MODULE 5 - PART B: SMART OBSERVATIONS FOR BOOSTING INNOVATION IN MONITORING AND BLUE GROWTH

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BRIDGE-BS

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"Blue Growth" and Smart Observations

- **"Blue growth"** is defined by the European Commission as "smart, sustainable and inclusive economic growth from the oceans, seas and coasts".
- **Smart observations** (monitoring) means deploying sensors, digital technologies (Internet of Things, AI/ML, digital twins, remote sensing) and data-platforms to observe the marine/coastal environment more efficiently, comprehensively, and in near-real time.
- **Smart observations in the blue economy** enables new types of business models, improves environmental management, allows earlier warning of risks/stressors, and supports innovation and growth in marine-related sectors (aquaculture, marine biotech, offshore energy, monitoring services, marine data platforms).

Why it’s important

Improved responsiveness & risk reduction

Real-time or high-frequency monitoring helps detect changes (e.g., pollution, deoxygenation, harmful algal blooms, microplastic concentration spikes) faster.

Data-driven decision making & innovation enabling

With better observational data, you can build predictive models, digital twins, decision-support systems.

Supporting ecosystem services and sustainable use

Observations help quantify ecosystem services, monitor ecosystem health, thereby underpinning sustainable growth of marine sectors (marine biotechnology, aquaculture, sustainable fisheries) and backing new business models.

Stimulating new sectors, business models and technologies

Smart monitoring in the blue economy creates markets: e.g., marine sensor networks, underwater robotics, remote analytics, data services for marine/coastal industries. The “smart blue economy” framework emphasizes R&D, digital technologies, and innovation.

Regional strategic advantages

Embedding smart observation systems and linking them to blue growth strategies helps meet regional innovation agenda goals (Black Sea SRIA goals)

Smart Observations and BRIDGE-BS project

Recently developed technologies present a wide variety of advantages. In the BRIDGE-BS project several new cost-effective tools were applied for the understanding of ecosystem functioning and rapid biodiversity assessments of high innovation potential:

Cutting-edge Biodiversity Methods

- eDNA metabarcoding → smart, rapid biodiversity monitoring
- Metagenomics → marine enzyme discovery
- Advanced benthic observing systems

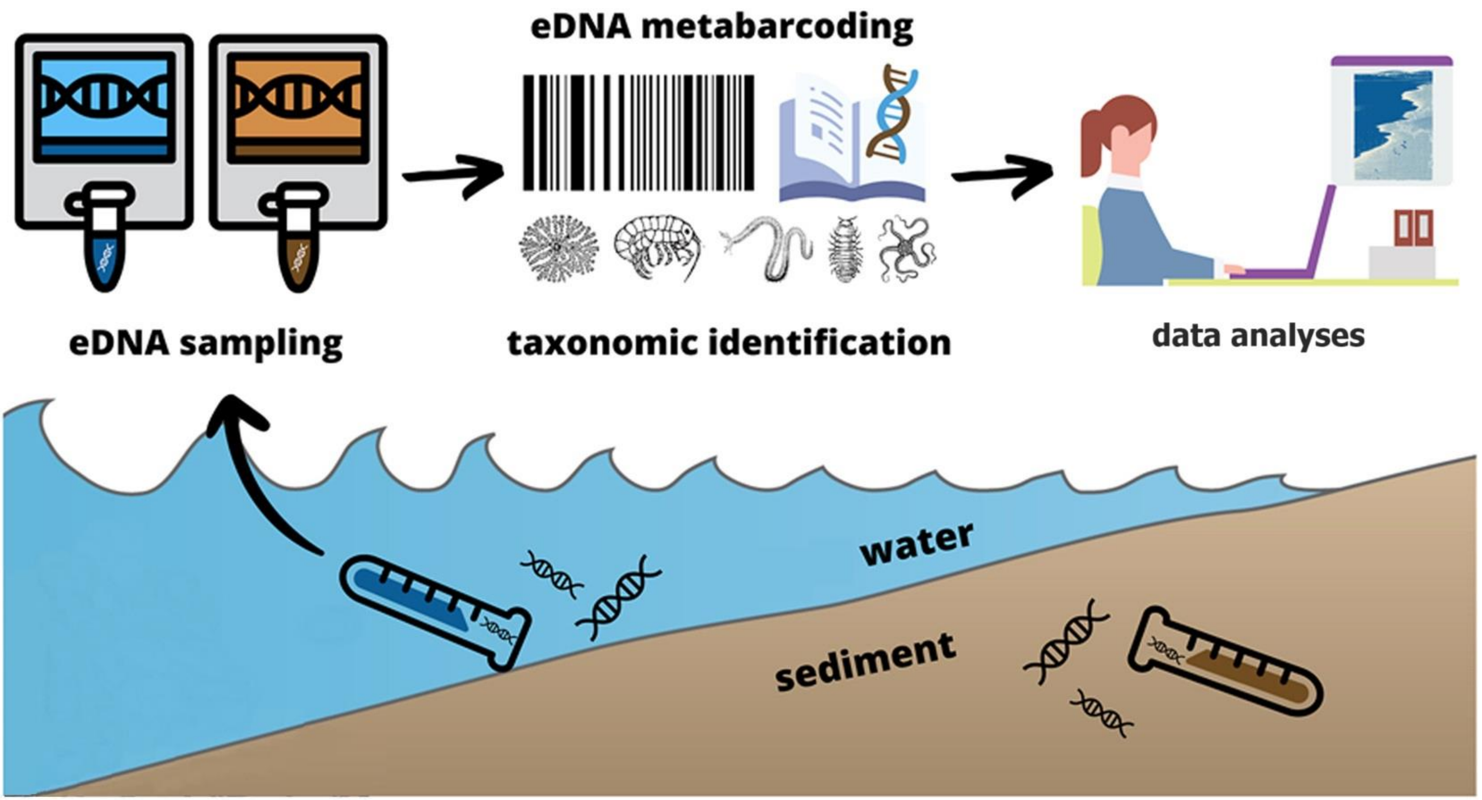
Early-Warning Demonstrators - sensing platforms tailored for specific stressors

