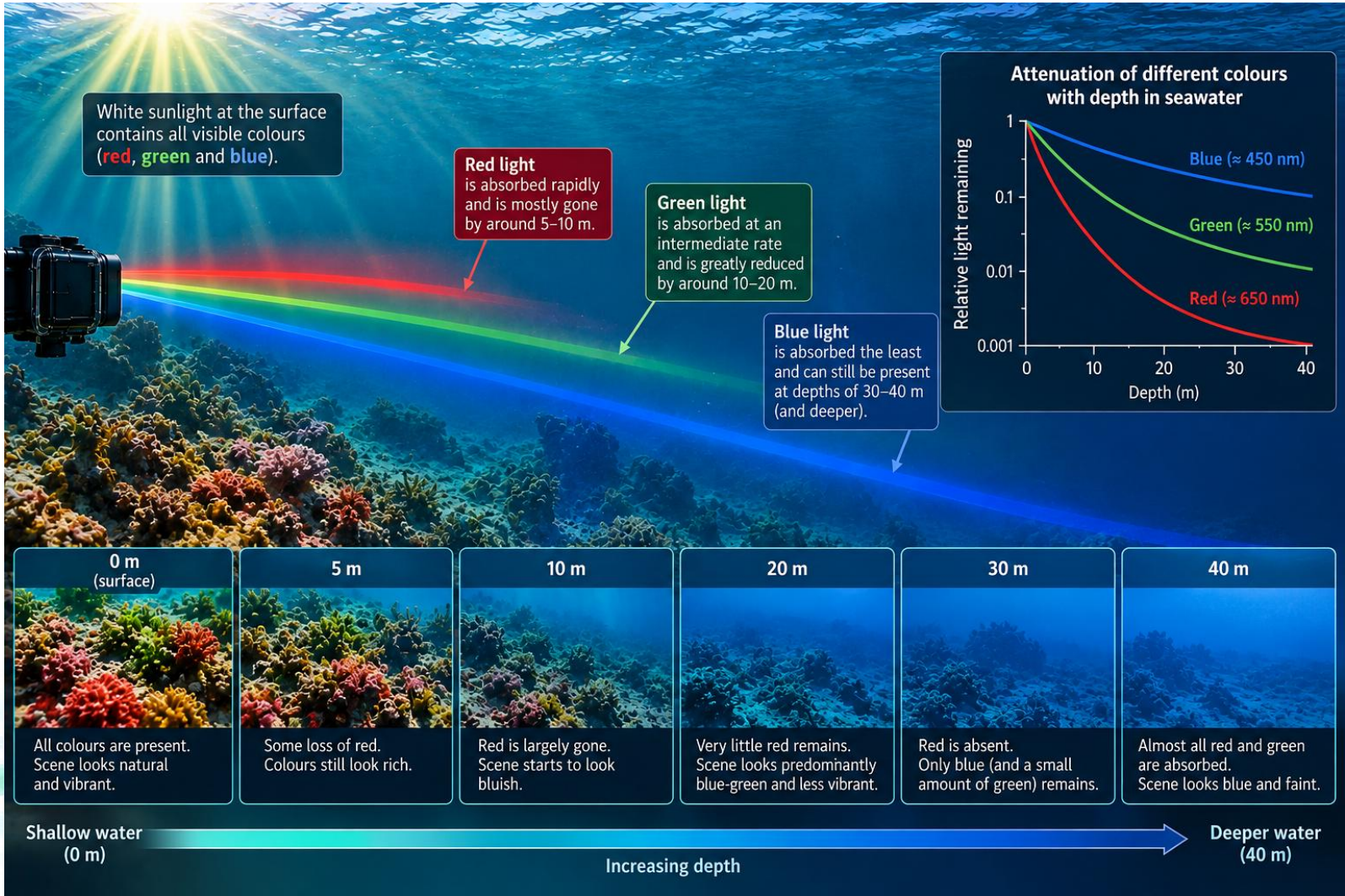
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Why Colours Fade with Depth

- Sunlight at the surface contains **all visible colours**.
- Water **absorbs red first**: it is mostly gone by 5–10 m.
- **Green fades next** and is greatly reduced by 10–20 m.
- **Blue travels furthest** and is still present at 30–40 m.
- Deeper scenes look **blue and faint**, with little colour contrast.



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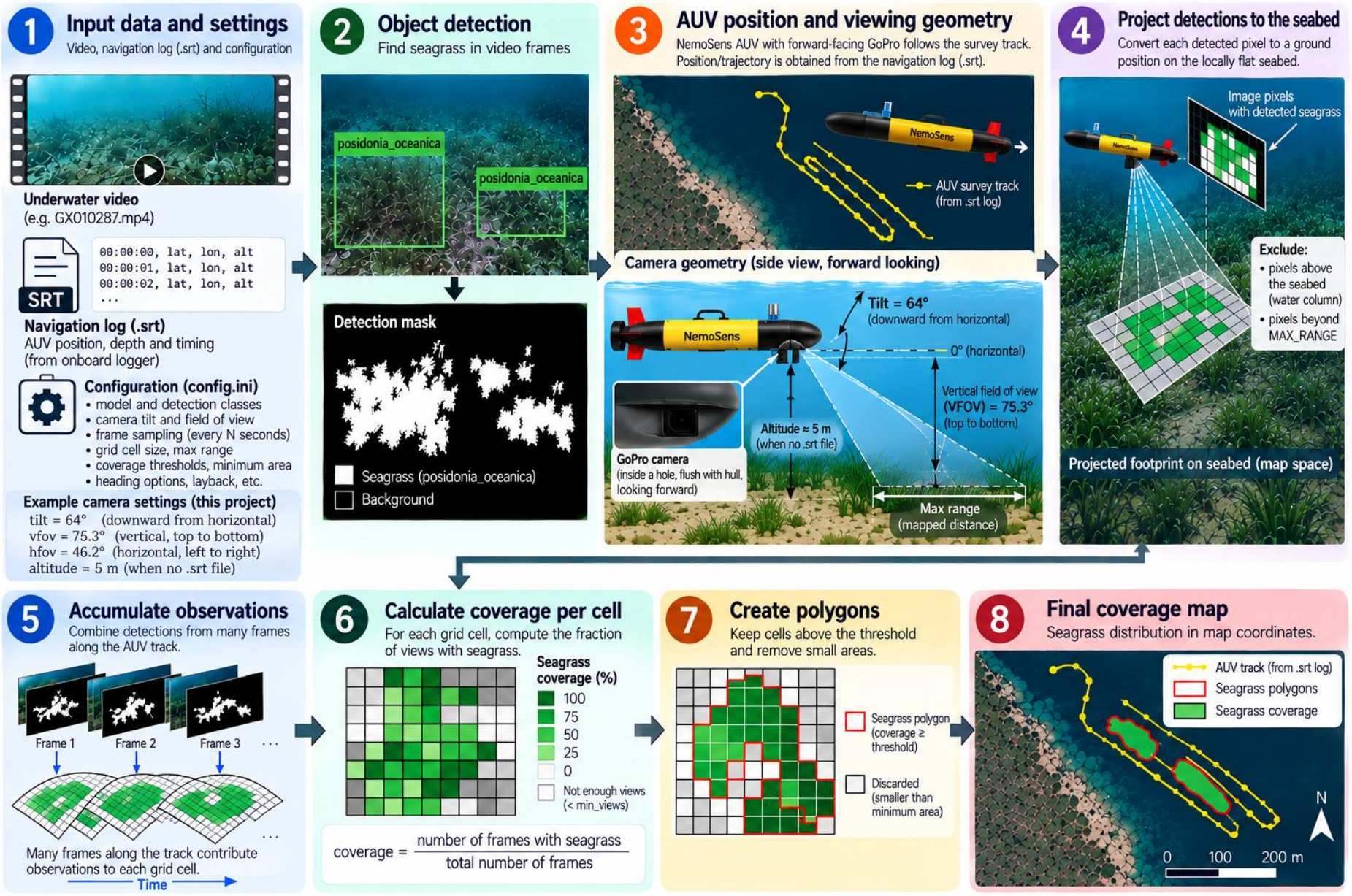
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From Survey Video to Seagrass Map

- **Detect** seagrass in each video frame.
- **Locate** each frame from the AUV navigation log and camera geometry.
- **Project** detected pixels onto a seabed grid.
- **Accumulate** detections from many frames in each grid cell.
- **Compute coverage**: frames with seagrass ÷ total frames.
- **Map** cells above the threshold as seagrass polygons.



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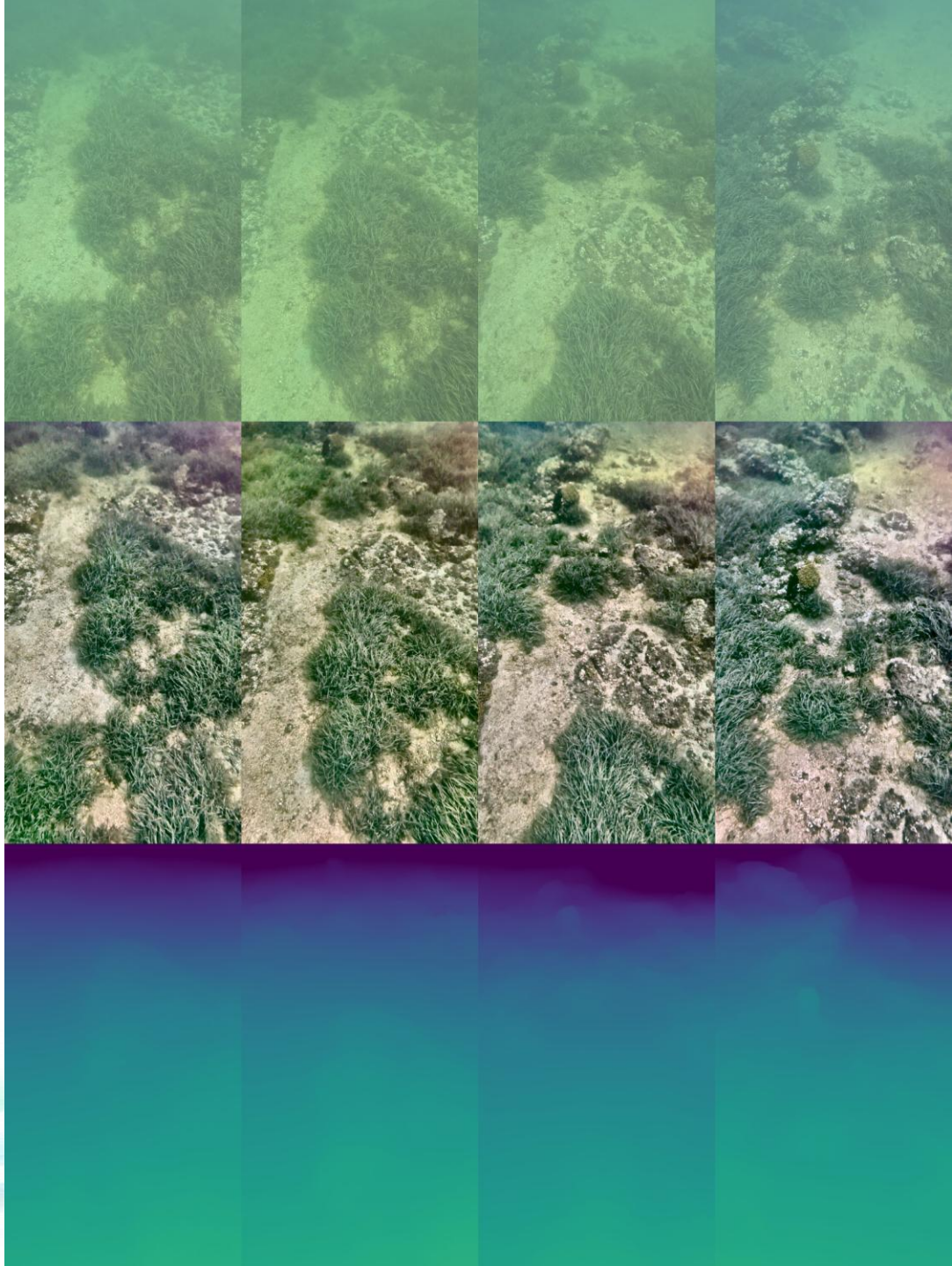
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Step 1: Import and Clean the Video

```
1 1
2 00:00:00,000 --> 00:00:00,500
3 2026/07/16-10:48:02 -- lat:40.828139 lon:24.340438
  imm.:4.585355 alt.:10.893332 -- light state:1
4
5 2
6 00:00:00,500 --> 00:00:01,000
7 2026/07/16-10:48:03 -- lat:40.828140 lon:24.340447
  imm.:4.464695 alt.:11.919866 -- light state:1
8
```

- **Import** the GoPro survey video and its navigation log.
- **Clean** each frame: remove haze and restore lost colours.





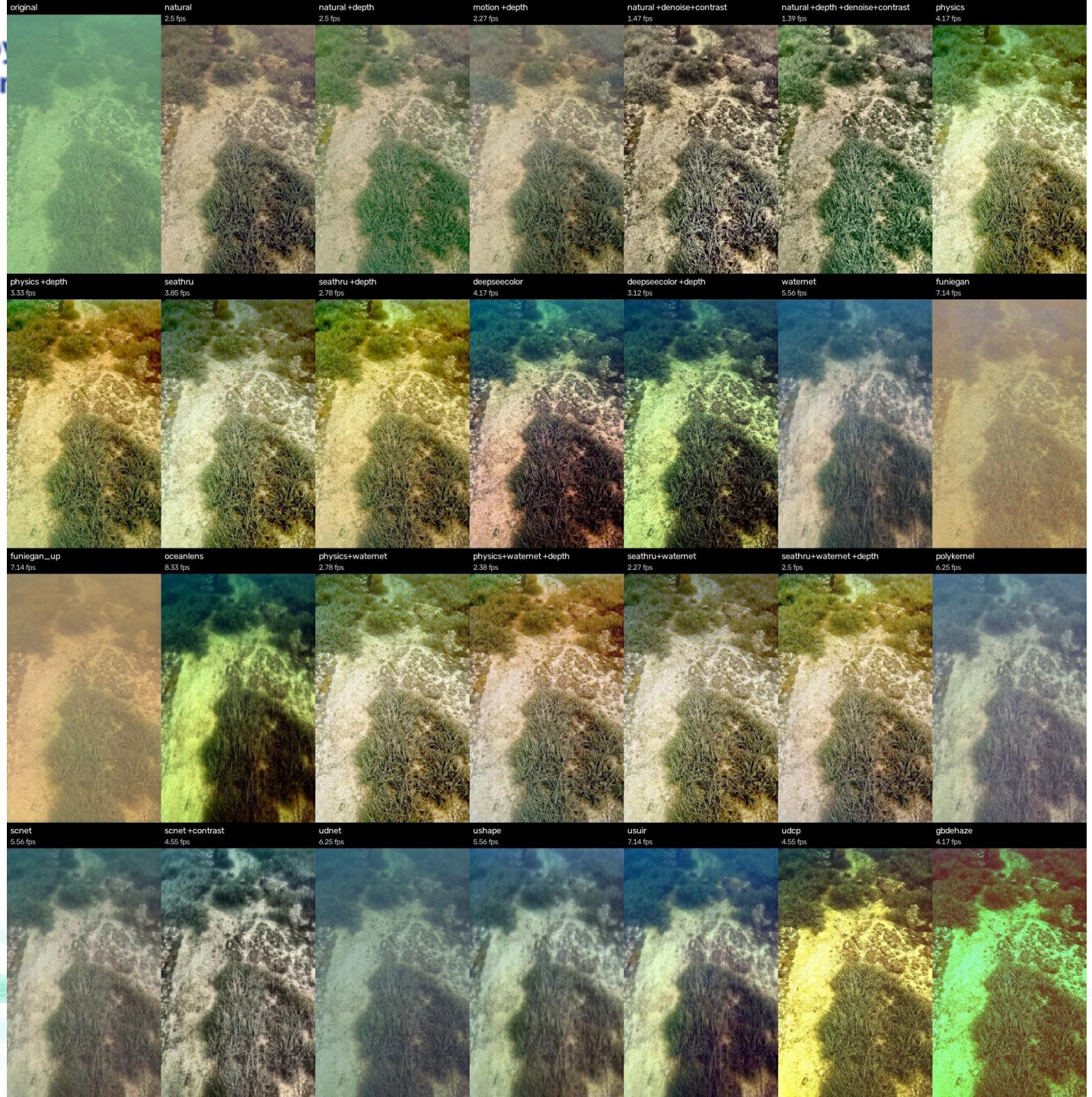
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Step 1: Import and Clean the Video

- **Tested 28 methods** on the same frame, including depth-based variants.
- **Goal**: the clearest view of seagrass for detection.



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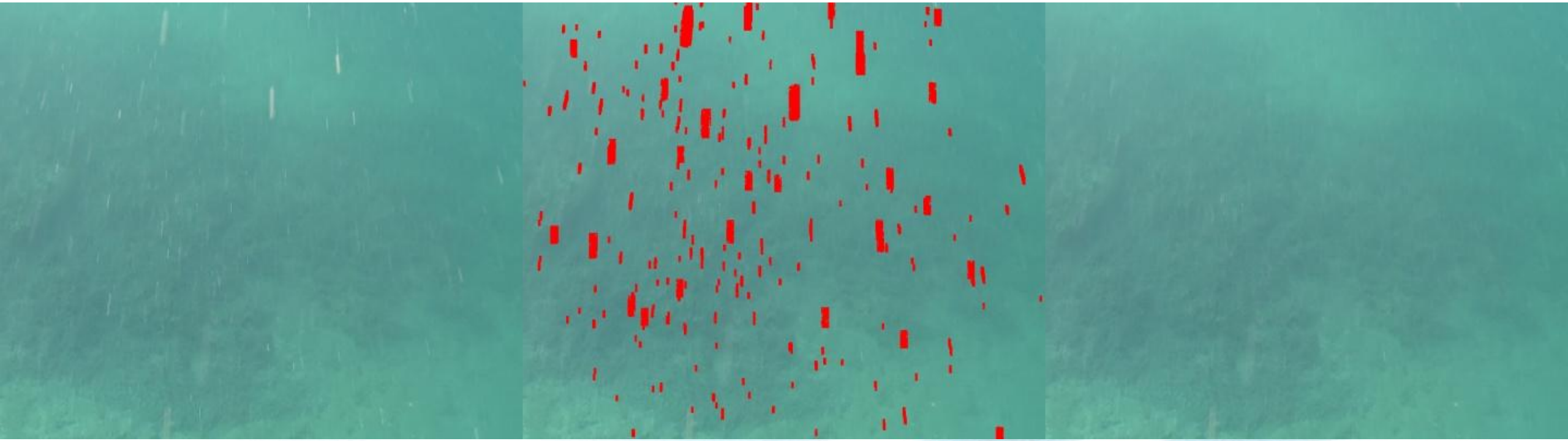
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Step 1: Removing Particles from Murky Water

Original frame
Suspended particles cloud the view

Particles detected
Each particle marked in red

Cleaned frame
Particles removed before detection

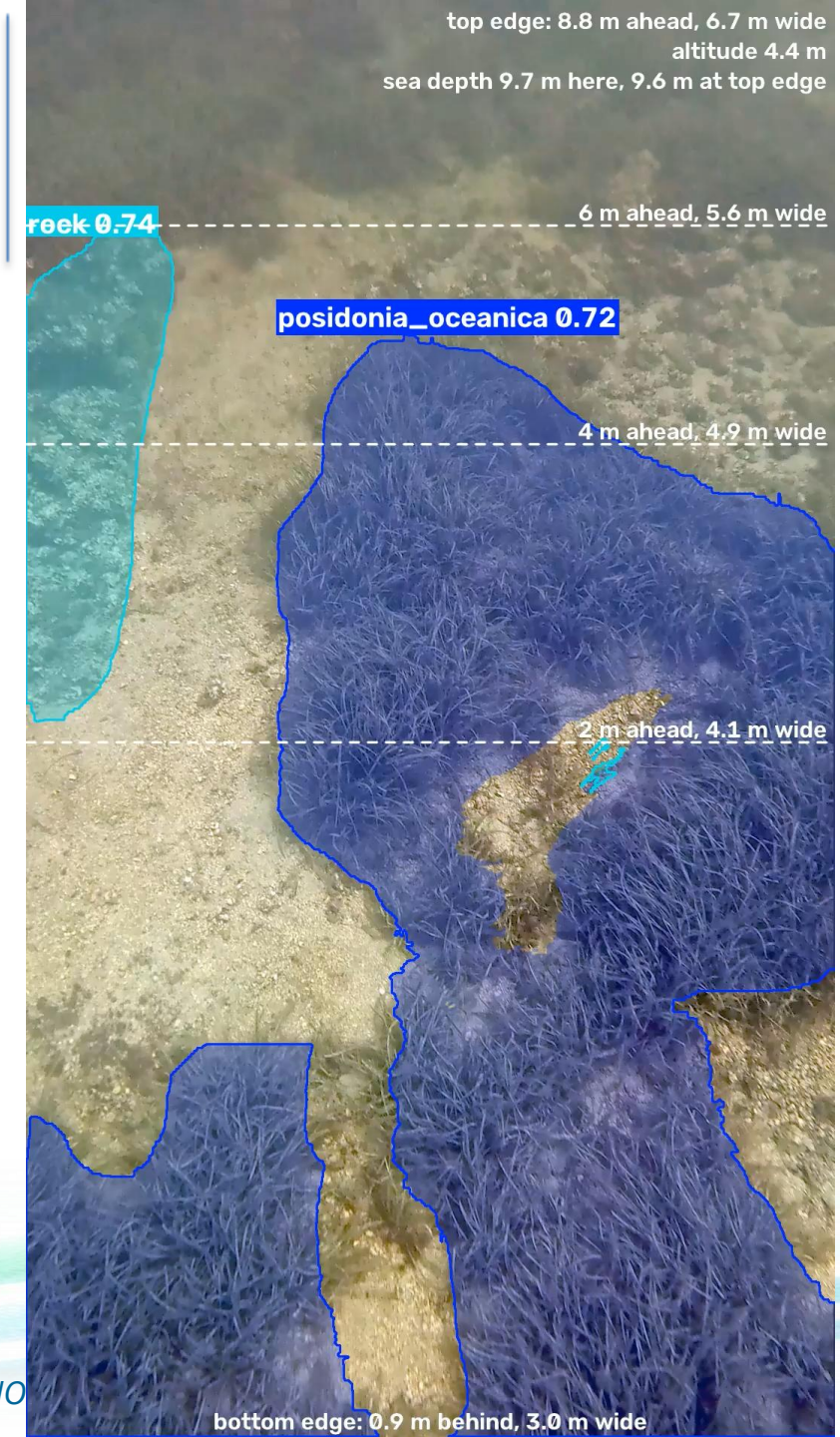


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Step 2: Detect Seagrass in Each Frame

- **Detect** seagrass (Posidonia oceanica) in frames sampled from the cleaned video.
- **Output**: a detection mask per frame, separating seagrass from background.
- **Settings**: the model, detection classes and sampling interval come from config.ini.