- Jellyfish bloom monitoring
- Radioactivity observation
- Underwater noise detection

High-innovation platforms with strong application potential!

1. ENVIRONMENTAL DNA (eDNA)

What is eDNA monitoring?
General definition



Modified from Tagliabue, Alice, et al. (2023)
https://doi.org/10.1016/j.ocecoaman.2023.106785

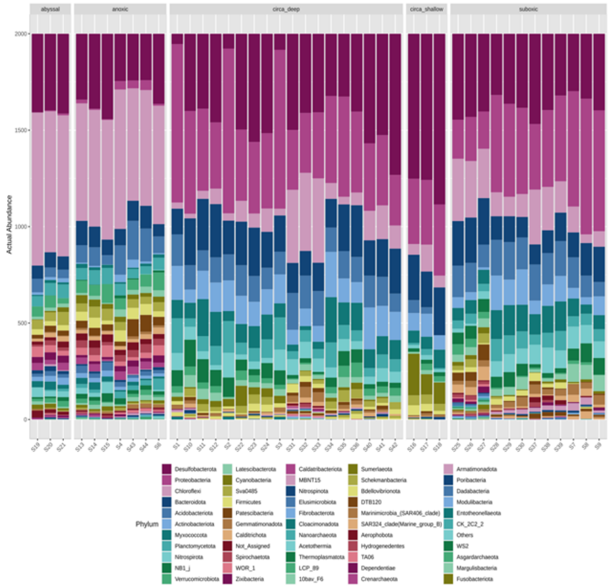
eDNA monitoring is a method of analyzing genetic material (environmental DNA) shed by organisms into their environment, like water, soil, or air, to detect their presence without direct observation. It is used for a variety of purposes, including tracking endangered and invasive species, monitoring ecosystem functioning, and assessing biodiversity in a cost-effective and less intrusive way compared to traditional methods. Samples are collected and filtered, and the eDNA is then analyzed in a lab using techniques like metabarcoding for a full ecosystem assessment.

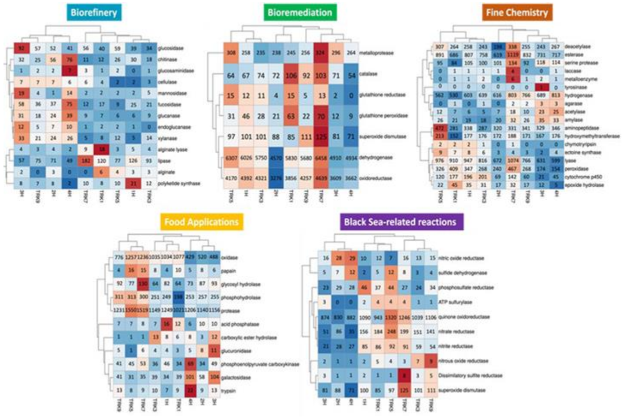
What is eDNA monitoring?
Key features

1. Non-invasive and Non-destructive
2. High Sensitivity
3. Broad Taxonomic Coverage
4. Scalability and Cost-effectiveness
5. Standardization and Reproducibility
6. Rapid Turnaround and Real-time Potential
7. Taxonomic Assignment Based on Genetic Reference Databases
8. Environmental Integration
9. Multidisciplinary Integration

eDNA Applications
Pilot Site Case Studies approach from the Black Sea

- Monitoring overall biodiversity (prokaryotic and eukaryotic) in the water column
- Assess fish biodiversity and support fisheries management
- Investigate the dietary preferences and gut microbiota of marine mammals
- Examine the diversity and community composition of phytoplankton, including the occurrence of HAB species, in the water column and sediment
- Pilot non-invasive, genomic-based approaches to assess the environmental status, focusing on the benthic macroinvertebrate ecosystem element
- Provide a detailed characterization of the bacterial communities colonizing sediments
- Investigate the Black Sea's potential in blue biotechnology, particularly for the discovery of new enzymes with applications across various industries





Details on the case studies can be found in D5.3.

eDNA Applications
Conclusions Based on the Case Studies

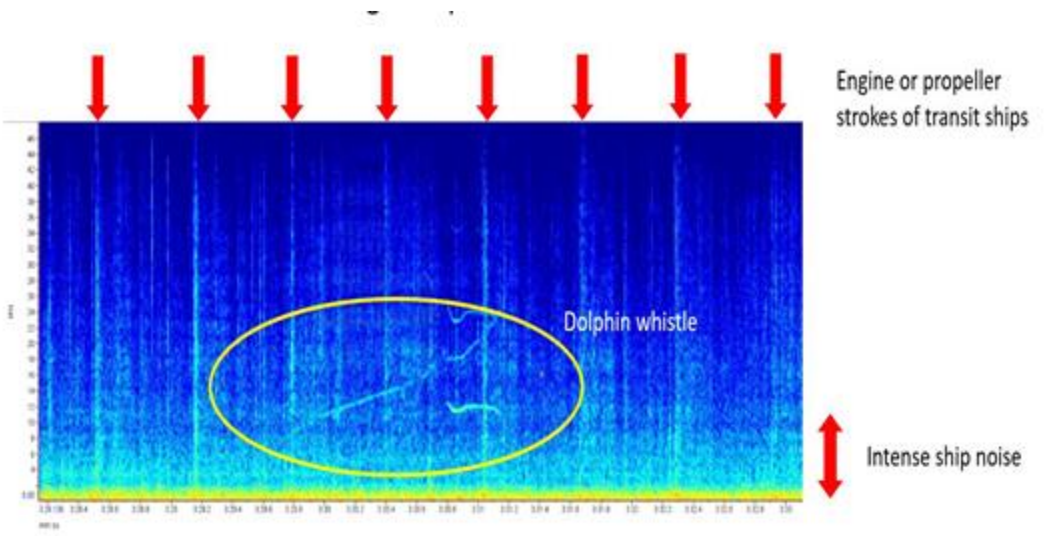
- Non-invasive, sensitive, **powerful, and cost-effective instrument** for monitoring biodiversity of various taxonomic groups, significantly providing insights into our understanding of the Black Sea ecosystems.
- However, considering the challenges (e.g. biases related to sampling, DNA extraction, amplification primers and conditions, bioinformatic analysis, reference databases, and lack of standardization) that need to be further resolved, **the integration of eDNA with traditional methods is essential** to maximize the potential in biomonitoring programs in the Black Sea and provide material to improve the methods.
- The Black Sea has **great potential** for discovering novel enzymes that can be utilized in the various areas of the industry. Thousands of industrial enzyme candidates are waiting to be explored and exploited.
- However, a detailed biochemical and structural characterization of novel enzymes is still needed to understand the chemical limits of their enzymatic activity and the structural basis to highlight their differences from the other catalase enzymes.

Details on the case studies can be found in D5.3.