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Steps 3–5: Place Detections on the Seabed

- **Locate**: position and depth of each frame from the navigation log (.srt), plus camera tilt (64°) and field of view.
- **Project**: seagrass pixels onto a flat seabed grid, excluding water column and pixels beyond max range.
- **Accumulate**: detections from many frames along the AUV track in each grid cell.



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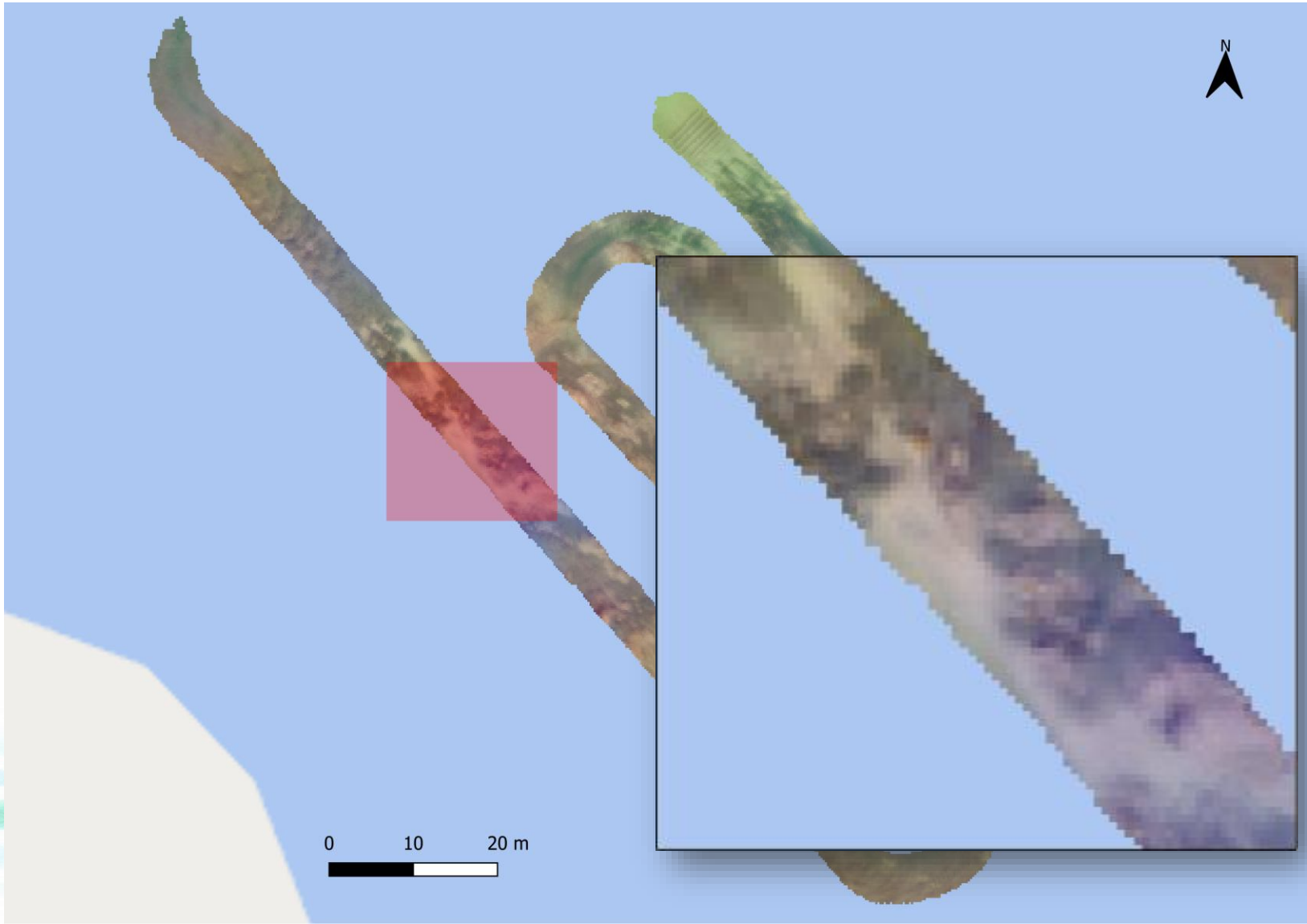
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Steps 3–5: Place Detections on the Seabed

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- **Accumulate**: detections from many frames along the AUV track in each grid cell.



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Steps 6–8: Turn Detections into a Coverage Map

- **Coverage**: for each cell, frames with seagrass ÷ total frames; cells with too few views are skipped.
- **Polygons**: keep cells above the coverage threshold and remove small areas.
- **Map**: seagrass distribution along the AUV track, in map coordinates.



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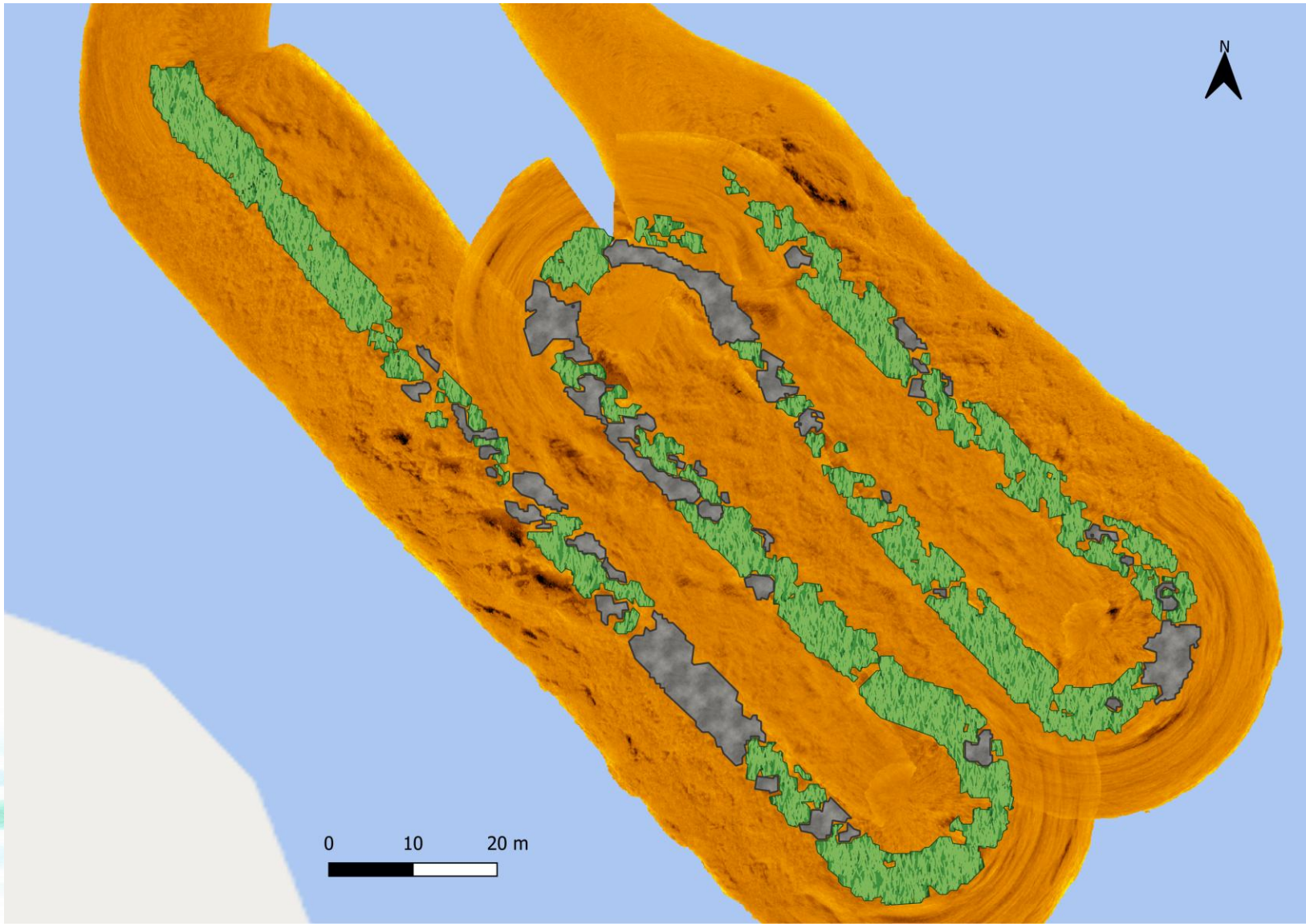
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Video Coverage vs. the Full Side-Scan Sonar Image

- **Overlay**: video-detected coverage on the side-scan sonar (SSS) mosaic (orange).
- **Video** maps only a narrow strip along the AUV track.
- **SSS** covers the full swath on both sides of the track, so most of the surveyed seabed is seen by sonar only.



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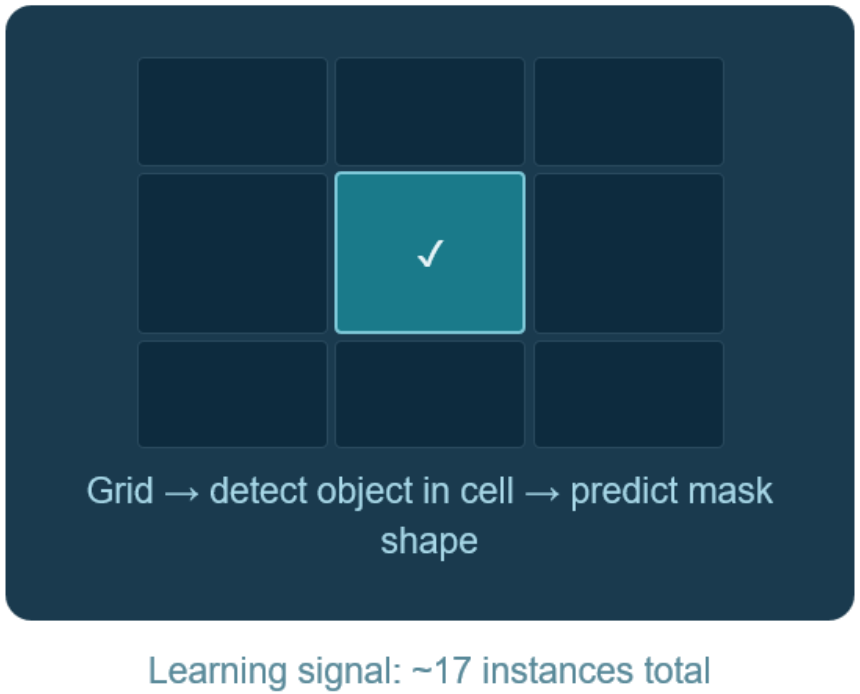
ML on Side Scan Sonar Images

YOLO — "You Only Look Once"

YOLO is an **instance detection model**. It looks at an image and asks: "Where are the objects, and what shape is each one?"

- Divides the image into a grid and predicts a bounding box + polygon mask for each detected object
- Extremely fast, designed for real-time video detections of cars, people, animals
- Learns from **labeled object instances.**

The catch: each labeled object count as one training signal regardless of how many pixels it covers. With only 17 labeled patches, there isn't enough to learn from.

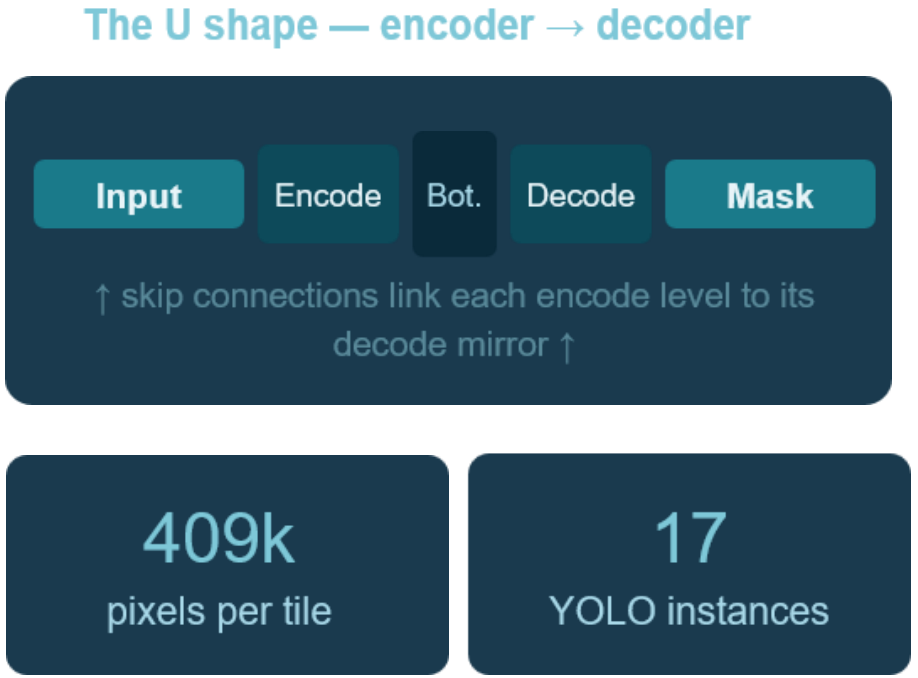


U-Net – Pixel by pixel segmentation

Unet is a **dense segmentation model**. Instead of finding objects, it answers a simpler question for every single pixel "Is this seagrass? Yes or no?"

- Encoder: compresses the image to understand context – "What kind of texture is this region?"
- Decoder: rebuilds the image at full resolution, pixel by pixel, outputting a yes/no mask
- Skip connections: bridges between encoder and decoder to preserve fine spatial detail

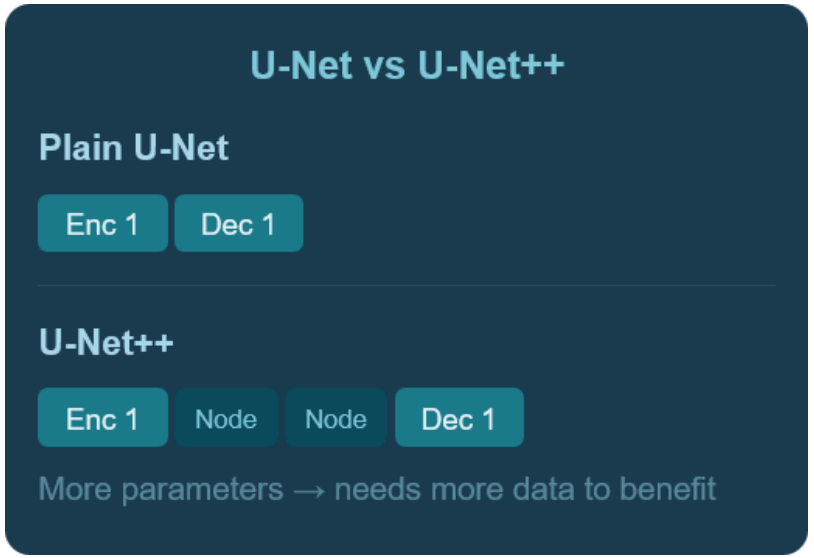
The advantage: a 640 by 640 tile has 409.600 pixels. Every one contributes to the loss. That's a way bigger learning signal than that of 17 object instances.



U-Net^{++} – Nested Skip Connections

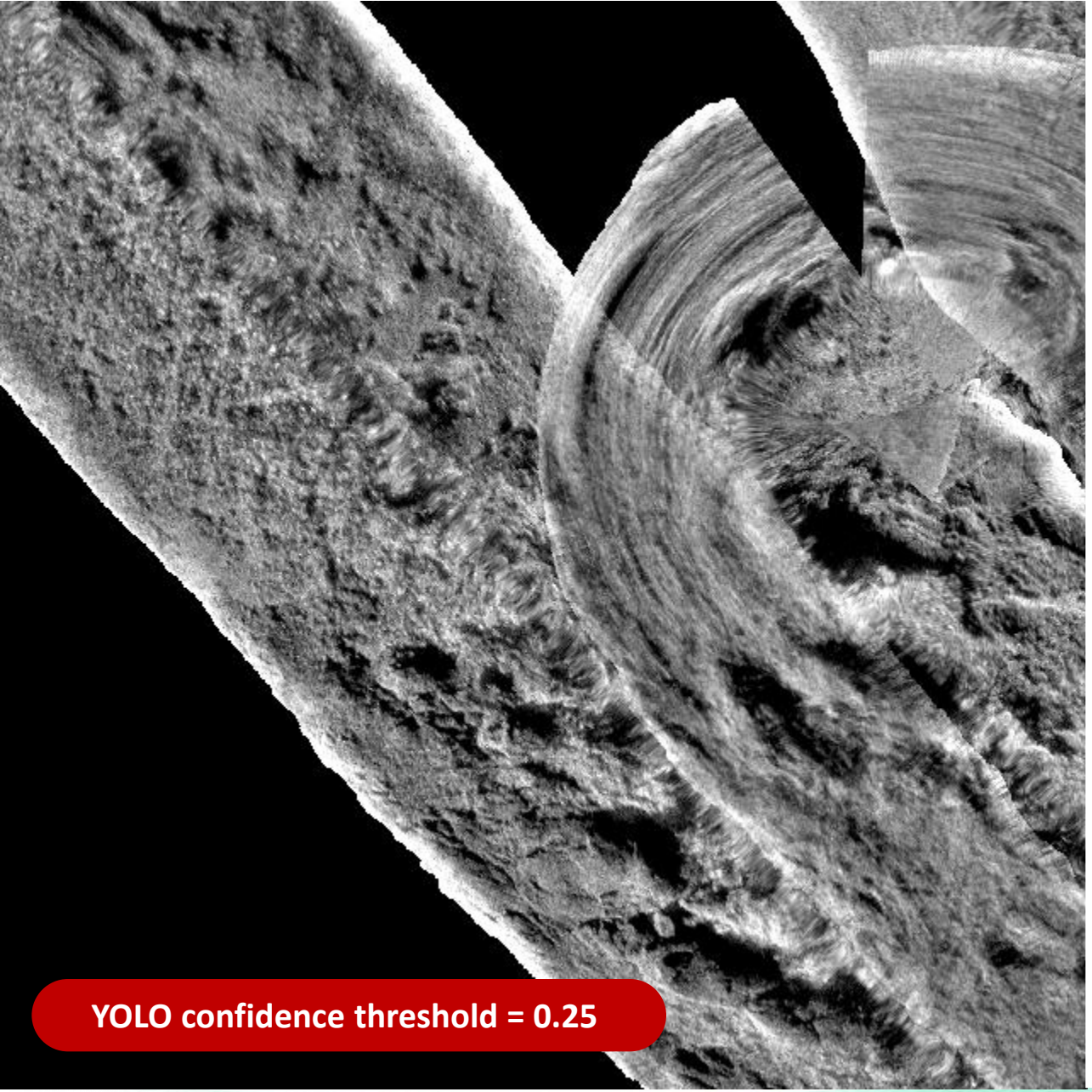
Unet++ is an **upgraded version on U-Net**. It keeps the same encoder-decoder structure, but adds extra intermediate nodes between the two halves.

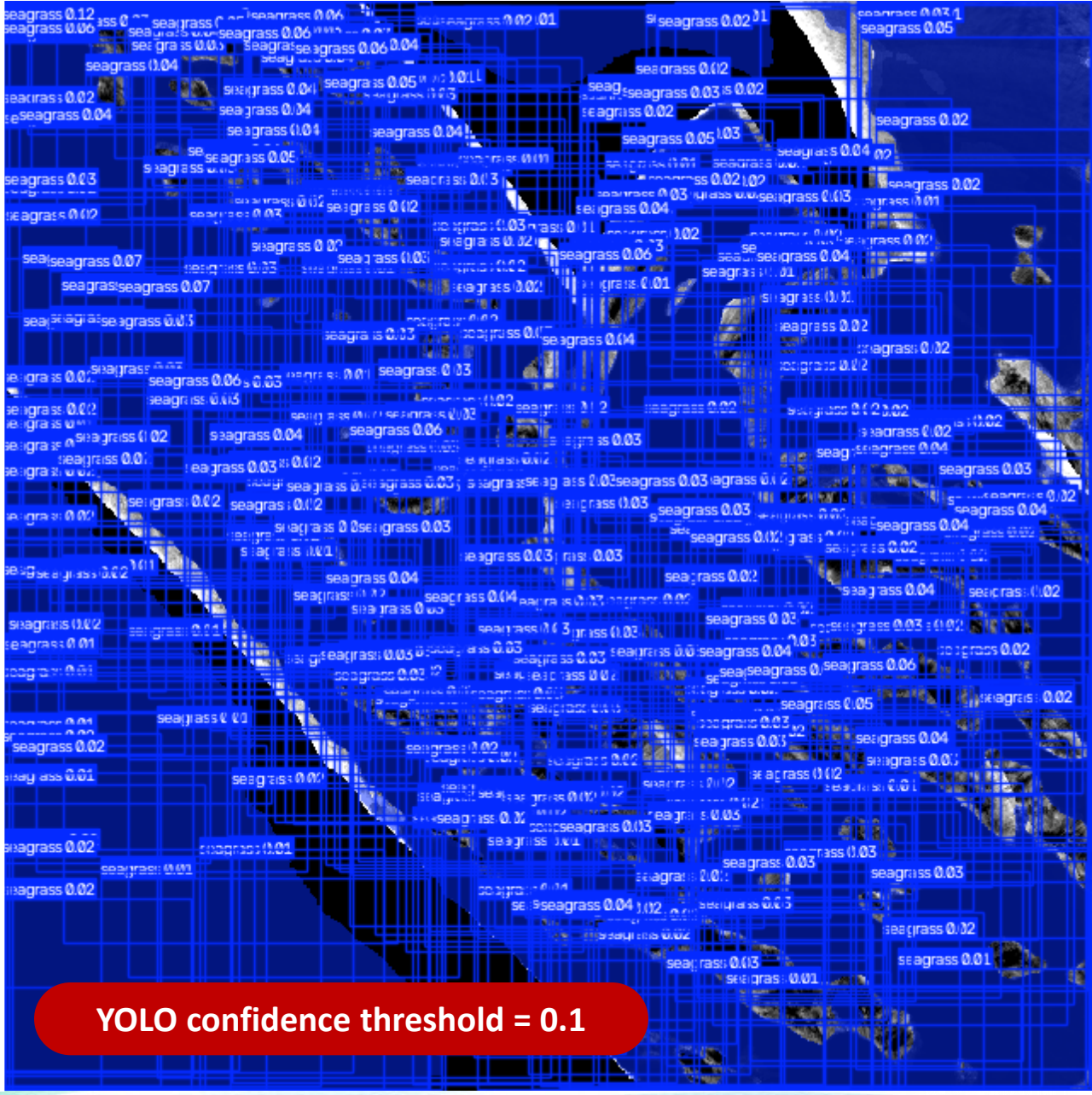
- In a plain U-Net, skip connections jump directly from raw pixel detail to high level context
- Unet++ inserts intermediate processing steps along those bridges
- This results in finer boundary detail and better performance – when enough data exists to train those extra nodes.