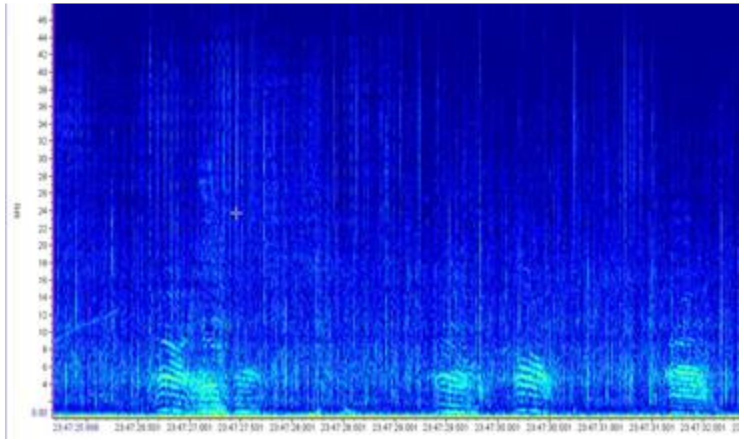
2. ACOUSTICS MONITORING

Acoustics Monitoring For Mammals

Passive acoustic monitoring (PAM) is a powerful technique for assessing the presence and behavior of wild animals as well as the environment as a whole. The combination of all sounds within an ecosystem can be considered as a single ‘soundscape’, which contains information about spatial and temporal variation in ecosystem health, the diversity and behavior of acoustic organisms, and instances of anthropogenic disturbance, such as shipping and seismic surveys. Marine mammals spend most of their time underwater where the visibility can be extremely limited. In particular, cetaceans (whales, dolphins and porpoises) depend heavily on acoustics for navigation, foraging and communication. To monitor their presence and movement, thus, PAM techniques have been used worldwide. **PAM has many advantages, such as** cost-effectiveness (no need to run an expensive survey), non-invasive **method (it does not harm animals) and constant monitoring (day and night, all year round, regardless of the weather).**



General image of audiogram as recording of Soundtrap



General images of audiogram showing “moans” as recording of Soundtrap

Acoustics Monitoring
Pilot Site Case Study from the Black Sea

Passive acoustic monitoring (PAM) was successfully conducted using the latest model of the acoustic recording device SoundTrap in the northern part of the Istanbul Strait (within PS1). Although there were some challenges, such as finding a secure deployment location and the time-consuming nature of data processing, **the system provided detailed information on both cetacean presence and human activities at sea**. Further analyses and broader use of such devices will shed light on the development of effective conservation measures for cetaceans and the marine ecosystem.

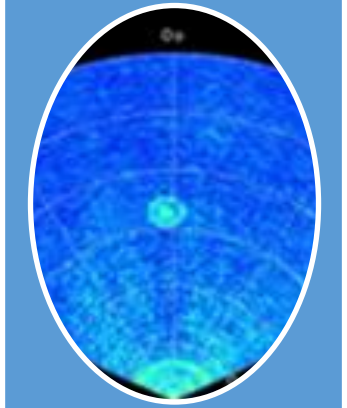
Details on the case study can be found in D5.3.