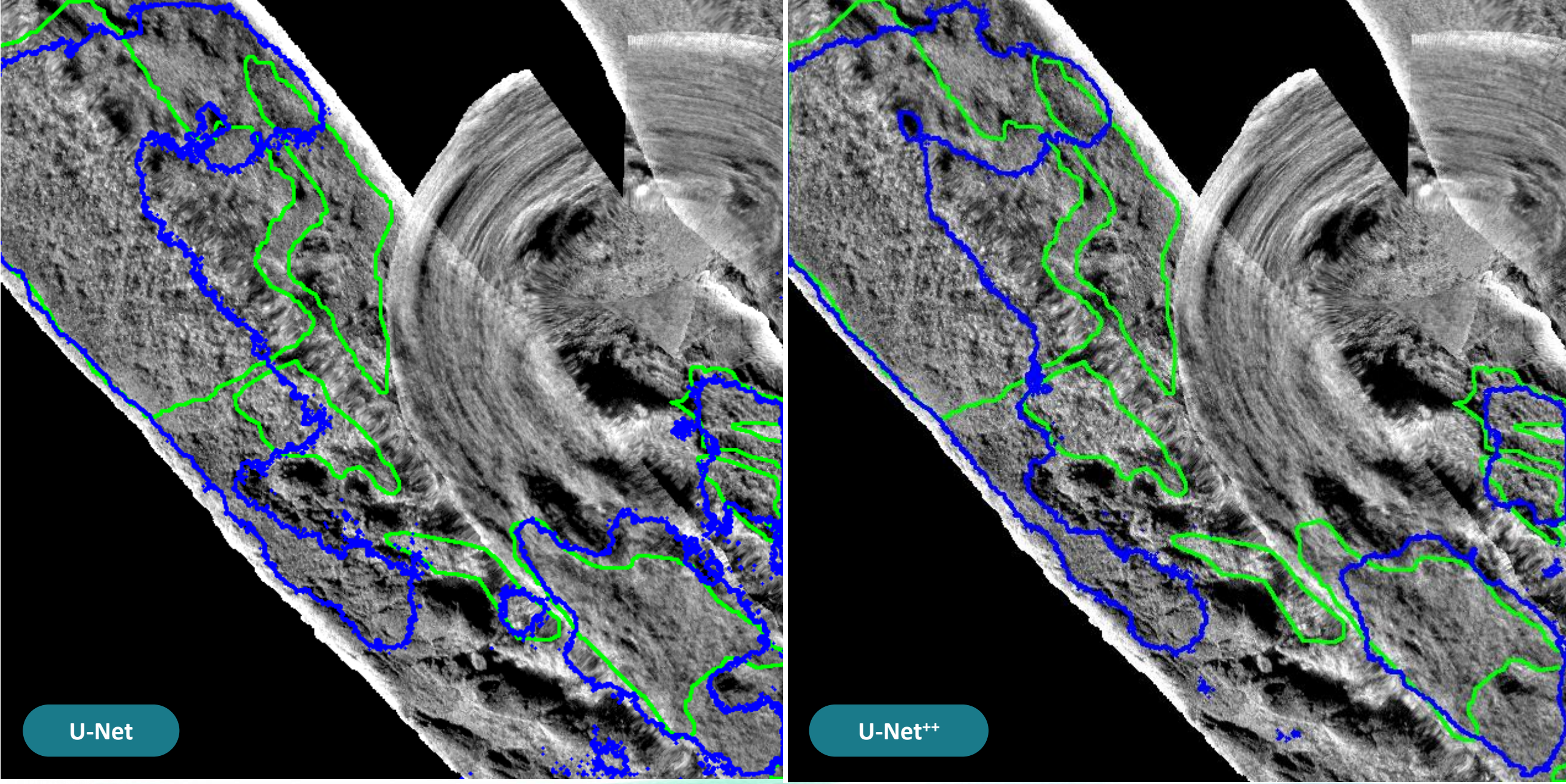


In this project: U-Net^{++} scored IoU 0.456 vs plain U-Net's 0.495. The extra capacity didn't pay off – the nested nodes had too little data to learn from and added noise instead of precision.




YOLO confidence threshold = 0.25


YOLO confidence threshold = 0.1


U-Net
U-Net++

Why U-Net won at this scale?

YOLO

Instance-level supervision

Learns from the 17 labeled object instances. There simply isn't enough to learn from.

17

training signals from 17 patches (too little)

U-Net

Dense per-pixel supervision

Learns from every pixel. The same 17 patches contain hundreds of thousands of pixels – each one teaches the model something.

~400,000

training signals from the same 17 patches

Conclusion: for this data scale, dense segmentation is the right architecture family – not instance detection. YOLO remains valid if enough verified data can be collected.

Known Limitations

Data scale

Only 13 training-5 validation images from a single tile mosaic. Too little for a statistically reliable performance estimate.

Label uncertainty

Ground truth carries acknowledged uncertainty – GoPro correlation is a rough field estimate, not a precise survey. GPS offset, imprecise boundaries.

Unseen mosaics unscored

Predictions on different Sonar files can only be judged qualitatively – no ground truth to score accuracy against.

Next Steps

1. ***More GoPro verified survey sites***
Grow and diversify the training set, create a unique test set in order to test the model on unseen data.

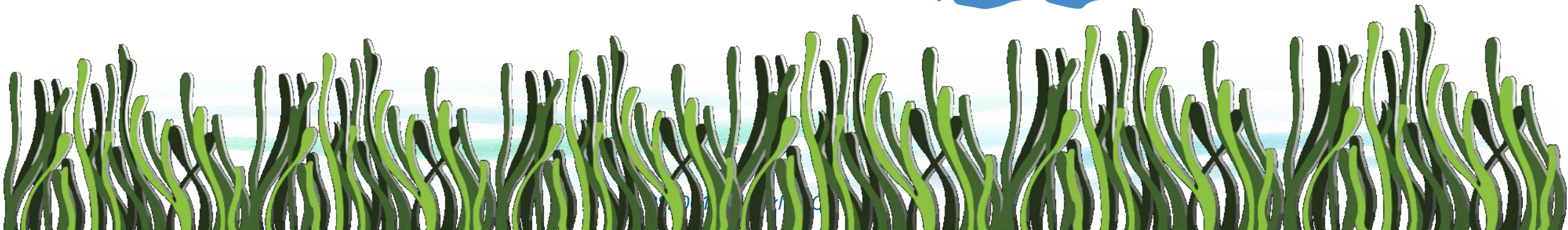
2. ***Revisit U-Net^{++} and larger models***
U-Net++ and YOLO, both underperformed at 13 images. With more verified data, the extra capacity may pay off.

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Thank you!



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Integrated Marine Monitoring in the Georgian Black Sea: The EfxINNOs Approach and Experience

Ketevan Kupatadze;
Tamar Edisherashvili;

Romania, Constanța, 28 October , 2026

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Why Continuous Marine Monitoring Matters in the Black Sea

•The Black Sea is a semi-enclosed marine basin exposed to multiple natural and anthropogenic pressures.

•Coastal water quality is influenced by river discharge, urban activities, port operations, and seasonal environmental changes.

•Conventional periodic sampling provides valuable information but may miss rapid fluctuations in environmental conditions.

•**Continuous, high-frequency monitoring** enables the detection of short-term changes, seasonal trends, and relationships between key water-quality parameters.

•Smart buoy systems provide an effective technological approach to collecting long-term environmental data and supporting evidence-based marine management.

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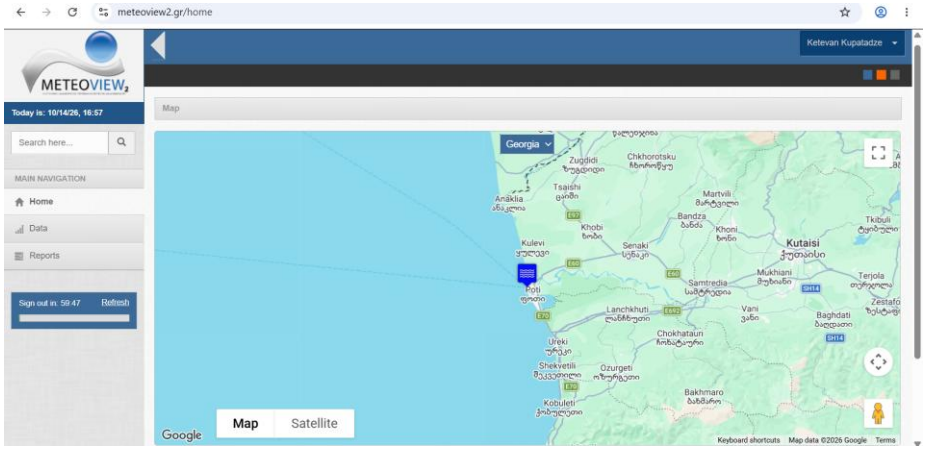
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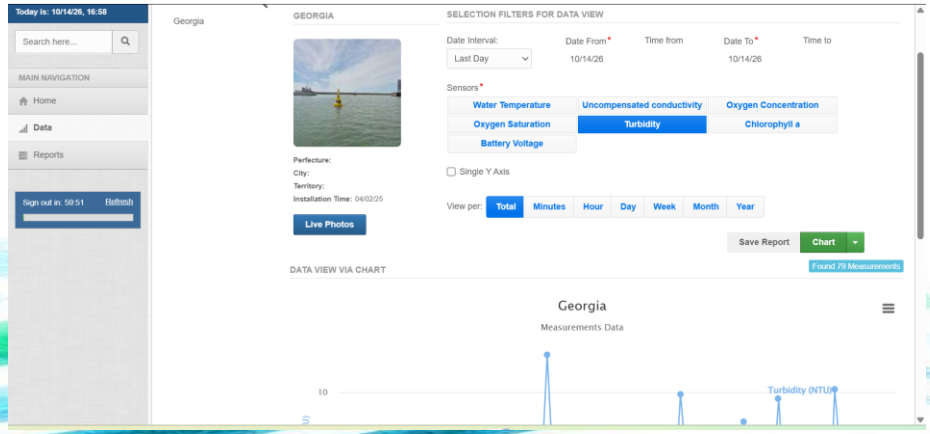
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• Background

Temperature; conductivity electrode (0-500 mS/cm) (salinity) turbidity analyzer(no wiper)(0~10/100/1,000/4,000 NTU), chlorophyll a analyzer(no wiper)(0~500 mg/L)







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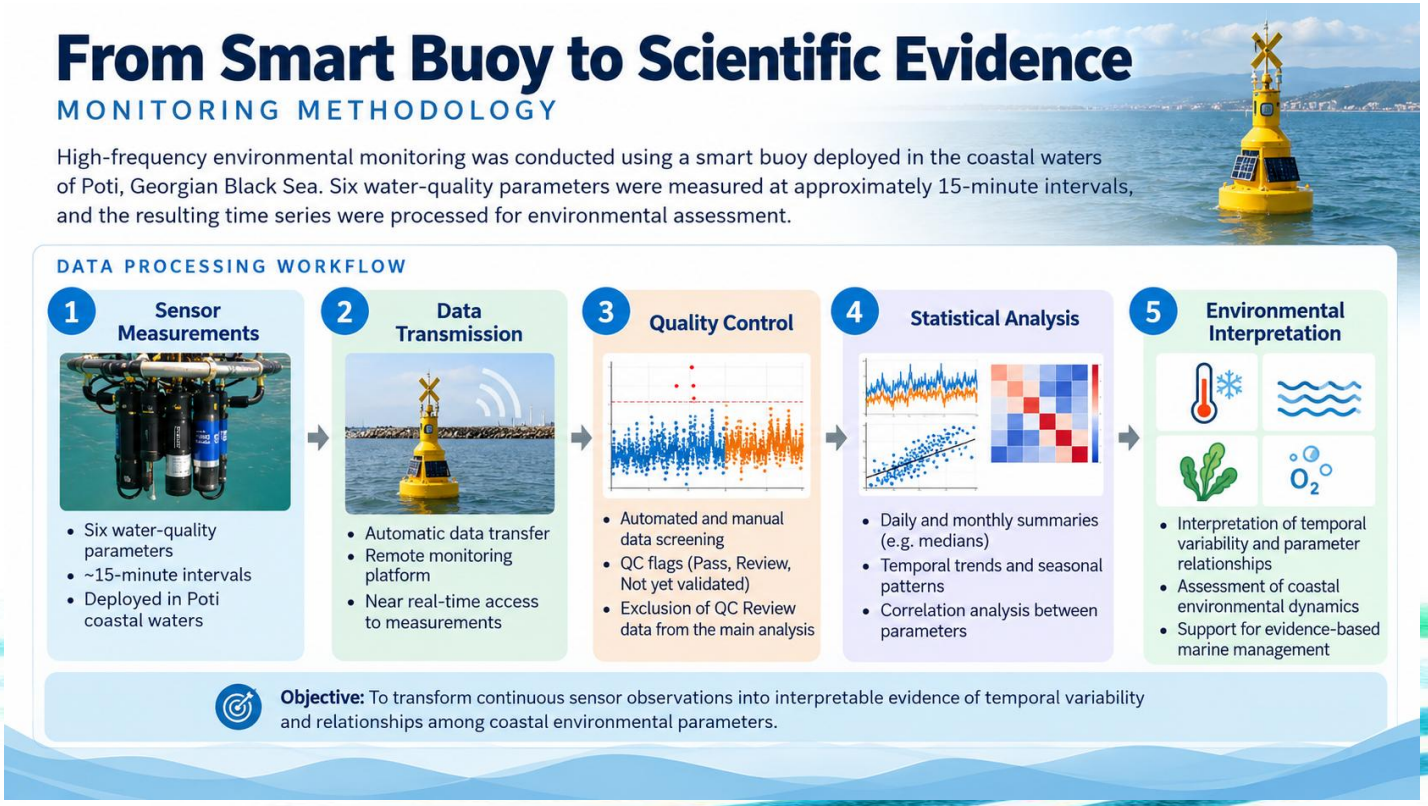
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From Smart Buoy to Scientific Evidence
MONITORING METHODOLOGY

High-frequency environmental monitoring was conducted using a smart buoy deployed in the coastal waters of Poti, Georgian Black Sea. Six water-quality parameters were measured at approximately 15-minute intervals, and the resulting time series were processed for environmental assessment.



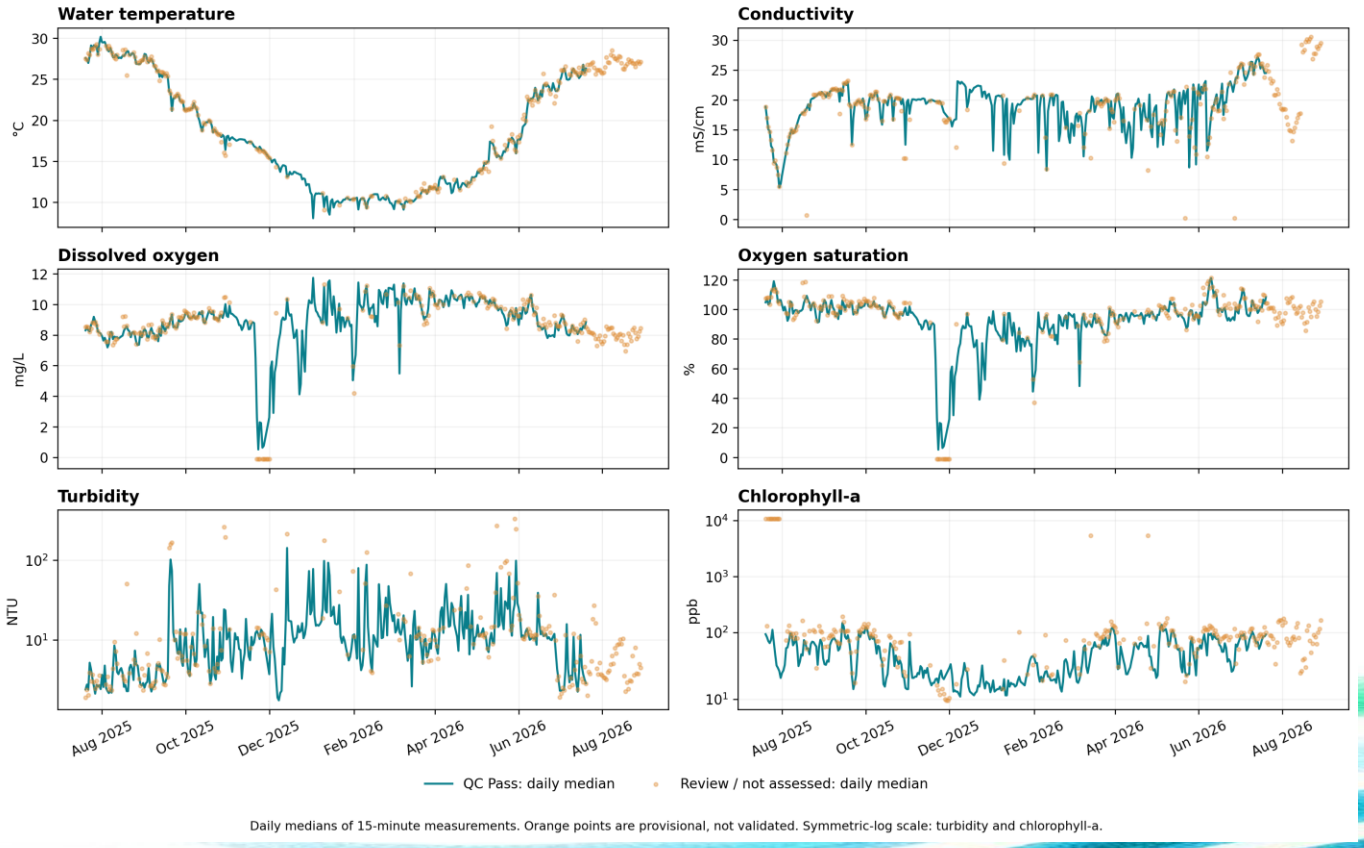
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EfxINNOs | Long-term coastal monitoring overview
Poti, Georgian Black Sea • 20 Jul 2025 – 29 Aug 2026

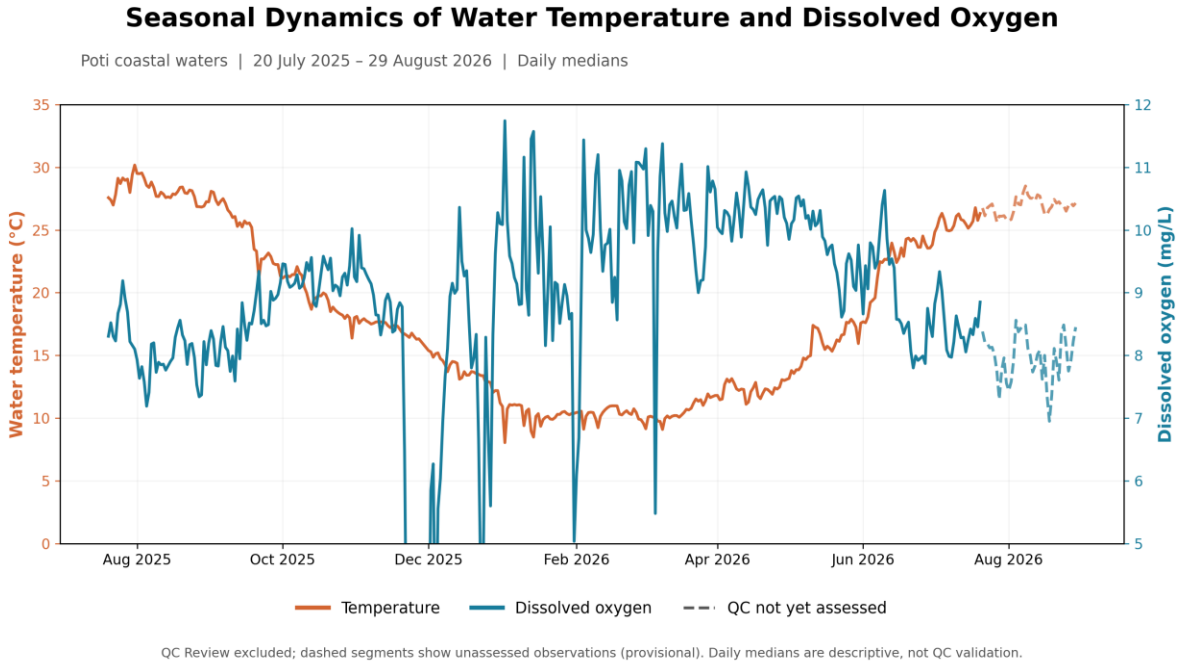


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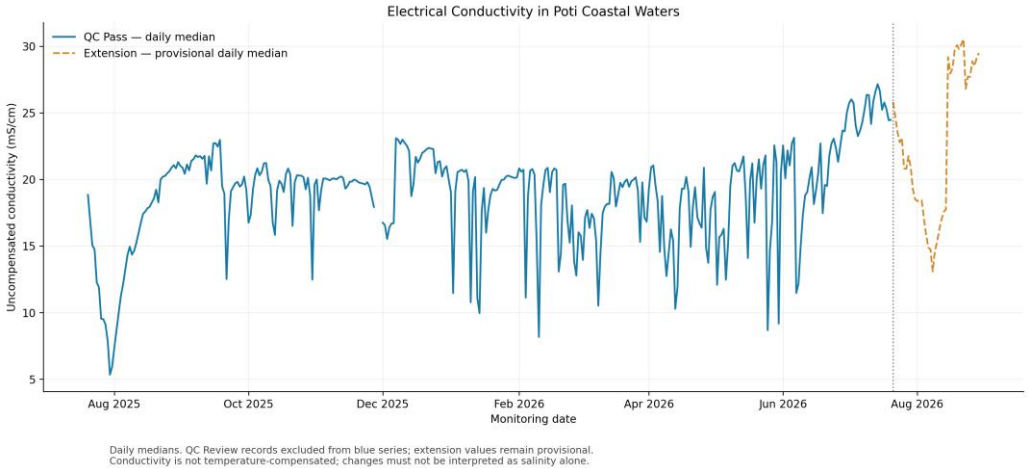
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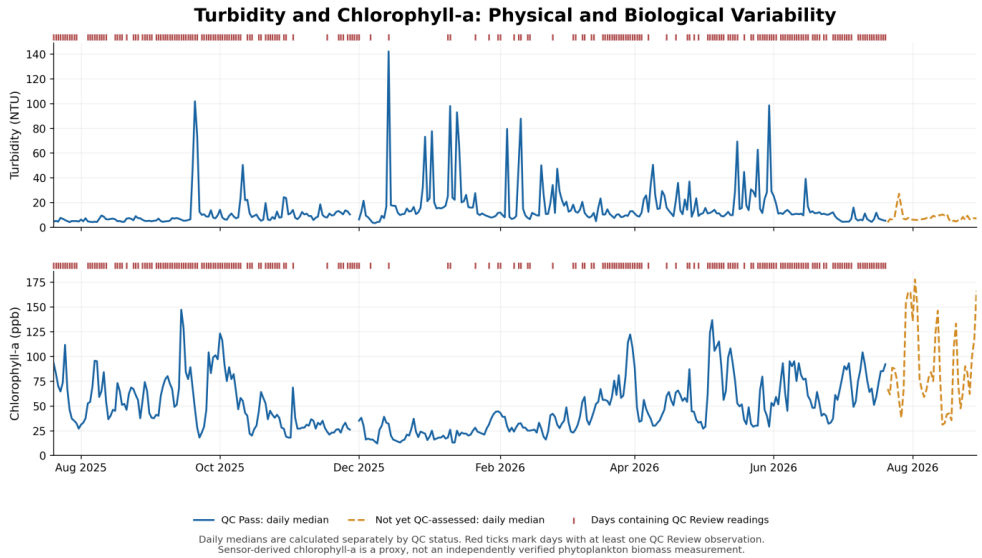
Water temperature exhibits pronounced seasonal variability, accompanied by an inverse pattern in dissolved oxygen concentration. This relationship highlights the importance of continuous monitoring for understanding seasonal changes in coastal water conditions.



Electrical conductivity exhibited considerable temporal variability throughout the monitoring period. These fluctuations may reflect changes in coastal water composition and hydrological conditions, although additional information is needed to identify their causes.

The solid blue line represents the daily medians of QC Pass data, while the dashed orange line indicates the period for which quality control has not yet been finalized.

Important note: The sensor measures temperature-uncompensated electrical conductivity. Therefore, observed fluctuations should not be directly interpreted as changes in salinity.



Turbidity and chlorophyll-a exhibited substantial temporal variability, reflecting complex and potentially distinct physical and biological processes in coastal waters.

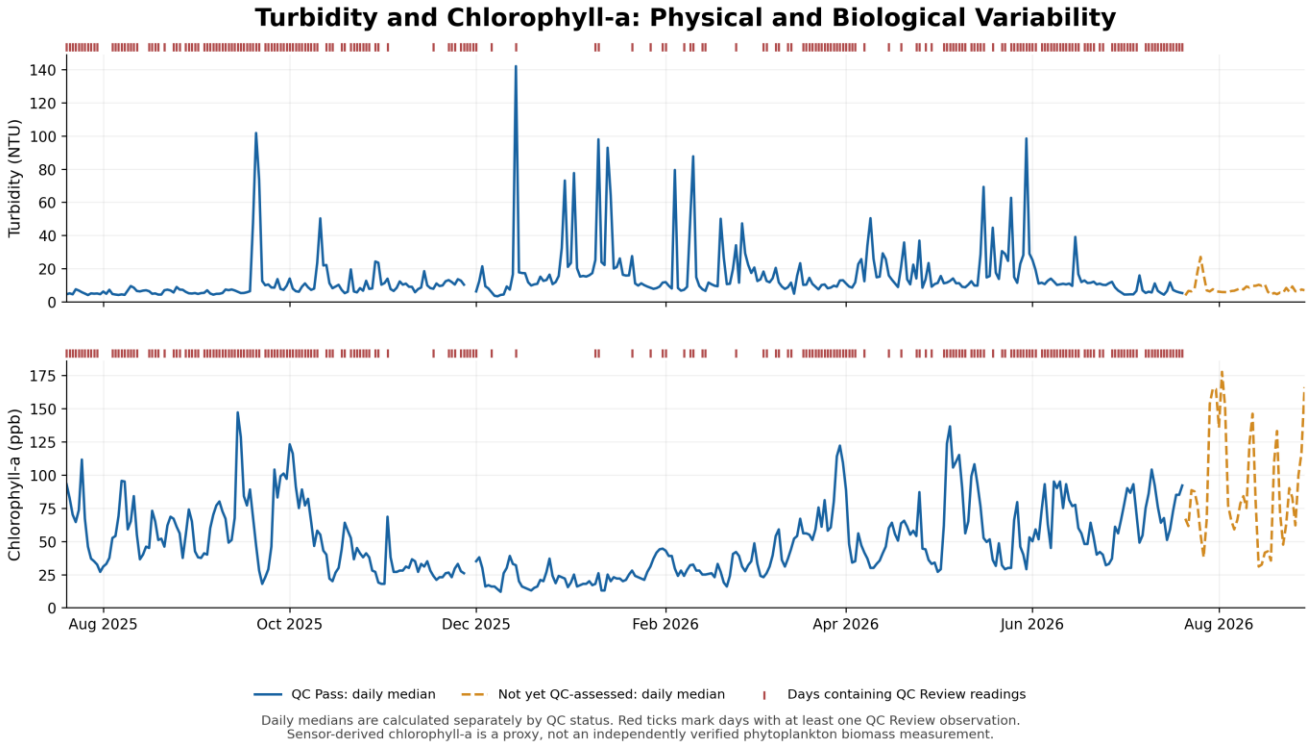
Blue lines represent daily medians of QC Pass measurements; orange dashed lines represent data awaiting final quality assessment. Red markers identify days containing QC Review observations.

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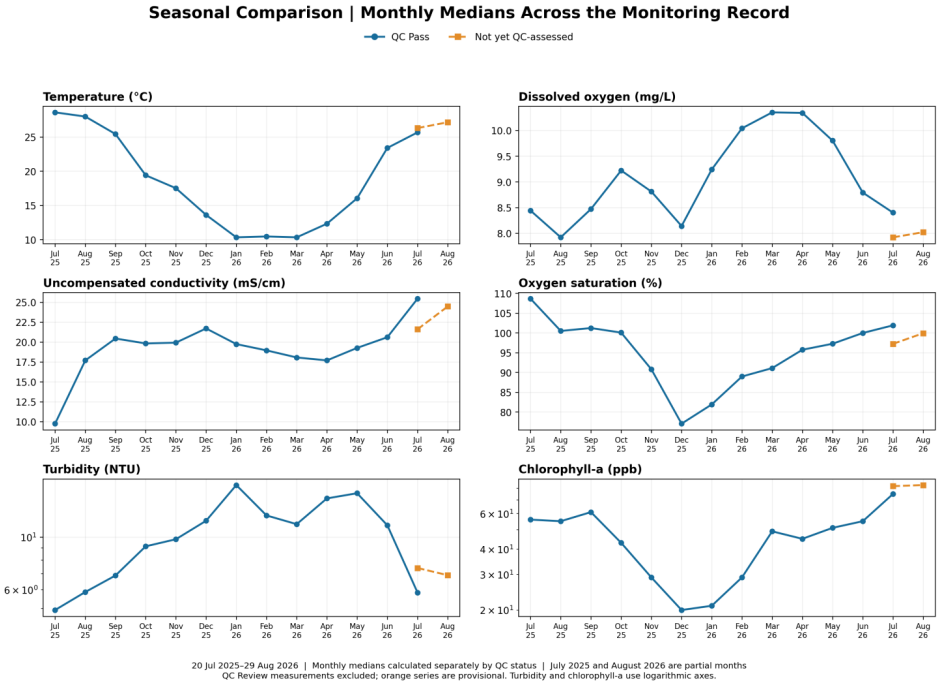
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Seasonal Comparison: What Changed Across the Monitoring Period?

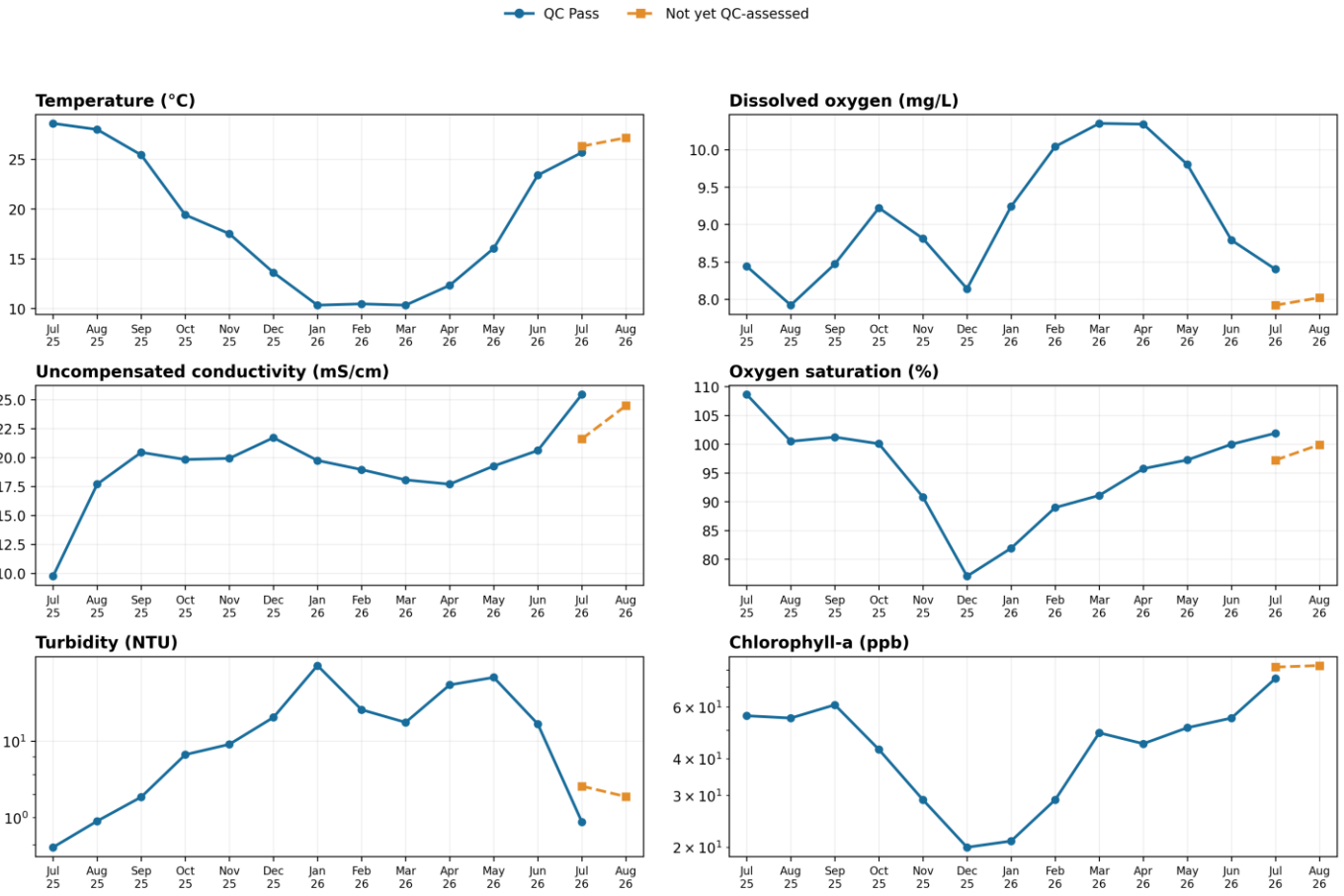
•Water temperature and dissolved oxygen show contrasting seasonal patterns.

•Electrical conductivity exhibits considerable variability across the monitoring period.

Data interpretation: Monthly medians are presented separately for QC Pass data (blue) and measurements awaiting final quality assessment (orange). QC Review observations are excluded.



Seasonal Comparison | Monthly Medians Across the Monitoring Record



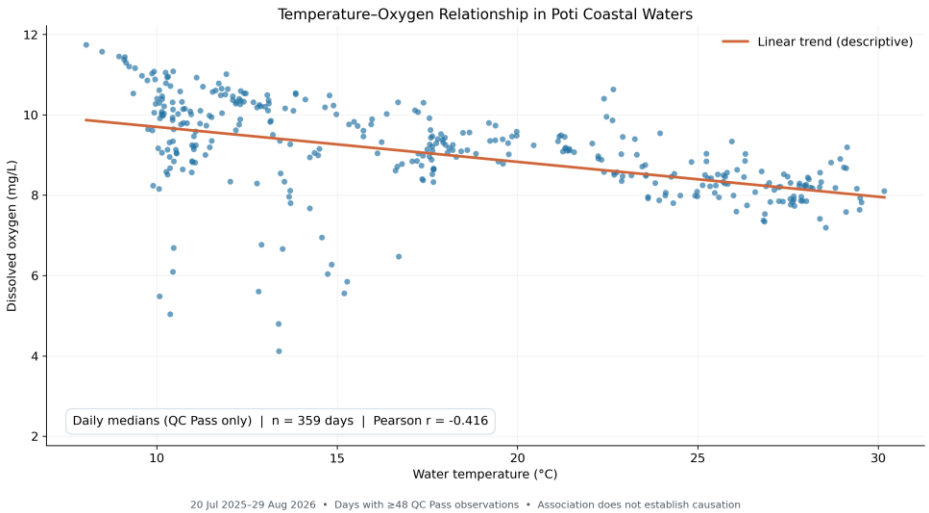
20 Jul 2025–29 Aug 2026 | Monthly medians calculated separately by QC status | July 2025 and August 2026 are partial months
QC Review measurements excluded; orange series are provisional. Turbidity and chlorophyll-a use logarithmic axes.

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Temperature–Oxygen Relationship



Key findings

- Water temperature and dissolved oxygen exhibit a moderate negative correlation (Pearson r = −0.416).
- Higher water temperatures are generally associated with lower dissolved oxygen concentrations.
- The observed relationship is consistent with the temperature dependence of oxygen solubility, although additional environmental processes may also contribute.

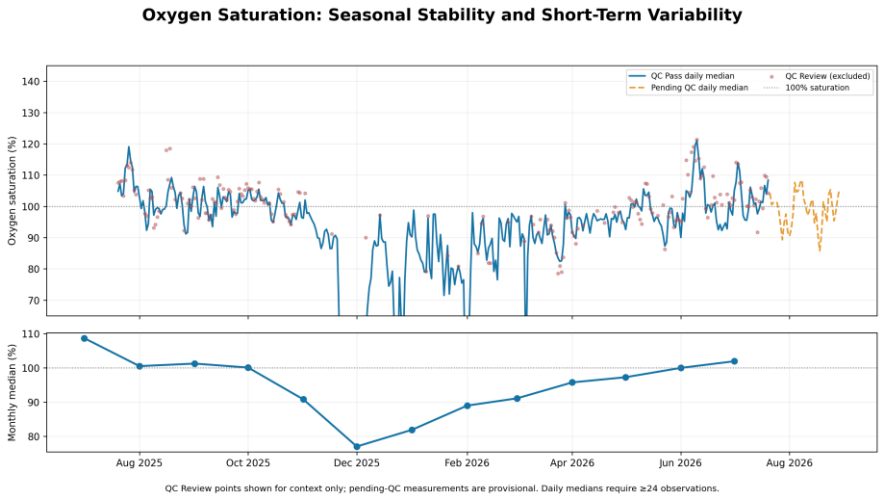
The analysis is based on daily medians from 359 days with at least 48 QC Pass observations per day.

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Oxygen Saturation: Seasonal Stability and Short-Term Variability



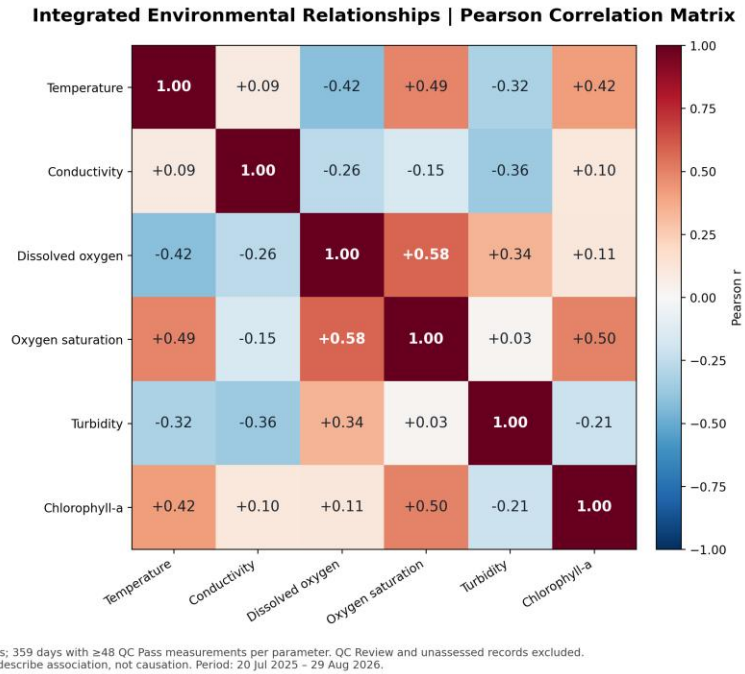
- Oxygen saturation exhibited seasonal and short-term variability throughout the monitoring period.
- Values frequently approached or exceeded 100%, although periods of lower saturation were also observed.
- Short-term fluctuations may reflect interacting physical and biological processes, but their causes cannot be established from oxygen saturation alone.

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Integrated Environmental Relationships: Correlation Matrix



Key findings

•Water temperature and dissolved oxygen exhibit a moderate negative correlation (r = −0.42).

•Dissolved oxygen concentration and oxygen saturation are positively correlated (r = +0.58).

•Temperature and oxygen saturation show a positive association (r = +0.49).

•Turbidity and conductivity exhibit a negative correlation (r = −0.36).

Pearson correlations were calculated using daily medians from 359 days with sufficient QC Pass measurements. Correlation does not imply causation.

Key Scientific Findings and Environmental Implications

1. Pronounced seasonal variability

Water temperature exhibited a clear seasonal pattern, accompanied by contrasting changes in dissolved oxygen concentration.

2. Dynamic coastal conditions

Electrical conductivity and turbidity showed considerable temporal variability, highlighting the dynamic nature of the monitored coastal environment.

3. Complex biological responses

Chlorophyll-a concentrations fluctuated substantially, indicating the need for careful interpretation of potential biological signals and sensor-related anomalies.

4. Interconnected environmental processes

Correlation analysis revealed associations among physical, chemical, and biological indicators, demonstrating the value of integrated monitoring.

5. Importance of continuous observation

High-frequency measurements captured short-term fluctuations that could be overlooked by conventional periodic sampling.

Conclusions and Future Perspectives

•The EfxINNOs smart buoy demonstrated the value of high-frequency, multiparameter monitoring in the Georgian Black Sea coastal environment.
•Long-term observations revealed pronounced seasonal variability and short-term fluctuations in key water-quality parameters.
•Integrated analysis provided insights into relationships among physical, chemical, and biological indicators.
•The monitoring experience highlighted the importance of sensor maintenance, data quality control, and consistent interpretation of environmental measurements.

Future Perspectives
•Continue long-term monitoring to strengthen the assessment of seasonal and interannual variability.

•Integrate buoy observations with complementary environmental and meteorological data.
•Promote the use of monitoring results for coastal environmental assessment and evidence-based management.

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EfxINNOs Takes the Stage! 🎭





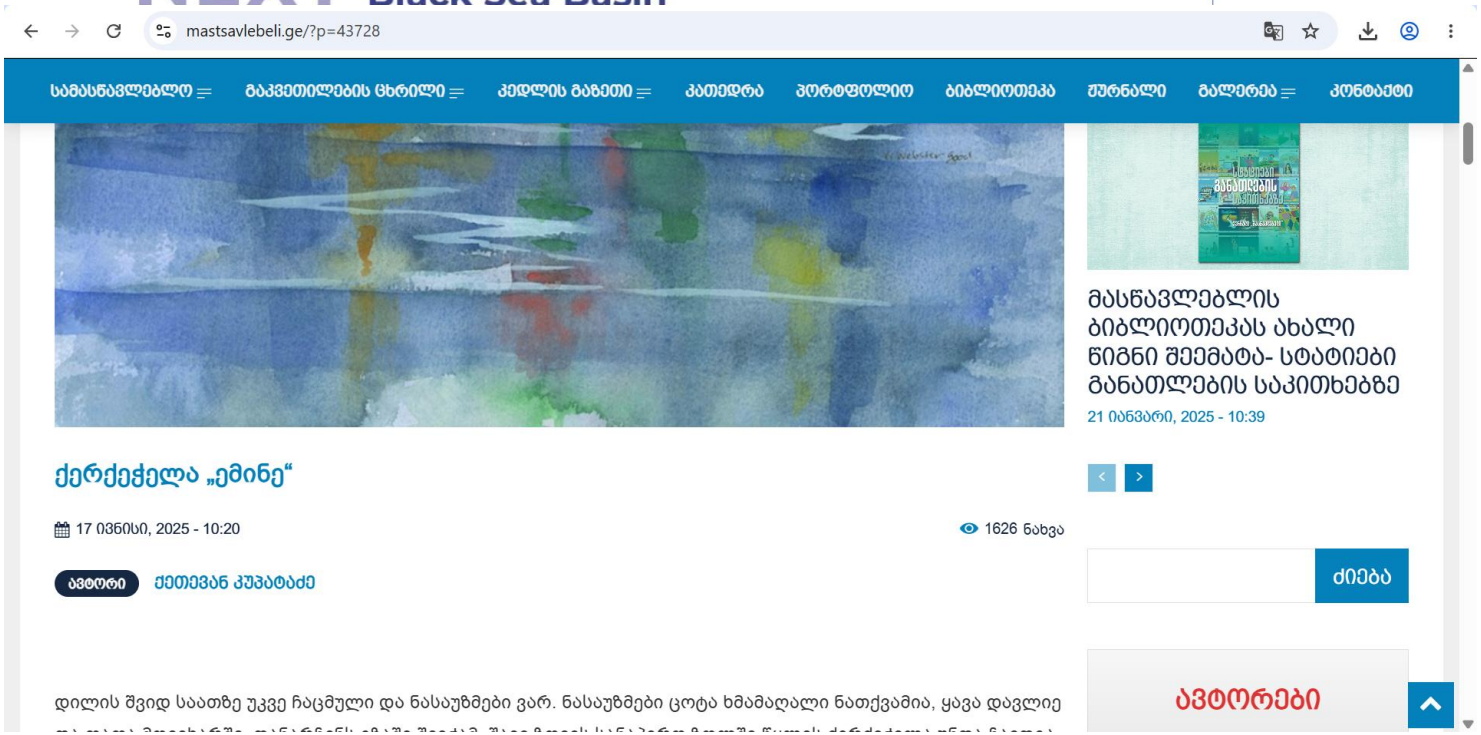


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EFXINNOS REGIONAL HACKATHON IN GEORGIA – REGISTRATION NOW OPEN

NEWS



Ilia State University invites students, young researchers, and individuals interested in environmental sciences, marine research, technology, and innovation to participate in the **EfxINNOs Regional Hackathon**, taking place in **Tbilisi, Georgia, on 14–15 November 2026**.