3. Early-Warning Demonstrators

BRIDGE-BS

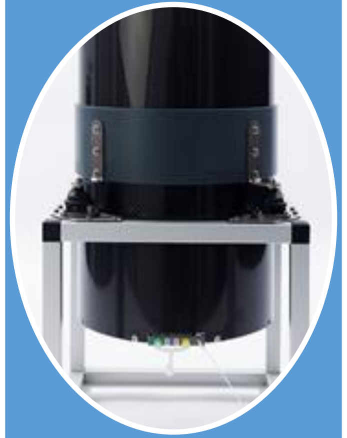
UNMANNED VEHICLES APPLICATION FOR JELLYFISH MONITORING

UNDERWATER DRONE FOR JELLYFISH MONITORING



UNDERWATER ACOUSTIC DETECTOR FOR JELLYFISH

RADIOACTIVITY OBSERVATION TOOL



IMAGING FLOW CYTOMETRY FOR PHYTO-PLANKTON MONITORING

EARLY-WARNING DEMONSTRATORS

BACKGROUND

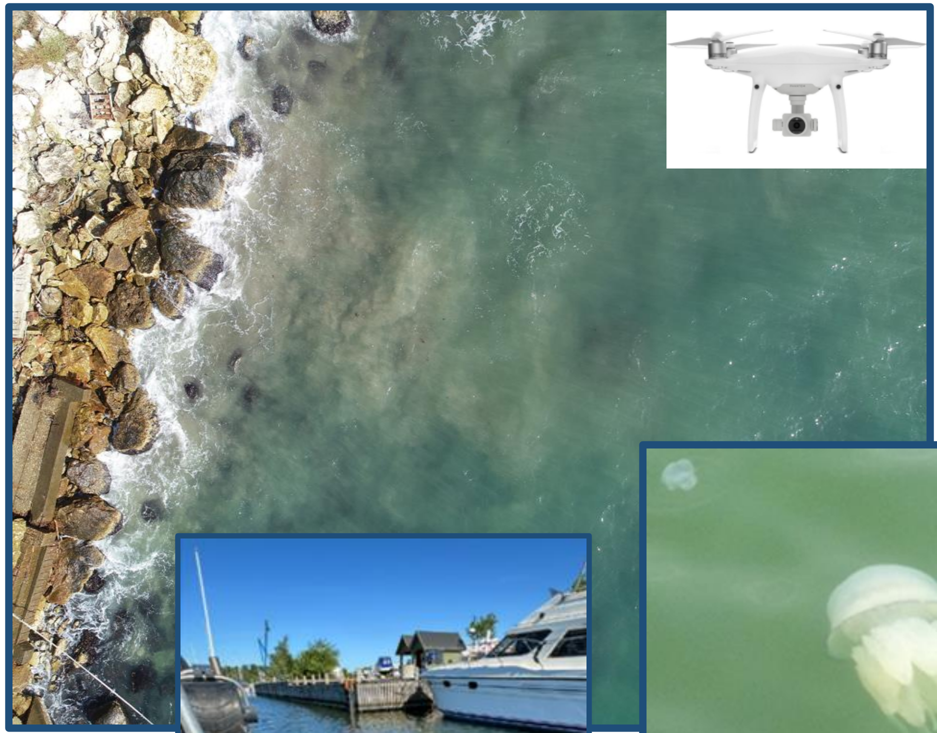
The group of solutions features demonstrator systems into operational monitoring solutions across the Black Sea region. This involves the deployment of integrated sensor arrays by combining aerial drones, acoustic detectors, and in situ flow cytometers in coordinated coastal surveys and early-warning networks. By validating these platforms under real-world conditions with industry and policy partners, we aimed to improve cutting-edge technology within existing marine-management frameworks for HAB forecasting and adaptive ecosystem management.

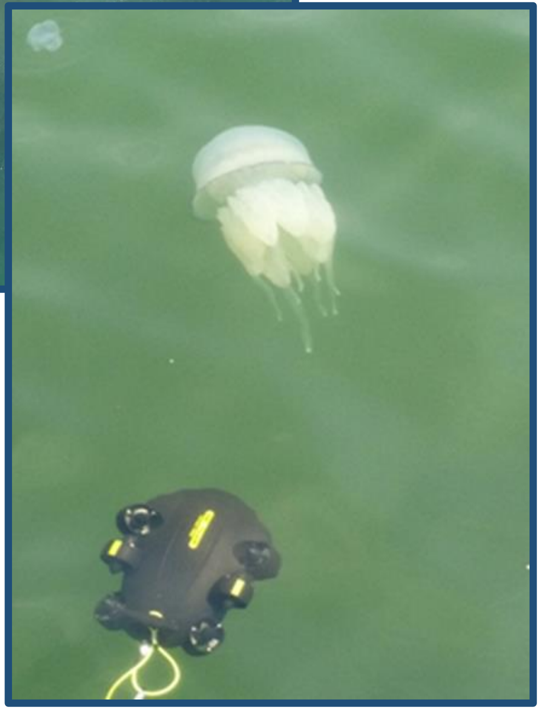
JELLYFISH ASSESSMENT SPECIFIC AIMS

Develop and validate an innovative, non-invasive jellyfish monitoring system for the Black Sea