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Main Hackathon Challenge Areas

Participants are encouraged to develop innovative solutions addressing one or more of the following areas:

Coastal and Marine Ecosystem Monitoring – Digital tools for assessing biodiversity, monitoring environmental conditions, and detecting changes in coastal and marine ecosystems.

Marine Ecosystem Restoration – Innovative tools for identifying vulnerable marine habitats, prioritizing restoration measures, and monitoring ecosystem recovery.

Marine Data Processing and Visualization – GIS-based applications, interactive dashboards, web platforms, and other tools for processing, integrating, and visualizing marine monitoring data.

Artificial Intelligence for Marine Monitoring – Applications of artificial intelligence and machine learning for underwater image analysis, object and anomaly detection, habitat classification, and environmental change assessment.

Digital Solutions for Marine Spatial Management – Data-driven tools supporting marine spatial planning, environmental management, and informed decision-making.

Innovative Solutions for a Sustainable Blue Economy – Technologies and digital services promoting sustainable marine resource management, environmental protection, and the development of the blue economy in the Black Sea region.

Throughout the Hackathon, participants will collaborate with specialists from different fields and EfxINNOs project experts, exchange knowledge and experience, and develop their ideas into practical prototypes with the potential for further refinement and real-world application.

From Tbilisi to the International Hackathon in Varna!



Thank You!



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Quantifying Aquatic Ecosystem Metabolism in Coastal Waters of Georgia (Black Sea)

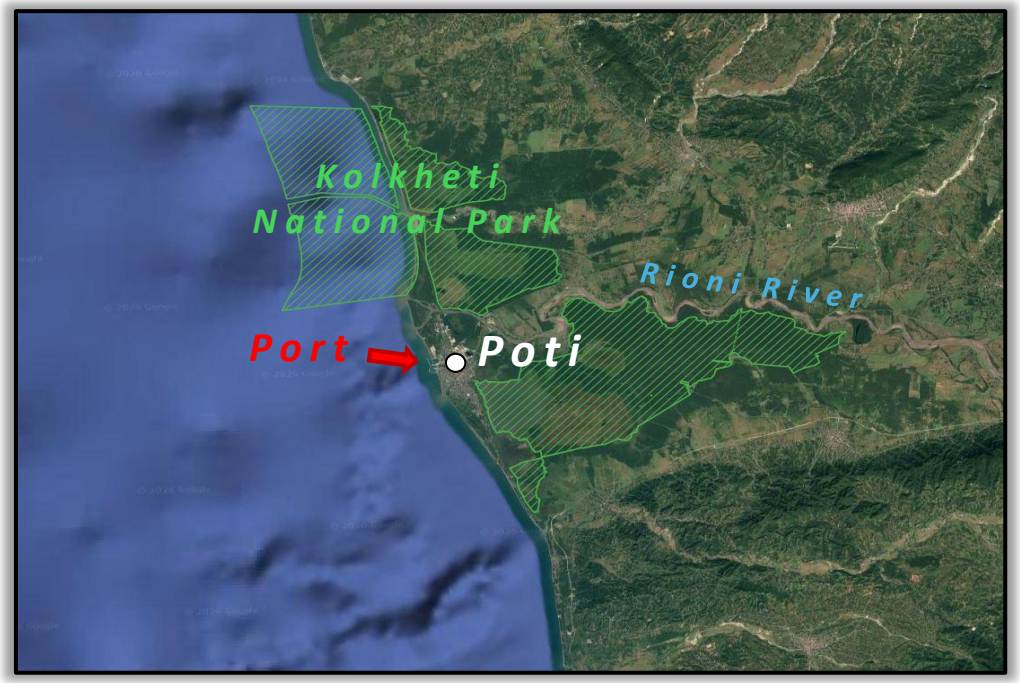
Tracking the ecosystem dynamics of the Kolkheti shelf via In-Situ Sensors and Satellite Imagery

Giorgi Mikeladze, Geospatial Scientist

Environmental Setting: The Poti Dynamic Convergence

The coastal area around Poti is ecologically rich, but it faces strong environmental pressure. It is shaped by three main forces:

- ***The Rioni River Delta:*** ***Discharges freshwater, rich dissolved nutrient loads, and heavy terrestrial sediment into the coastal shelf.***
- ***Poti Port Infrastructure:*** ***Introduces commercial maritime activity, urban runoff, dredging, and industrial shoreline pressure.***
- ***Ecological Sanctuary, wetlands :*** ***Bordered directly by Kolkheti National Park wetlands, a coastal sanctuary of international significance under the Ramsar Convention.***



We structured our investigation around three core questions:

1. *Under normal conditions, does this river-fed shelf act as a net producer or net consumer of organic carbon?*

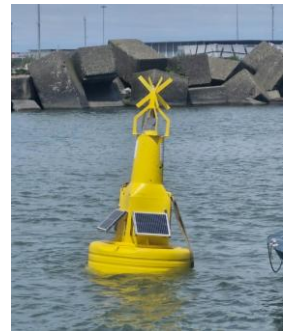
2. *Can we clearly separate true biological metabolism from atmospheric wind mixing?*

3. *How can we scale single-point buoy measurements into continuous satellite maps across the broader shelf?*



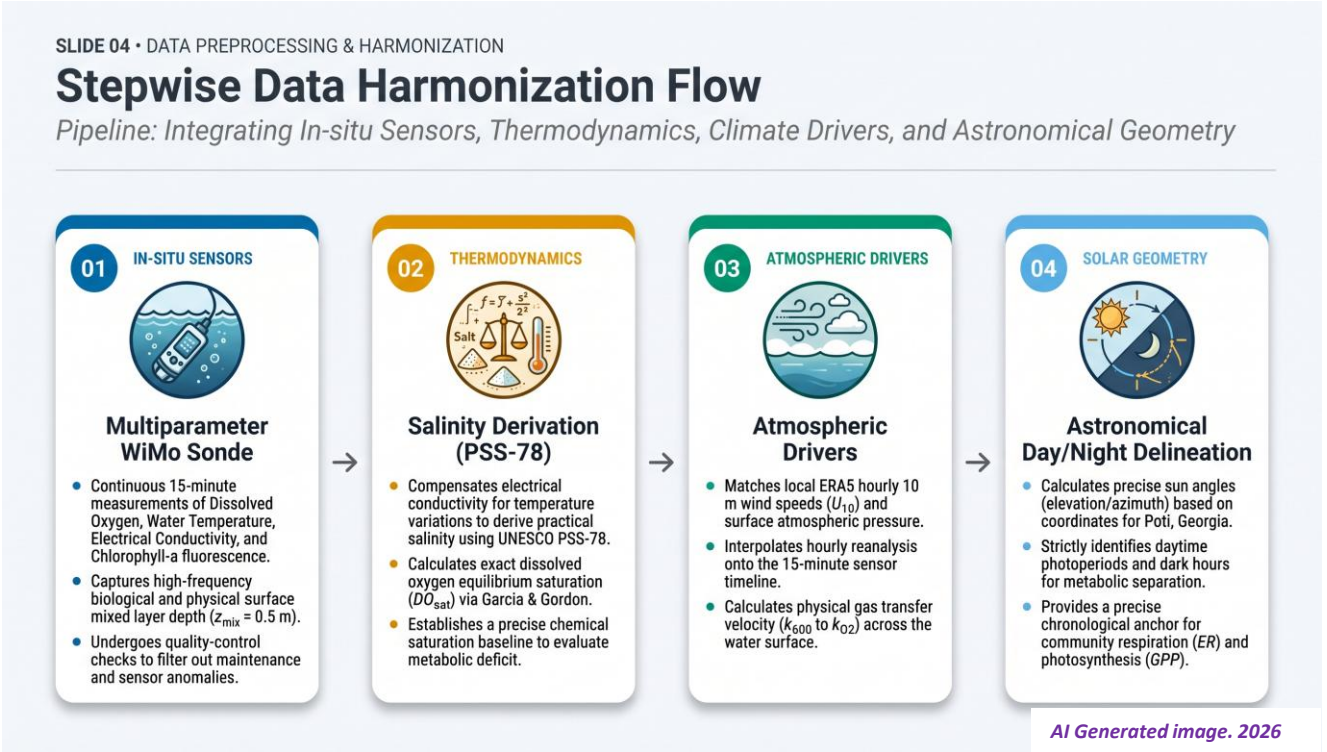
AI Generated image. 2026

High-Frequency Field Monitoring Pipeline



Our main dataset comes from a WiMo sensor placed at half a meter depth in Poti port, recording every 15 minutes for 411 days.

- ***Multiparameter WiMo Sonde:*** ***Continuous 15-minute measurements of Dissolved Oxygen, Water Temperature, Electrical Conductivity, and Chlorophyll-a fluorescence.***
- ***Salinity Derivation (PSS-78):*** ***Compensated electrical conductivity for temperature variations to derive practical salinity and exact oxygen equilibrium saturation.***
- ***Atmospheric Drivers:*** ***Matched local ERA5 wind speeds and atmospheric pressure to account for physical gas transfer across the water surface.***
- ***Astronomical Day/Night Delineation:*** ***Calculated sun angles to strictly identify daytime photoperiods and dark hours for metabolic separation.***

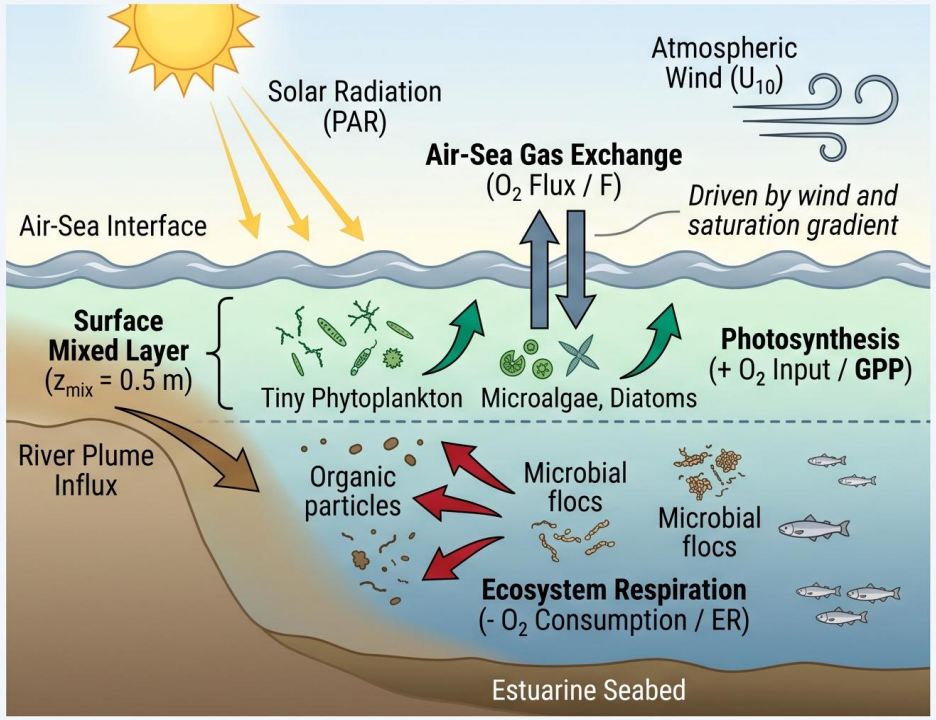


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SLIDE 05 • METHODOLOGY & THEORETICAL FRAMEWORK

The Open-Water Metabolic Framework

Quantifying 'Ecosystem Breathing' by Balancing Biological Activity and Physical Gas Exchange



Metabolic Mass Balance

$$\Delta DO / \Delta t = GPP - ER \pm F$$

Change in Dissolved Oxygen = Gross Primary Production - Ecosystem Respiration ± Air-Sea Gas Exchange

01 | BIOLOGICAL PRODUCTION (GPP)

Photosynthetic input (daytime only) converting solar energy and river-borne nutrients into dissolved oxygen and organic biomass.

02 | ECOSYSTEM RESPIRATION (ER)

Continuous oxygen consumption (24-hour) by bacteria, plants, and animals breaking breaking down organic matter.

03 | PHYSICAL GAS EXCHANGE (F)

Atmospheric reaeration driven by wind speed (U_{10}) and the boundary gradient to restore oxygen equilibrium.

Chronological Integration

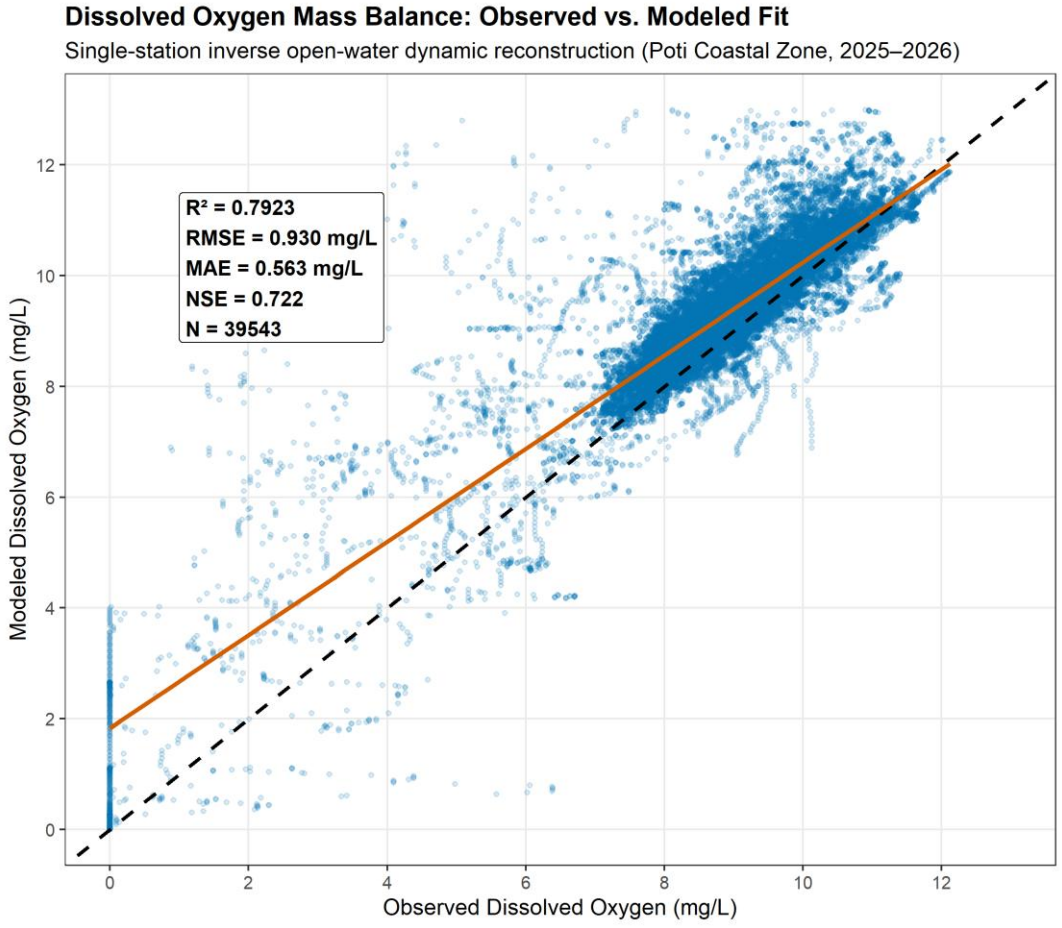
Calculations are grouped daily from dawn to dawn, capturing the complete diurnal light cycle.

AI Generated image. 2026

Dynamic Model Validation: Tracking Observed Biology

- ***Validation Approach:*** ***We tested if our calculated biology was real by using our calculated numbers to rebuild the water's oxygen curve from scratch, and then checking if it matched the real sensor measurements across nearly 40,000 readings.***

- ***Strong model fit:*** ***R^2=0.79***



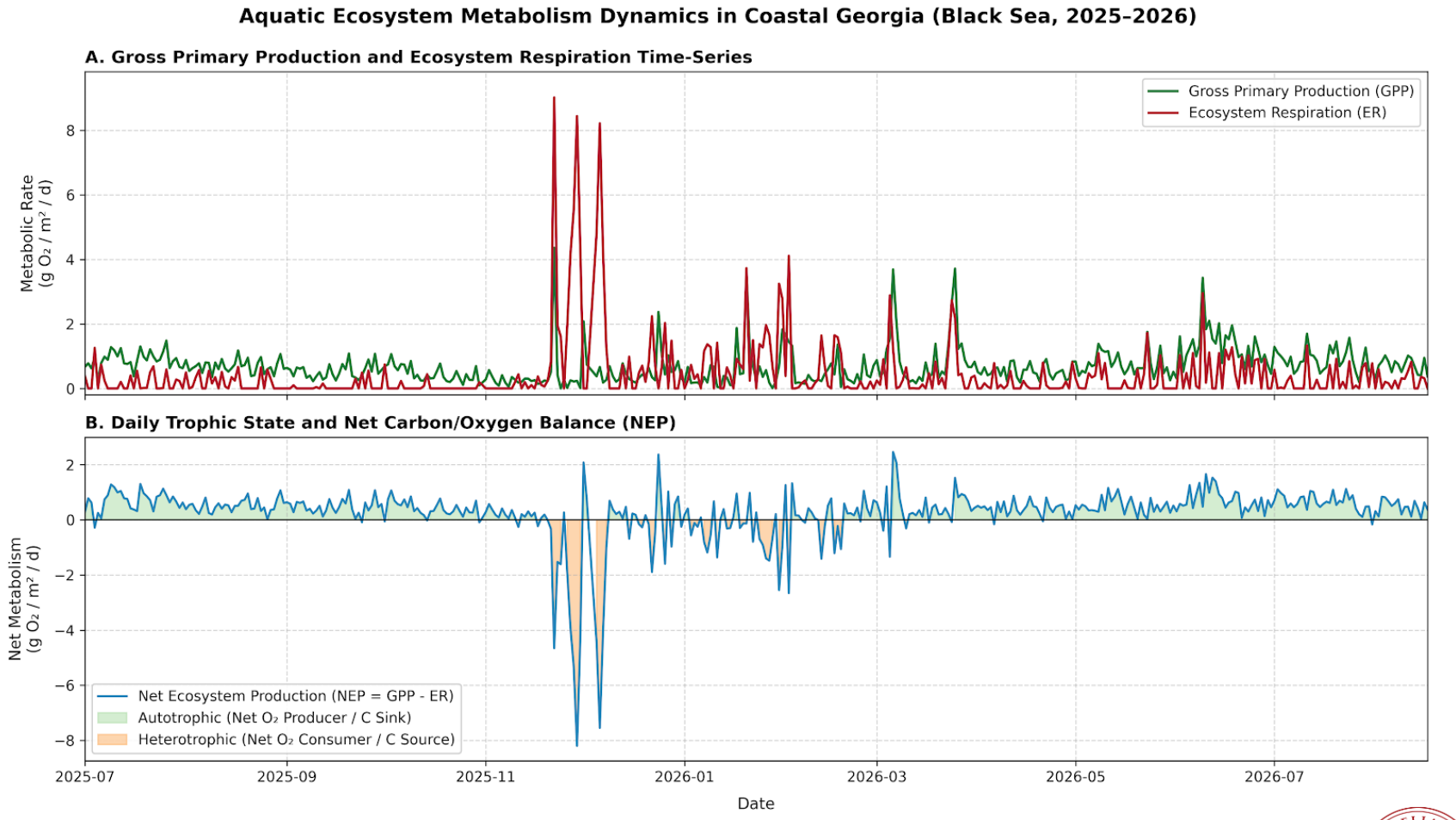
Baseline Ecosystem Metabolism

Annual Baseline Rates :

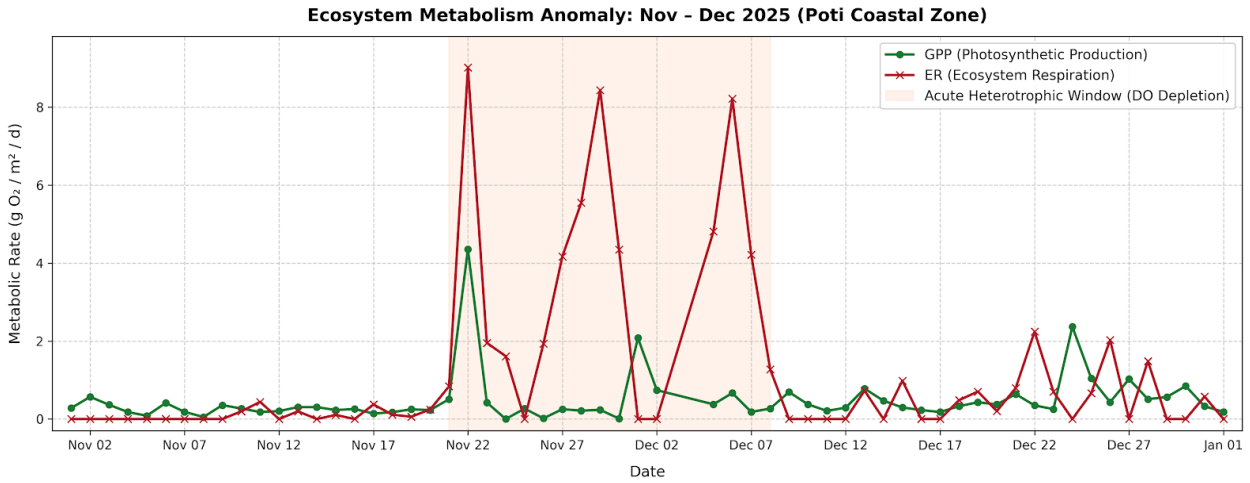
- ***Mean Daily Photosynthetic Production (GPP): 0.70***
- ***Mean Daily Community Respiration (ER): 0.45***
- ***Ecosystem Production (NEP): +0.26***

Trophic Classification: ***Under standard marine regimes, the Kolkheti shelf is consistently autotrophic—photosynthetic oxygen production exceeds organic matter decay.***

Ecological Driver: ***Stable riverine delivery of inorganic nutrients (nitrogen, phosphorus, silica) sustains productive surface phytoplankton blooms in the nearshore plume.***



The Eutrophication Anomaly & Heterotrophic Crash



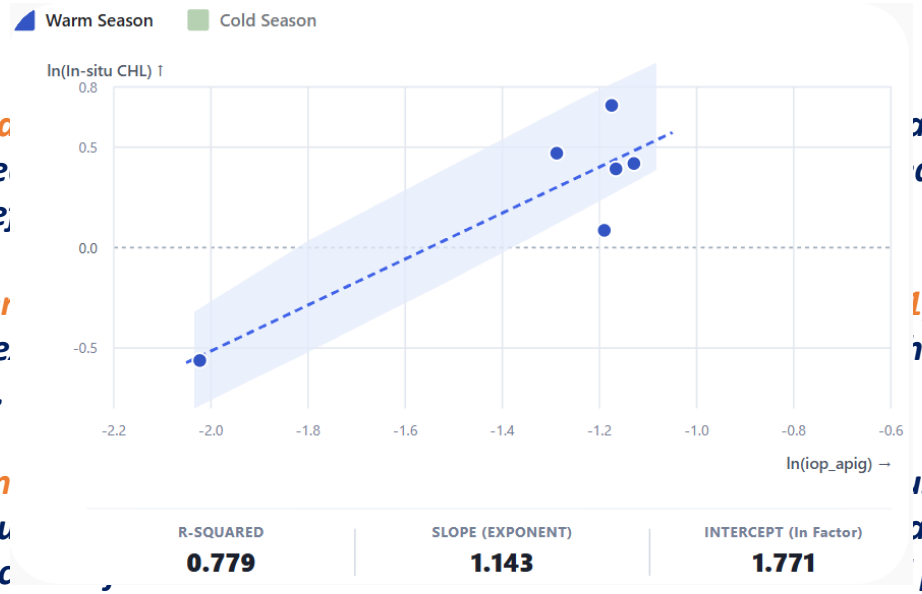


In late 2025, fish-processing waste entered the Poti port area.

- ***Organic Effluent Discharge:*** ***Disposal of wastewater rich in fish-processing byproducts into the semi-enclosed port basin.***
- ***Bacterial Oxygen Depletion:*** ***Accelerated microbial decomposition consumed dissolved oxygen far faster than atmospheric reaeration could replace it.***
- ***Hypoxic Crisis:*** ***Resulted in a prolonged near-anoxic collapse (DO = 0.00–0.26 mg L^{-1}), driving the ecosystem into acute heterotrophy.***

Optical Barriers in Turbid Coastal Waters

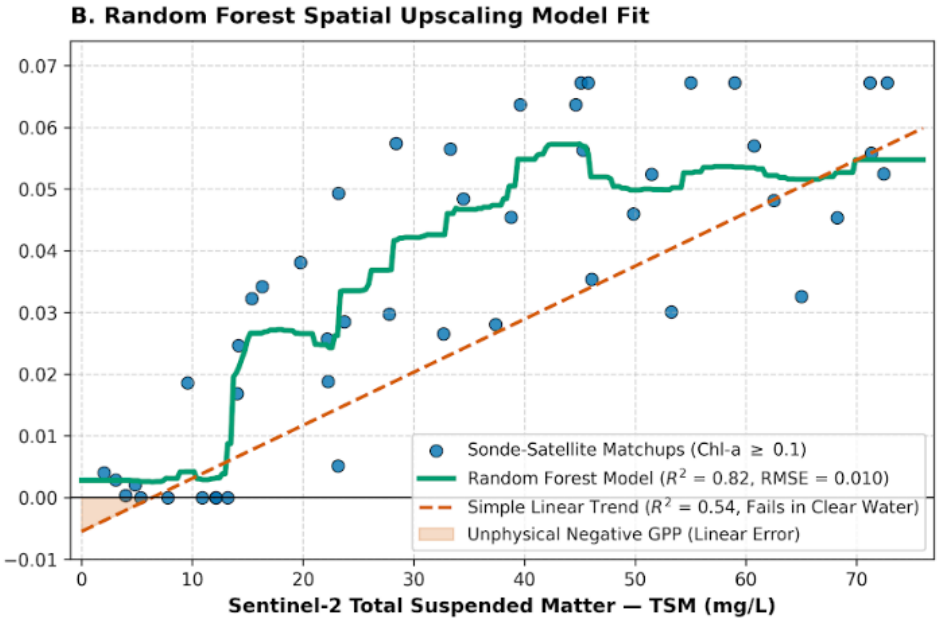
- ***Failure of Sa*** ***poorly in ne*** ***shoreline re***
- ***Total Suspe*** ***sediments e*** ***production.***
- ***The Co-Tran*** ***dissolved nu*** ***optical indic***





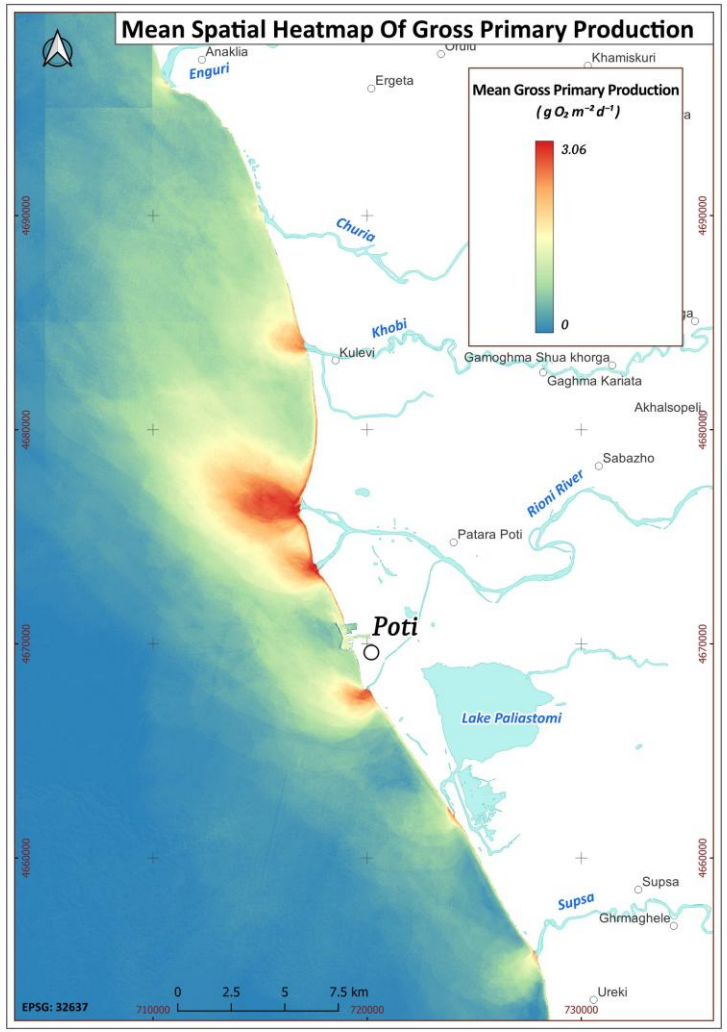
Mapping Production from Space

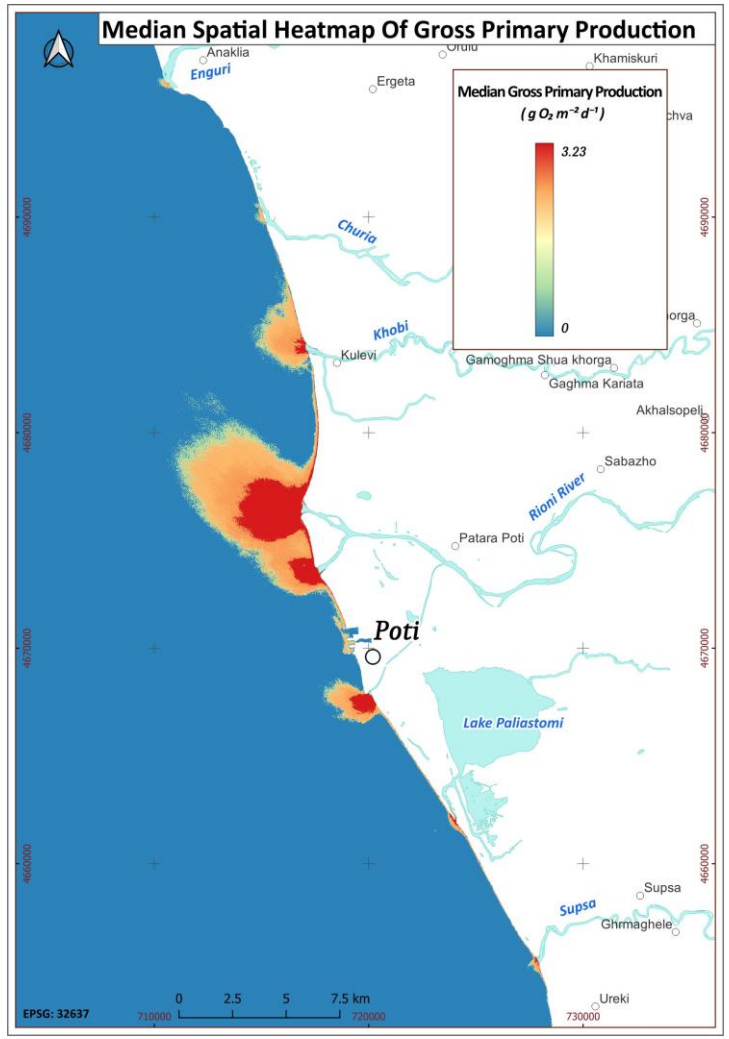
- ***Random Forest Modeling:*** ***An ensemble of 500 decision trees was trained to predict instantaneous primary productivity from satellite-derived Total Suspended Matter (TSM) observations.***
- ***Model Accuracy:*** ***The model demonstrated strong predictive performance with $R^2 = 0.82$***



Seascape Metabolism: Coastal Heatmaps

- ***Plume Volatility & Advection:*** ***Spatial variance maps identify dynamic coastal transition zones north and south of Poti where longshore currents shift the nutrient plume.***





Conclusion

01 TEMPORAL RESOLUTION



Continuous Monitoring Matters

- High-frequency in-situ telemetry captures acute, episodic hypoxic crashes that grab sampling misses.
- 411-day timeline resolves dynamic day-night metabolic cycles and sudden storm runoff pulses.
- Essential for detecting transient ecosystem collapses before physical mixing dilutes the biological deficit.

02 EARTH OBSERVATION



Solving Optical Blind Spots

- Total Suspended Matter (TSM, r = 0.736) bypasses Case-2 mineral sediment masking where satellite Chl-a fails.
- Exploits sediment-nutrient co-transport as a reliable optical proxy for active river plume production.
- Random Forest machine learning (R^2 = 0.82) upscales 1D mooring data to 2D GPP maps across 53 scenes.

03 TROPHIC SENSITIVITY



Ecosystem Sensitivity

- Surface waters sustain a baseline autotrophic state (P/R > 1.0) under routine Rioni River nutrient delivery.
- Late-autumn storm runoff and processing effluents triggered a tenfold respiration surge and near-anoxic collapse.
- Demonstrates that semi-enclosed coastal basins have finite assimilative capacity under heavy biological oxygen demand.

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From ROV Data to Benthic Habitat Assessment: Experience from EfxINNOs Türkiye



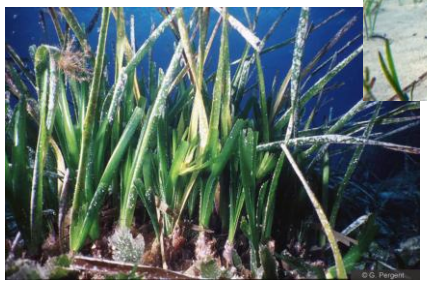
EfxINNOs Joint Open Workshop

Yelda AKTAN
İstanbul University

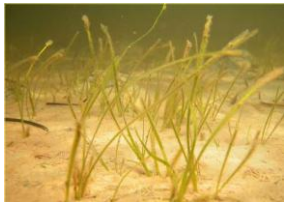
28.10.2026
University of Constanta, Romania

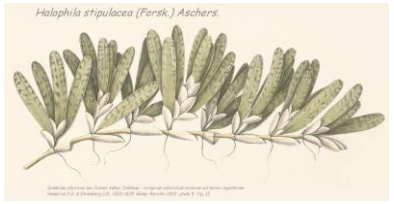
4 genus, 5 species

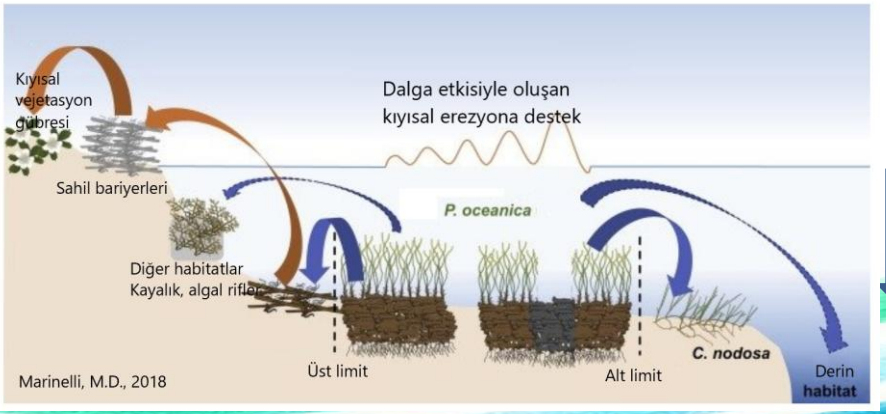
- *Cymadocea nodosa*
- *Zostera noltii*
- *Zostera marina*
- ***Posidonia oceanica***
- *Halophila stipulacea*











Surface

50 m Lower limit

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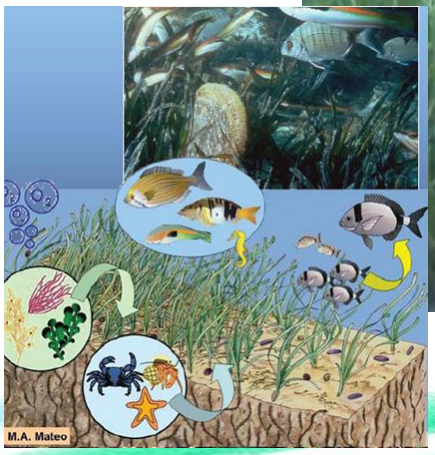
NEXT Black Sea Basin

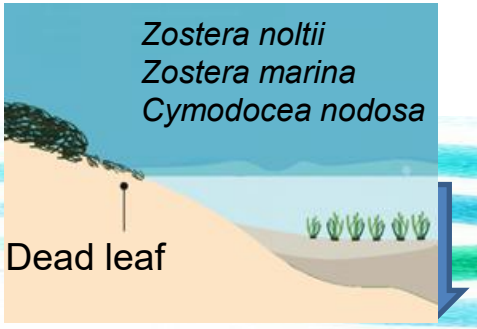
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Seagrass Meadows in the Black Sea Basin



- Key primary producers
- Areas of high biodiversity
- Shelter and breeding grounds for benthic invertebrates and fish species
- Carbon sinks «*blue carbon*»
- Coastal erosion reduction, wave attenuation, nutrient balance, etc.





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Human impacts on the Black Sea Basin















- Physical damage: coastal construction and modification, fishing activities, anchoring






- Pollution: eutrophication, deep-sea discharge, uncontrolled aquaculture practice









PRESSURES		IMPACTS
	Coastal development	 Habitat loss / fragmentation
	Sedimentation and turbidity	 Reduced light / limited seagrass growth
	Eutrophication and pollution	 Deterioration of water quality / epiphyte pressure
	Physical disturbances	 Dragging, anchoring, damage to the seabed habitat
	Climate change	 Changes in distribution and ecosystem functions

 We need to look beyond the presence or absence of seagrass. 



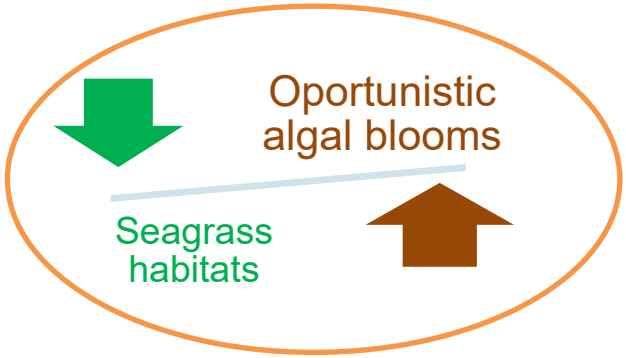






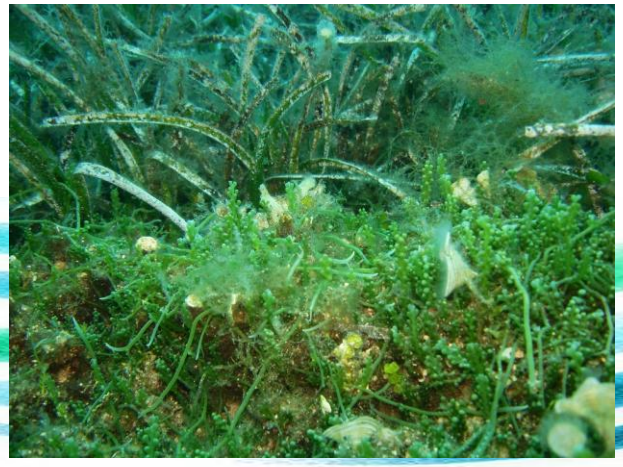



- Algal blooms





- Invasive species





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Seagrass transplantation

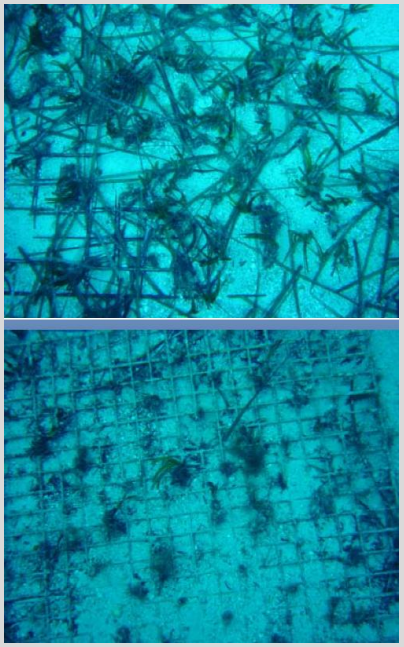
Transplanted cuttings of Posidonia

- Survival ratio: 30-70%
- Growth: 2 to 6 cm/year
- Cost: 60000 Euro/ha



Pergent et al., 2008 from France

- 2 years after





TURMEPA., 2024 from Türkiye, Göcek

MONITORING & PROTECTING

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*«**The starting point for the project** is the need to establish a sustainable and comprehensive marine monitoring network in the Black Sea and Northern Aegean marine ecosystems.»*

A HEALTHY, BALANCED ECOSYSTEM ⟹ PRODUCTIVE SEA



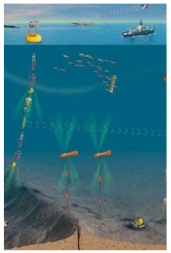
Data gaps and fragmented monitoring activities

Limited, inconsistent and incompatible data across countries in the Black Sea basin...



Climate change and increasing human pressure

urbanisation, tourism, maritime transport, fishing and pollution



Need for technological & scientific innovation

AUVs, ROVs, sensor networks, remote monitoring tools, innovative, low-cost and sustainable technologies



Strengthening regional cooperation

Common standards, data sharing and capacity building

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- Main activity: monitor & map seagrass meadows with ROV, semi-quantitative, non-destructive, fast
- Verification: SCUBA diving
- Studying marine biodiversity & human impacts on the seafloor.
- Coastal human activities will be evaluated in relation to benthic ecosystems.



- Underwater monitoring will also reveal obtain the impact of marine activities on sensitive habitats,
- Public awareness will be raised through training materials, workshop and seminars.

Destructive fishing activities,
Mooring ,
Coastal filling, etc

Non-indigenious species
Marine litter

Why ROV-Based Monitoring?