Demonstrate operational feasibility and accuracy across coastal zones

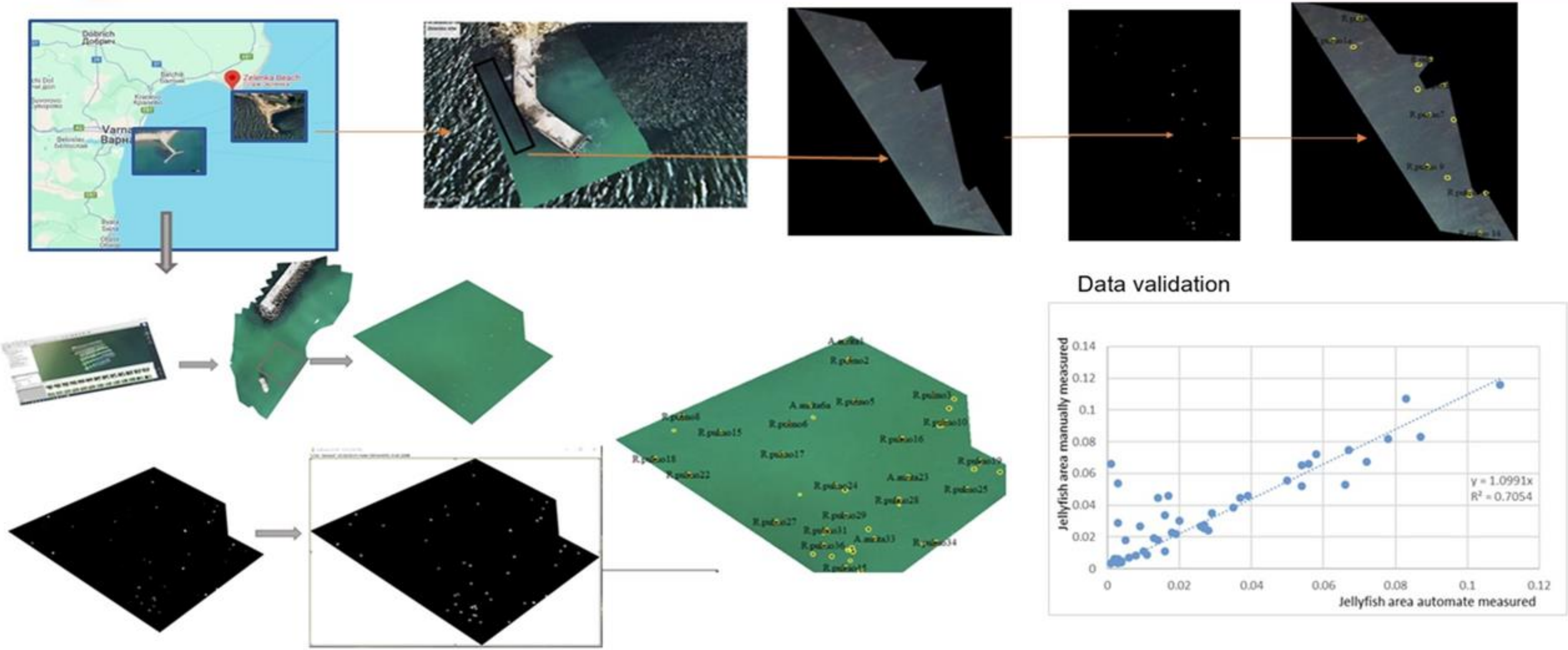
Integrate results into early-warning systems and policy-relevant marine management tools





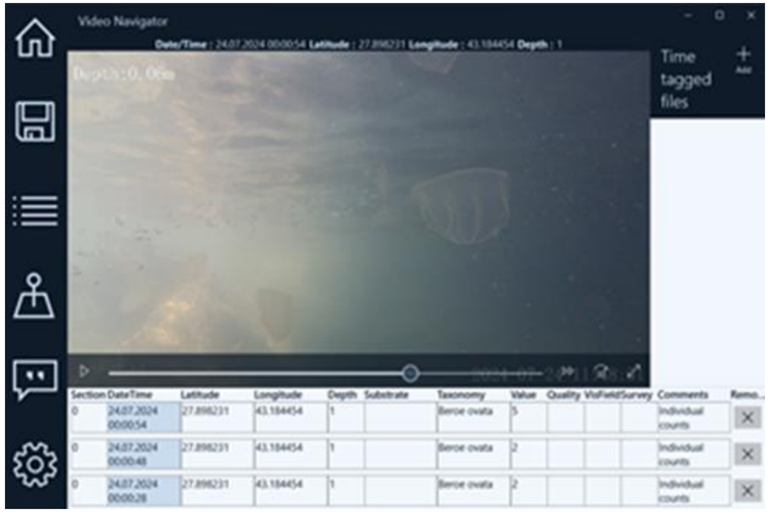
Further details on this study can be found in D5.5

UNMANNED VEHICLES APPLICATION FOR JELLYFISH MONITORING



Further details on this study can be found in D5.5.