- Larger area coverage
- Continuous video transcects
- Repeatable monitoring over time
- Habitat mapping in GIS
- Development of monitoring indicators

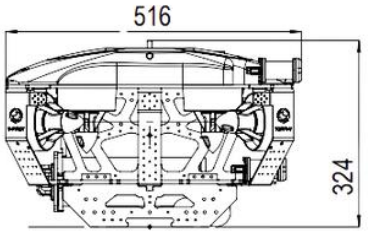


ROV (Remotely Operated Vehicle)

GENERAL SPECIFICATIONS

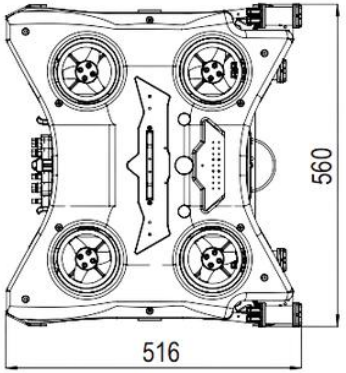


Width : 560 mm, **Length :** 324 mm
Weight (in air) : 21 kg
Body Material : Anodized Machined Aluminum, POM, & Buoyancy Foam
Window Material : Acrylic
Depth Rating : 500 m
Operating Temp : -10 to 50 °C



ROV Electrical System
Battery Voltage : 14.8 v 250 Wh Li-ion
Battery Run Time : 2 - 3 Hours (30-sec Battery Change)
Thruster Control : 100% Reversible





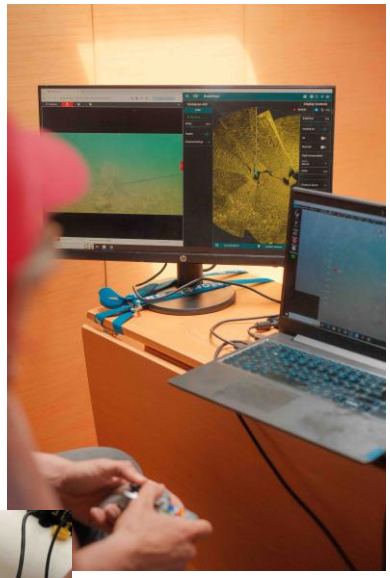
SONAR SYSTEMS
Sonoptix ECHO Multibeam Sonar
The Oculus M-Series Multibeam Sonar
Cerulean Omniscan450

NAVIGATION
The SeaTrac USBL
WaterLinked Underwater GPS G2
Cerulan Mark III ROV Locator
WaterLinked A50 & 125

AUXILLARY CAMERA
DVL Low Light Camera
4k Camera Optic ZOOM

MANIPULATORS&TOOLS
Newton Gripper
Reach Robotics Manipulators
Sediment Sampler
Swappable Jaws

ADDITIONAL SENSORS
Altimeter
Dissolved Oxygen
pH Sensors & ORP Sensors





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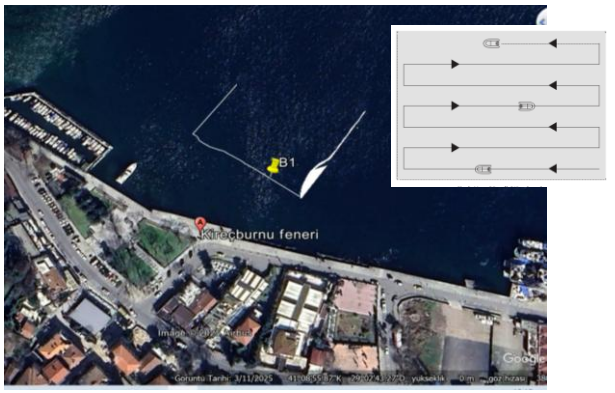
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FIELD STUDY

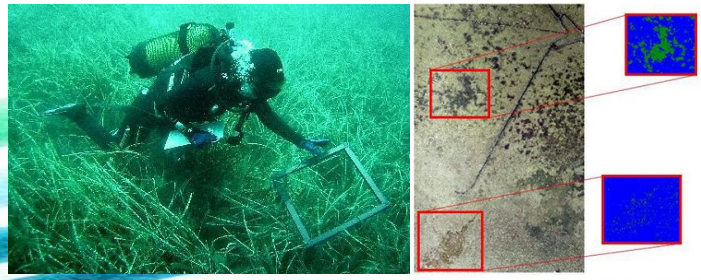
For each site:

- Acquisition of aerial imageries from Google Earth**.**
- Determination of the pilot sites according to the presence of benthic macrophytes.
- **Monitoring the critical habitats & marine litter:** Capturing the photogrammetric imagery by manta-towing the ROV in linear pattern
- **Groundtruthing the optical methods with georeferenced diving:** Detect the outlines of macrophytic communities by GPS coordinates.
- **Estimation of macrophytic cover (%):** X replicated photoquadratic vertical projection (20x20 cm) in a standart depth.
- Measure **key environmental parameters**: temperature, salinity, pH, conductivity, oxygen, turbidity
- Assess **human impacts** using the Land Use Simplified Index (LUSI).

Linear pathern







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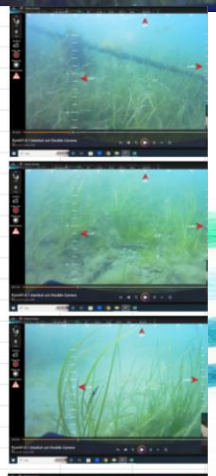
ROV Imagery & Data Labeling for Benthic Habitat Classification

- Coordinates
- Photogrammetric images: upper&lower limit depth
- Image labeling from videos for habitat type and marine litter



-

Pyrot 25.6.25/13-34-26 (lighthouse)						
Latitude	**Longitude**	**Depth (m)**	**Habitat type**	**meadow upper limit depth**	**meadow lower limit depth**	**Litter**
41.1489334	29.0459796	8.0	*Ulva* - sand- mussels	4.2	6.2	
41.1488942	29.0459832	6.9	*Ulva* - sand- mussels			
41.1489309	29.0458121	5.4	*Ulva* - pebble -sand			Tire x1
41.1490136	29.0457514	4.2	*Zostera-broken mussel shells*			
41.1490113	29.0457241	4.5	*Zostera -Ulva*			
41.1490802	29.0456895	4.9	*Zostera -Ulva*			
41.1490935	29.0457218	5.5	*Zostera -Ulva -sand*			
41.1490945	29.0456112	5.5	*Continuous Zostera*			
41.1491281	29.045629	6.5	*Ulva* - sand- mussels			
41.1491042	29.045591	5.9	*Zostera -Ulva -sand*			
41.1491099	29.0454644	5.6	*Ulva* facies			
41.1491503	29.0455085	6.0	Pebble -sand			
41.149196	29.0455767	7.8	Pebble -sand			
41.1491966	29.0455765	7.9	Pebble -sand			
41.1492306	29.0454523	5.2	*Ulva* - broken mussel shells			
41.1493082	29.0453957	5.3	*Ulva* facies			
41.1493097	29.0453916	5.2	*Ulva* facies			
41.1493215	29.045407	5.2	*Zostera -mucilageous aggregates*			Tire x3
41.1493444	29.0454276	6.5	sand -pebble			
41.1494175	29.045353	6.0	*Zostera*			



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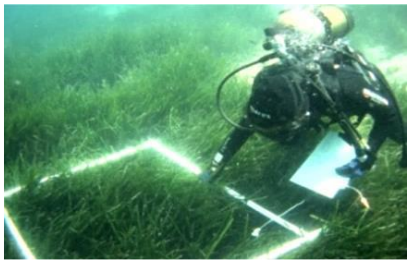
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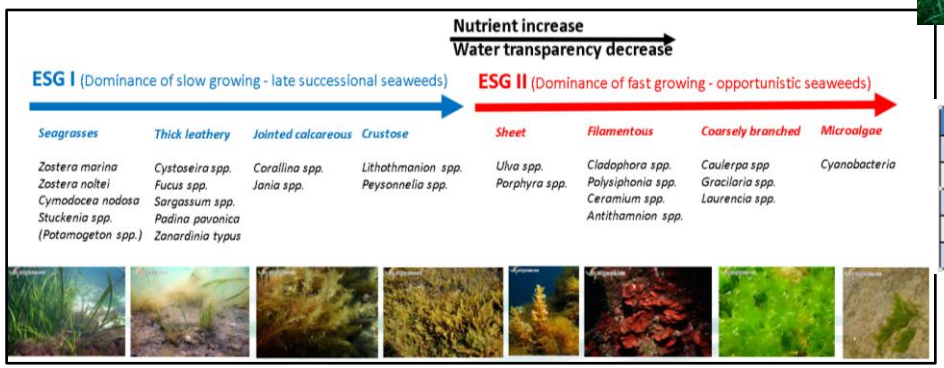
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Methodology followed during the data processing

Ground-truthing step
Quadrat-based field observations







EEI	EQR EEI	Status
10 ≥ EEI > 8	1 ≥ EQR > 0.75	High
8 ≥ EEI > 6	0.75 ≥ EQR > 0.5	Good
6 ≥ EEI > 4	0.5 ≥ EQR > 0.25	Moderate
4 ≥ EEI > 2	0.25 ≥ EQR > 0	Low
2	0	Bad

Genus	ESG	Cover on quadrat (%)
Acetabularia	I	
Acanthophora	II	
Amphiroa	I	
Anadyomene	I	
Antithamnion	II	
Bryopsis	II	
Calithamnion	II	
Caulerpa	II	
Ceramium	II	
Chaetomorpha	II	
Champia	II	
Chondria	II	
Cladophora	II	

Functional characteristics of marine benthic macrophytes

Ecological State Group	Functional form group	Morphology	Longevity (Succession)	Genera
ESG II	A. Sheet	Foliose	Annual (Opportunistic)	Ulva, Enteremorpha, Dictyota, Scystosiphon
ESG II	B. Filamentous	Delicately branched	Annual (Opportunistic)	Chaetomorpha, Cladophora, Polysiphonia, Ceramium, Spyridia
ESG II	C. Coarsely Branched	Coarsely branched upright	Annual (Mid-successional)	Acanthophora, Caulerpa, Chordaria, Gracilaria, Laurencia, Liagora
ESG I	D. Thick Leathery	Thick blades and branches	Perennial (Late-successional)	Cystoseira, Chondrus, Fucus, Laminaria,Padina, Sargassum, Udotea

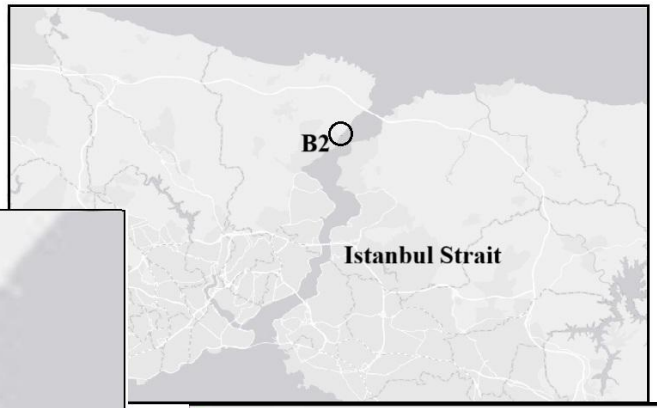
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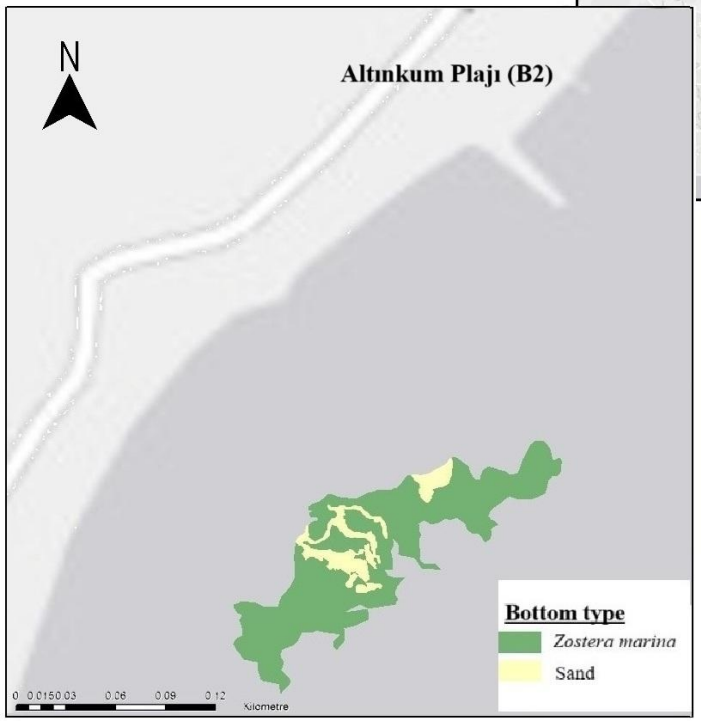
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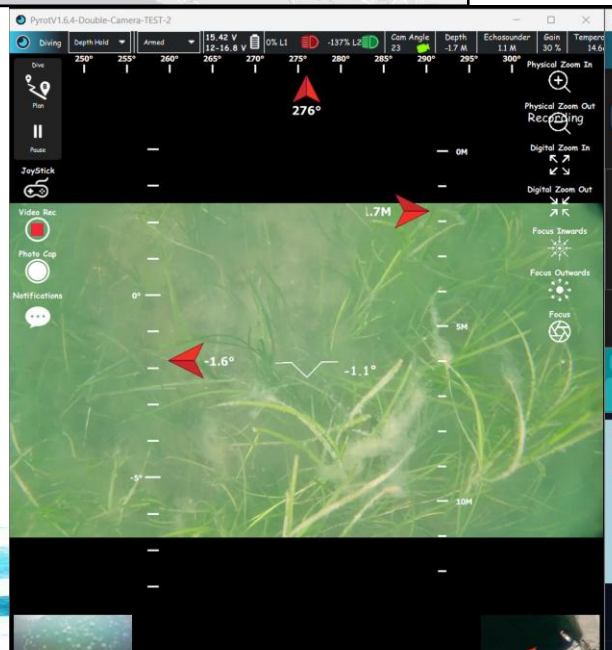
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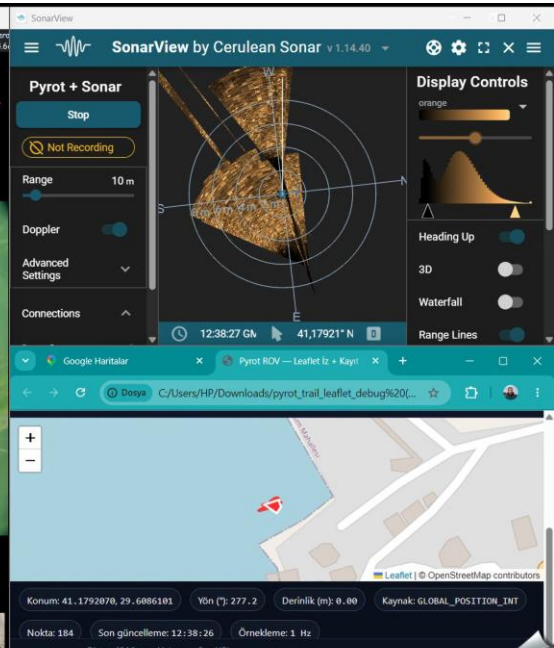
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- **Integration** of collected data to ArcGIS for **Mapping**.









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Preliminary Approach:

ROV-Based Seagrass Status Index (ROV-SSI)

Methodological Basis:

- Adapts diver-based ecological indices into an ROV-based operational mon framework
- Depth gradient & lower depth limit as primary reference
- Transect-based habitat labeling (*Zostera* meadows / foliose algae / filame
- Video-derived semi-quantitative scoring



	0	1	2	
Meadow cover	0-25%	26-50%	51-75%	
Meadow Continuity	Absent	Patchy	Semi-continuous	
Lower Limit	Clear regression	Fragmented/ unstable boundary	Stable and continuous	Expanding
Epiphytes / Opportunistic	Dense filamentous leafy dominance	High	Moderate	Low

Quality scores	SSI	Ecological Status Classification
0-3	?	Bad
3-6	?	Poor
6-9	?	Moderate
9-12	?	Good
12-15	?	High

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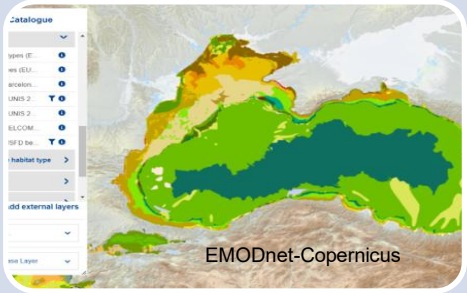
Project Results and Outputs

«EfxINNOs brings a sustainable and holistic approach to the monitoring of marine ecosystems through innovative technologies and regional cooperation»

Innovative aspect/Added value







Innovative research technologies (ROV, AUV, drone-based mapping, sensor systems)

The dissemination of scientific findings to the public and policymakers

Regional data-sharing network and sustainable monitoring model

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Reading the Seabed

How we monitor seagrass meadows and benthic habitats on the Romanian Black Sea coast

Dr. Adrian Filimon
Department of Ecology and Marine Biology, NIMRD „Grigore Antipa”, Constanța

28 October 2026

Scope: why, how and what we monitor

WHY

shallow coastal habitats require regular monitoring, and which pressures act on them

HOW

aerial and underwater drones, scientific divers and the laboratory are combined

WHAT

the data show, and how the baseline led to a restoration action



Diver video transect, rocky bottom with red algae

That is why we monitor: four questions we must answer

What do we still have?

Where are the habitats, how large, in what condition

Is it changing?

Spot decline or fragmentation before it becomes irreversible

Can we restore it?

Choose donor sites and check whether transplants survive

What should managers do?

Evidence for authorities, protected-area managers and coastal developers



01

Context and pressures

What is lost when a seagrass meadow disappears, and which pressures act on shallow habitats today?

Today, shallow habitats face pressure from three sides





Beach enlargement and hydrotechnical works along the Romanian coast

Coastal works

Beach nourishment, dredging and new structures bury shallow bottoms, change currents and raise turbidity

Eutrophication

Excess nutrients feed blooms of opportunistic algae that shade the seabed and cause hypoxia

Warming sea

Heat and rising sea level stress shallow plants — we measured 30 °C at 1.5 m in July 2024

Most at risk: seagrass grows at 0–3 m — exactly where these pressures concentrate.

Seagrass meadows work for nature and for people



Nursery and shelter

for fish, seahorses and invertebrates

Natural coastal protection

roots hold the sand, leaves soften waves

Cleaner water

meadows filter water and trap particles

Ecosystem engineers

they build the habitat others live in

Once common along the coast, now found mainly at Mangalia

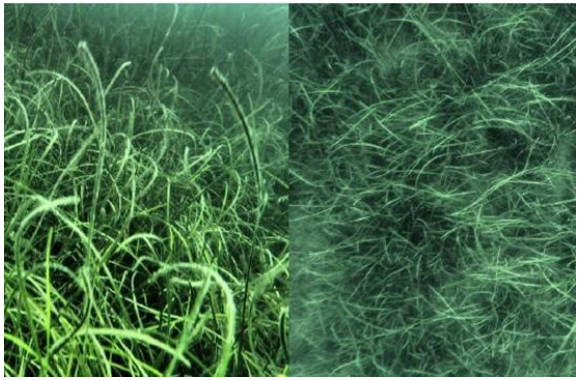
1970s–80s

Zostera marina and N. noltei meadows at Cape Midia, Eforie Sud, Tuzla, Comorova, Costinești and Mangalia port

Today

Large meadows only at Mangalia; small patches at Năvodari and 2 Mai. Critically Endangered in Romania (Order 488/2020).





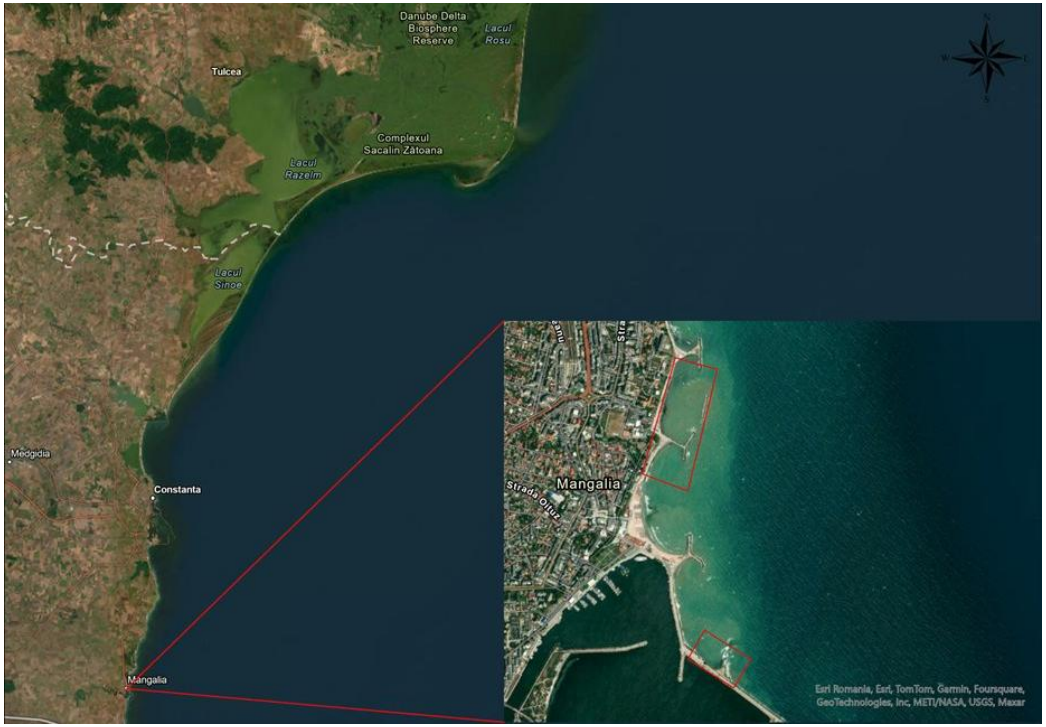


02

Seagrass: methods

How can the extent and condition of the meadows be assessed reliably?

Our case study: the last large meadows, at Mangalia



7 candidate meadows (Z1–Z7) spotted from the air

6 confirmed by divers — Z4 had no seagrass

1–3 m depth, on sandy bottoms

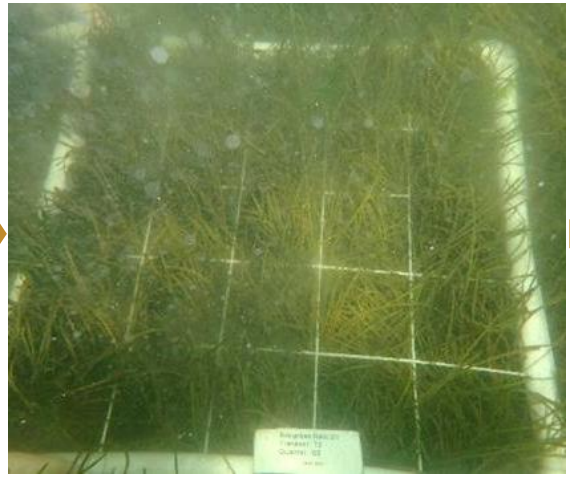
All meadows are formed only by N. noltei. A new small meadow was found in Mangalia Harbour.

The method: three views of the same meadow



1 From the air

The drone shows where the meadows are and how big they are



2 On the seabed

Divers check the map and measure the plants



3 In the lab

Samples reveal plant health; data become maps

Equipment · Aerial drone DJI Air 2S



Image from the aerial drone, Mangalia

Aerial drone · DJI Air 2S

- 1-inch sensor, 20 MP photos, 5.4K video
- About 30 min flight time, 595 g
- Used for: orthophoto mapping of the Mangalia seagrass meadows (2023)
- Works where the bottom is visible from the air: shallow, clear water

Step 1 · The drone shows where the meadows are





- Fly on calm days, with little sun glint
- Stitch hundreds of photos into one map (orthomosaic)
- Draw the meadow outlines in GIS
- Use the outlines to plan where divers go

Limit: the good-weather window is short, and dark patches can be algae, not seagrass.