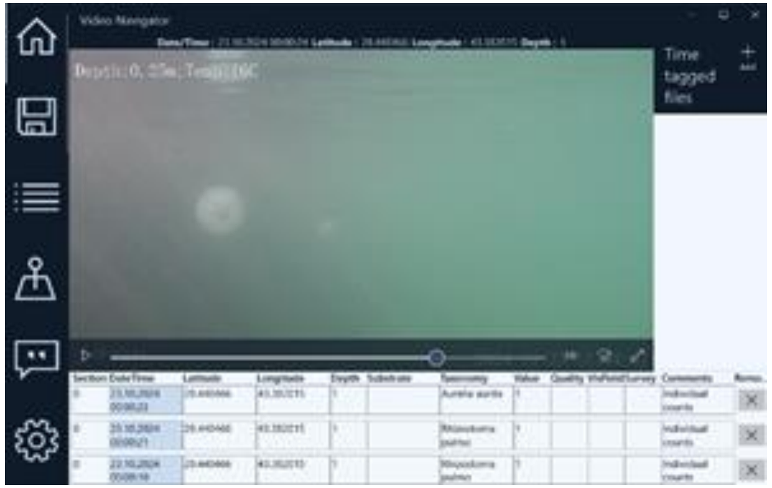
UNDERWATER DRONE APPLICATION FOR JELLYFISH MONITORING

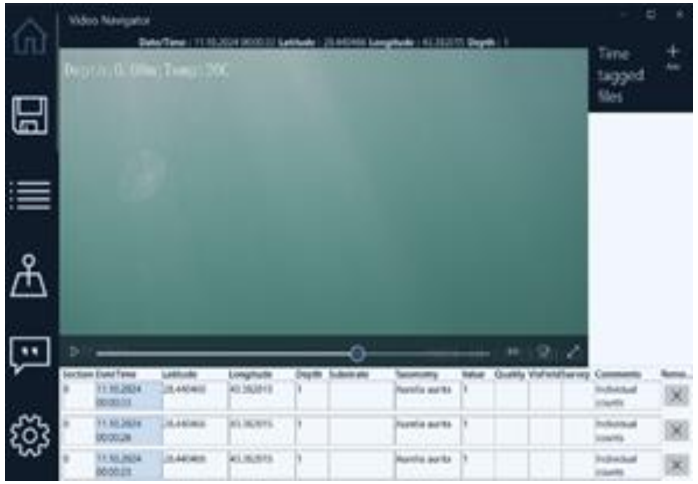


Key metrics include:

- Number of jellyfish per time interval
- Encounter rate (e.g., individuals per minute)
- Frequency of presence

These metrics allow comparison between stations, depth zones, or time periods, and can serve as indicators of bloom activity or distribution patterns.





Date	Time	Latitude	Longitude	Depth	Taxonomy	Value	VideoQuality	VisualField	SurveyMode	Comments
26.6.2024	0:00:02	27.898231	43.184454	1						sea snow
26.6.2024	0:00:02	27.898231	43.184454	1			Poor			
26.6.2024	0:00:02	27.898231	43.184454	1					Transit	
26.6.2024	0:00:14	27.898231	43.184454	1	*A. aurita*	1		Individual counts		
26.6.2024	0:00:17	27.898231	43.184454	1	*M. leidyi*	1		Individual counts		
26.6.2024	0:00:25	27.898231	43.184454	1	*M. leidyi*	1		Individual counts		
26.6.2024	0:00:42	27.898231	43.184454	1	*M. leidyi*	1		Individual counts		
26.6.2024	0:00:43	27.898231	43.184454	1	*M. leidyi*	1		Individual counts		
26.6.2024	0:00:51	27.898231	43.184454	1	*M. leidyi*	1		Individual counts		
26.6.2024	0:00:52	27.898231	43.184454	1	*M. leidyi*	1		Individual counts		
26.6.2024	0:01:05	27.898231	43.184454	1	*M. leidyi*	1		Individual counts		
26.6.2024	0:01:12	27.898231	43.184454	1	*M. leidyi*	1		Individual counts		
26.6.2024	0:01:26	27.898231	43.184454	1	*M. leidyi*	3		Individual counts		
26.6.2024	0:01:39	27.898231	43.184454	1	*A. aurita*	1		Individual counts		
26.6.2024	0:01:40	27.898231	43.184454	1	*A. aurita*	1		Individual counts		
26.6.2024	0:01:40	27.898231	43.184454	1	*M. leidyi*	4		Individual counts		
26.6.2024	0:01:43	27.898231	43.184454	1	*A. aurita*	2		Individual counts		
26.6.2024	0:01:58	27.898231	43.184454	1	*M. leidyi*	1		Individual counts		
26.6.2024	0:02:06	27.898231	43.184454	1	*M. leidyi*	1		Individual counts		
26.6.2024	0:02:16	27.898231	43.184454	1	*M. leidyi*	1		Individual counts		
26.6.2024	0:02:43	27.898231	43.184454	1	*M. leidyi*	1		Individual counts		