Step 2 · Divers check the map and sample along transects



Every quadrat is labelled and photographed



Measuring leaf length

14
transects

43
quadrats

10 m
between quadrats

What divers do

- Confirm the species
- Check the map edges against the real meadow
- Tell seagrass from macroalgae
- Lay transects east–west across each meadow
- Work without harming this protected plant

Step 3 · Four indicators describe the health of a meadow



1 Seabed cover

how much of the bottom is covered

2 Shoot density

shoots per m² — key for donor choice

3 Leaf length

growth and season

4 Lab samples

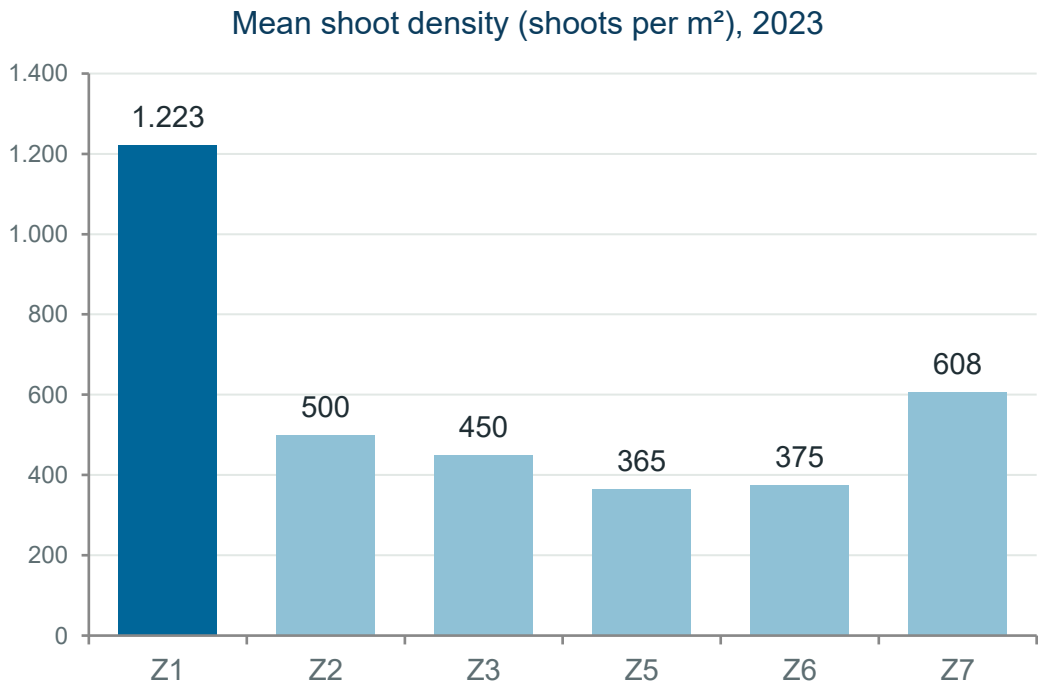
epiphytes, colour, damage

03

Seagrass: results

What is the status of the meadows, and can one of them support restoration?

Finding 1 · Z1 is the densest meadow — over 3× the sparsest

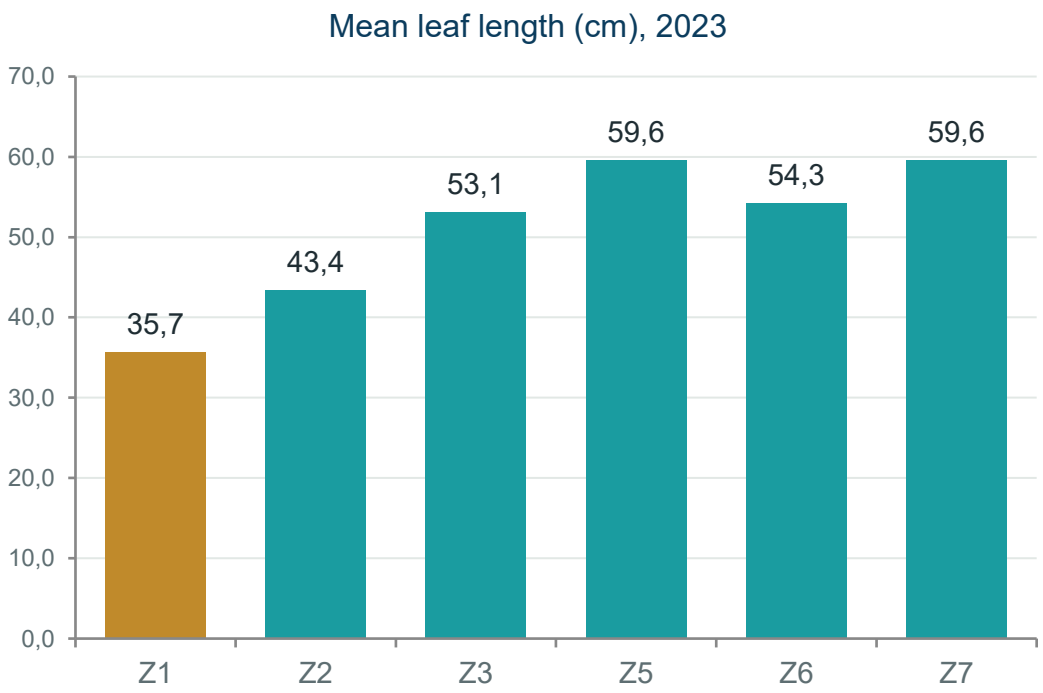




Shoot number is the main factor separating the meadows (Demsar plot: three clusters).

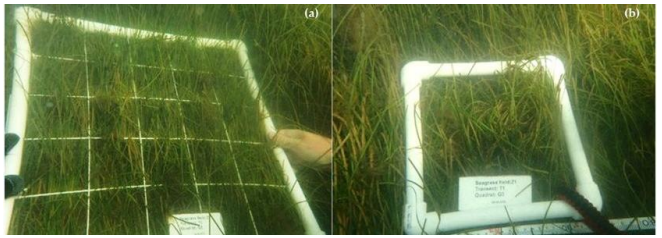
Z1 is significantly denser than all other meadows except Z7 (Kruskal–Wallis, Dunn's test).

Finding 2 · All meadows are compact; leaf length follows the season



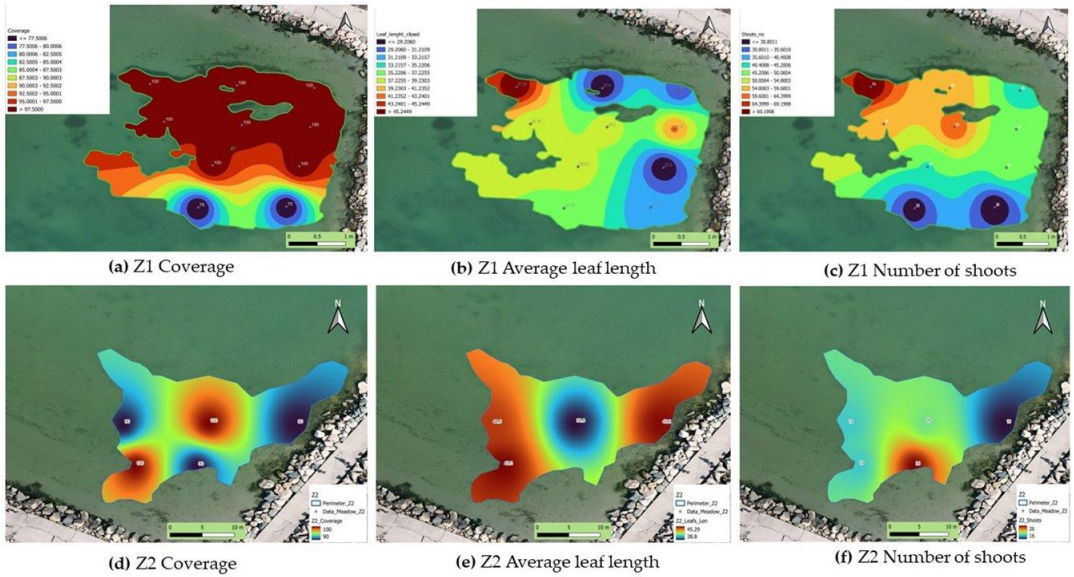
94–100%

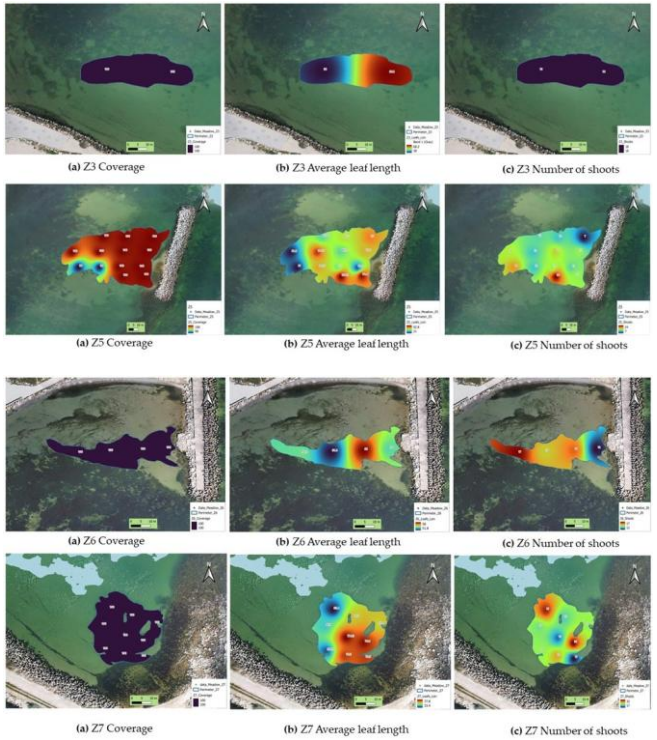
average seabed cover in every meadow



Sampling date: Z1 was sampled in late May, the others in late July. Shorter leaves in Z1 reflect the season, not poorer health.

Finding 3 · Maps reveal the structure inside each meadow





Blue = low, red = high. For each meadow we map cover, leaf length and shoot number. Uneven patterns warn us early about fragmentation.

Finding 4 · The plants are healthy, with a light epiphyte load



Acrochaetium spp. — the dominant epiphyte



Striatella delicatula (diatom) on a leaf



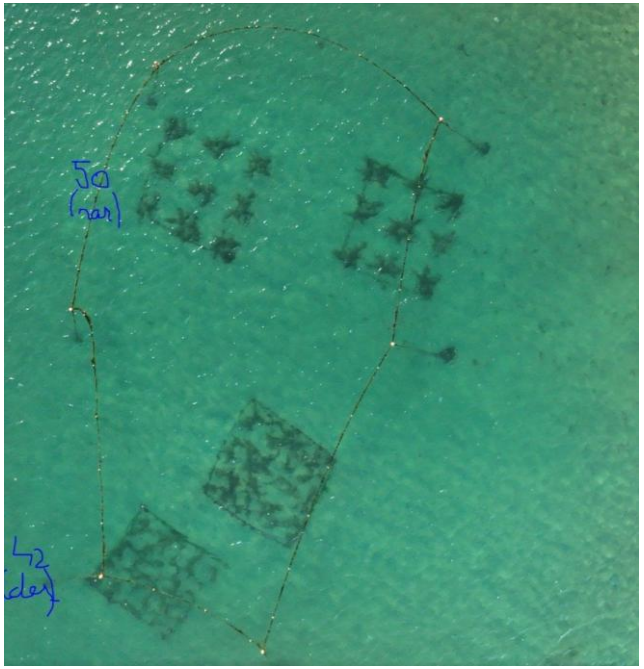
Myrionema orbiculare — rare on the Romanian coast

Epiphytes covered ⅓–⅔ of the leaf, mostly the tips — normal for summer. Shoots were green, without blackening or damage, and no green-algae blooms occurred in 2023.

From data to action: Z1 became the donor meadow

- ✓ **Dense** most shoots per m²
- ✓ **Healthy** green leaves, light epiphytes
- ✓ **Full cover** recovers quickly after harvesting

2023: sods from Z1 were transplanted to Eforie. Monitoring now follows their survival.



Transplant plots seen by drone



Tagged transplant unit in its quadrat

04

Beyond the meadows

How is the seabed covered where the aerial drone can no longer see the bottom?

Equipment · Underwater drone FIFISH V6 Expert



ROV deployment from the boat; the tether carries live video

Underwater drone · FIFISH V6 Expert

- Rated to 100 m; 4K video, 12 MP photos
- 6,000 lm lights, depth lock, 100–200 m tether
- Used for: habitat observation at Tuzla, 5–11 m (2024–2025)
- Works where depth or turbidity hide the bottom from the air

Impact study at Tuzla: the drone observes, divers take the samples

Purpose: assess benthic habitats and communities before and during construction works in the Tuzla area — 6 stations at about 10 m depth, same stations and methods in every campaign.



ROV: observation

Habitat type, substrate and algal cover; video tracks repeated between campaigns





Divers: underwater sampling

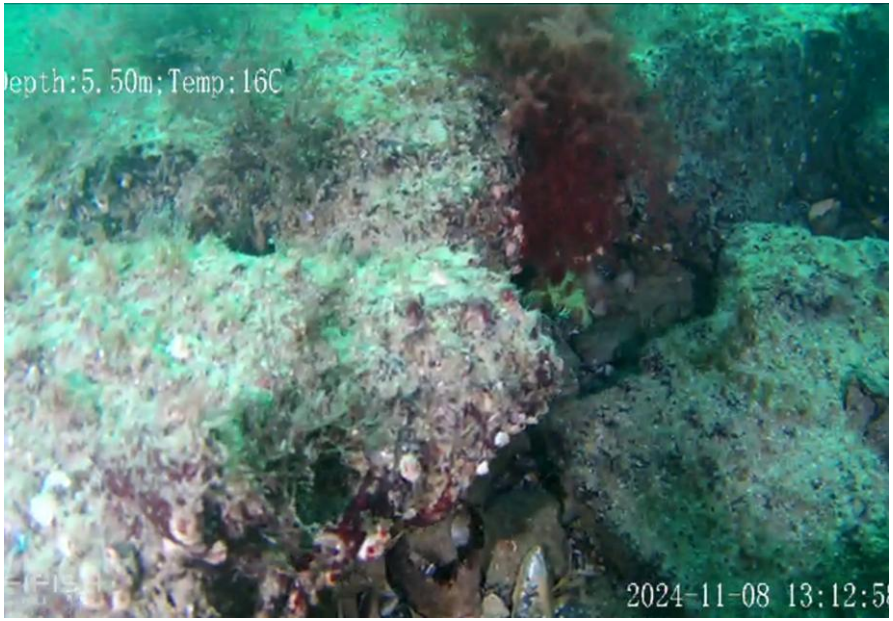
Divers scrape the bottom fauna from 20 × 20 cm of rock into a 0.5 mm mesh bag, 3 replicates per station



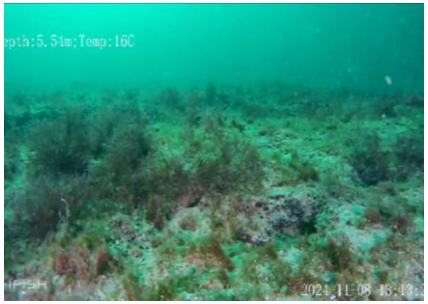
Boat: access, water samples

Takes divers and equipment to each station; surface water for chlorophyll-a and phytoplankton; net hauls for zooplankton

At 5–6 m: rocky bottoms with red and brown algae



ROV survey, 8 November 2024 · 5.1–5.8 m · 16 °C

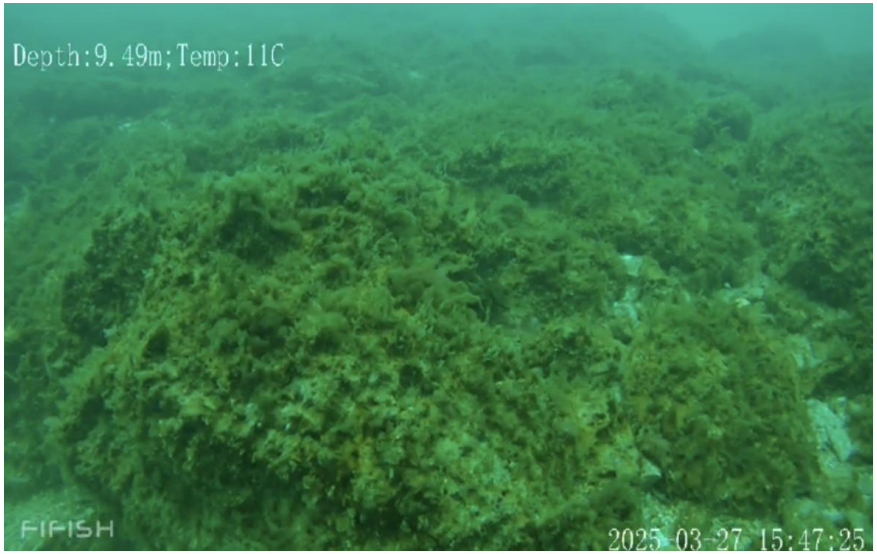




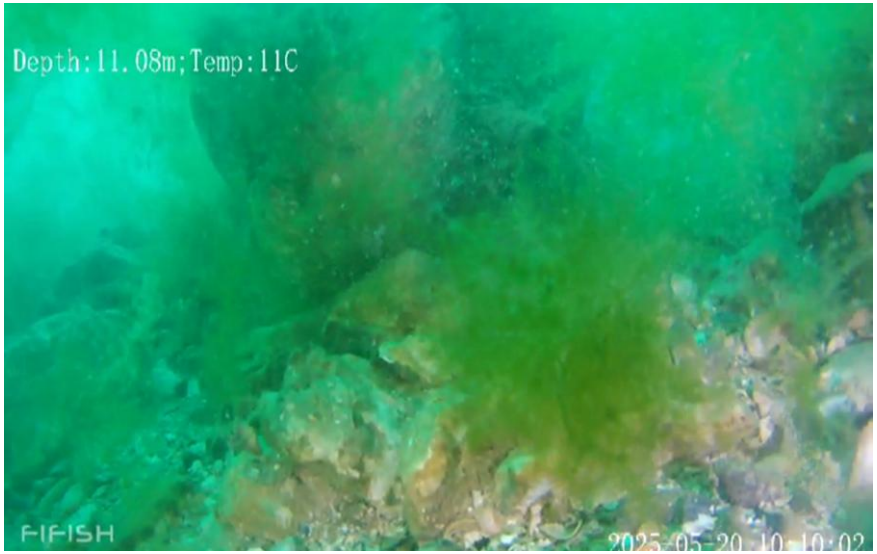


Algal turf, red and brown macroalgae and mussel shells on rock, recorded along a continuous ROV track.

At 9–11 m, Tuzla: the same rocky habitat in March and May 2025



27 March 2025 · 9.5 m · 11 °C · turf of red and green algae



20 May 2025 · 11.1 m · 11 °C · dense green algal cover

Habitat 1170-8, infralittoral rock with photophilic algae: annual algae, so composition shifts between seasons. Repeated ROV tracks make this change measurable.

We also record the pressures acting on these habitats



Opportunistic algae

green and filamentous algae signal nutrient enrichment

Coastal works

sediment and turbidity near shallow habitats

Litter and anchoring

logged wherever we see them

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Cost-effectiveness: drones for coverage, divers for samples

Area coverage

The aerial drone maps a whole meadow in one flight; the underwater drone covers longer tracks per deployment than a single dive.

Team and logistics

Small crew and a small boat; observation-class ROVs are inexpensive and quick to deploy (Sward et al., 2019).

Diver time

Diver-based surveys are costly and labour-intensive (Hammond, 2025): limited bottom time, larger team, safety requirements.



Underwater drone record, Tuzla, May 2025

Our approach: drones for observation and coverage, divers only for sampling and validation — more area surveyed at a lower cost than diver-only surveys.

05

Synthesis

What does each method contribute, and what are the main conclusions?

No single method is enough — each fills the gaps of the others

Method	Best for	Limitation
Aerial drone (UAV)	Area coverage in shallow, clear water	Depth and transparency; seagrass and algae look alike
Scientific divers	Sampling, validation and identification at all depths	Highest cost; small area per dive
Underwater drone (ROV)	Area coverage where the aerial drone no longer sees the bottom	Visibility still limited by turbidity
Laboratory & GIS	Plant health, statistics and maps	Depends on good field samples

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Conclusions

Modern platforms turn seabed monitoring from occasional snapshots into a repeatable, shared record of the Black Sea.

1 Cost-effective coverage

Aerial and underwater drones survey more area per day than divers; diving is kept for sampling and validation.

EfxINNOs: a cost-effective network of marine monitoring platforms

2 Comparable data

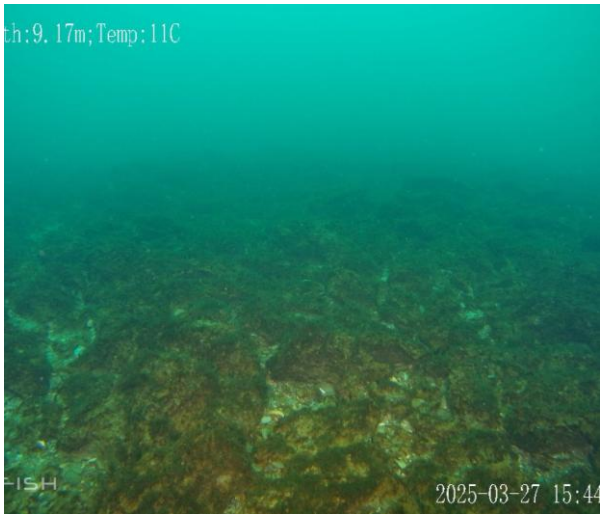
Georeferenced, time-stamped images can be repeated each season, re-analysed and shared between partners — and feed AI-based benthic maps.

EfxINNOs: harmonised data; ML/AI for benthic mapping and seagrass health

3 From data to protection

Baselines and change detection support restoration, protected-area planning and environmental impact assessment.

EfxINNOs: MPA prioritisation and science-based policy for the Black Sea



ROV record of infralittoral rock, Tuzla, 9.2 m

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Thank you

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NIMRD „Grigore Antipa”, Constanța, Romania

Further reading

Marin, O.A., Timofte, F., Filimon, A., Croitoru, A.M., van Broekhoven, W., Harper, C., van Zummeren, R. (2024). An integrative approach to assess and map Zostera noltei meadows along the Romanian Black Sea coast. J. Mar. Sci. Eng. 12(12), 2346.