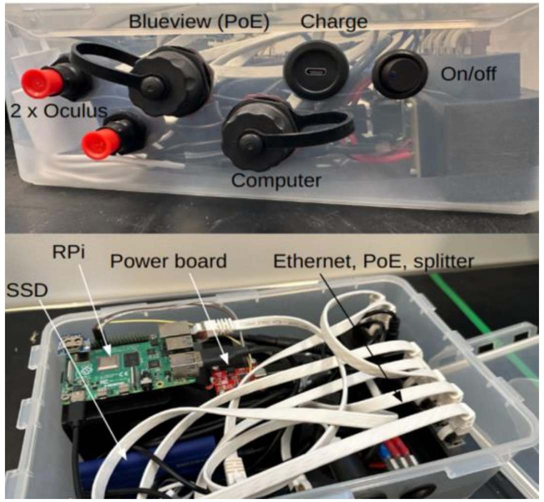
VideoNavigator tool (vs. 2.133.0)

Further details on this study can be found in D5.5.

UNDERWATER ACOUSTIC DETECTOR APPLICATION FOR JELLYFISH

Acoustic systems use sound waves underwater to detect and monitor jellyfish. A device sends sound pulses into the water; when the sound hits an object, part of it reflects back. By analyzing these echoes, we can estimate where jellyfish are and how many there might be.

View of Moon Jelly and corresponding sonar views from M750d (left) and M900-2250-130-Mk2 (right). The M750d resolves the jellyfish with more detail, since the BlueView uses more filtering functions to boost signal to noise.



Two Forward Looking Sonar (FLS) echosounders FLS for evaluation: the Oculus M750d from Blueprint Subsea and the BlueView m900-2250-130-mk2 from Teledyne Marine

Development of Sonar Support System (SSS)

In jellyfish aggregation, the reflected signal becomes strong enough to detect. Modern systems often use high-frequency sonar or acoustic cameras, which can create near-real-time images of jellyfish swarms.

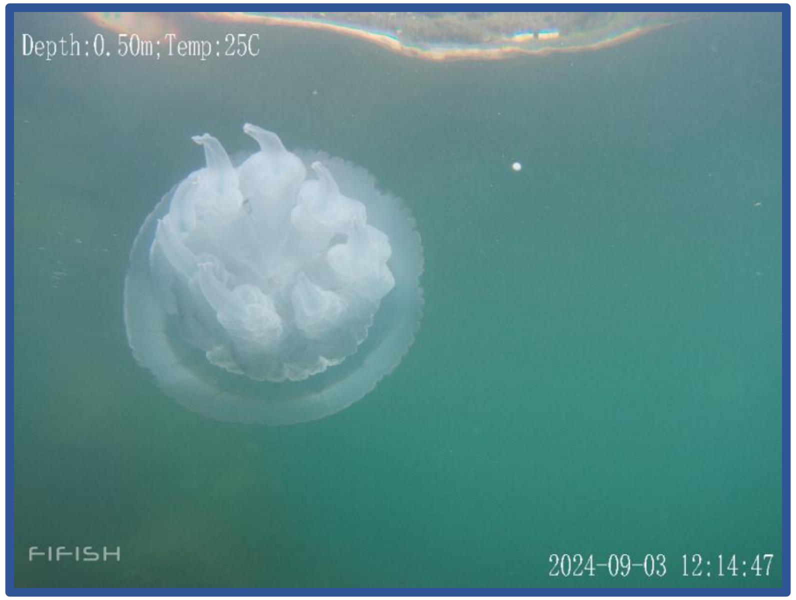
The system is demonstrated to work well in a simulated environment of the Black Sea

Further details on this case study can be found in D5.5.

Advantages & Disadvantages

Method	Pros	Cons
UAV (Drones)	✓ Non-invasive ✓ Wide area coverage High-resolution imagery for ID ✓ Cost-effective for long-term monitoring ✓ Real-time data collection	✓ Limited to surface observations ✓ Weather dependent (e.g., wind, rain) ✓ Limited battery life ✓ Surface reflection/turbidity may obscure visuals ✓ Requires skilled operators and post-processing

The integration of UAV/ROV into jellyfish monitoring fulfils two complementary functions: they serve as platforms for advancing and validating innovative marine observation technologies, and they support early warning capabilities. In a demonstration capacity, UAVs effectively illustrate the potential of non-invasive, real-time monitoring approaches, making them well suited for pilot initiatives, knowledge transfer, and stakeholder engagement.



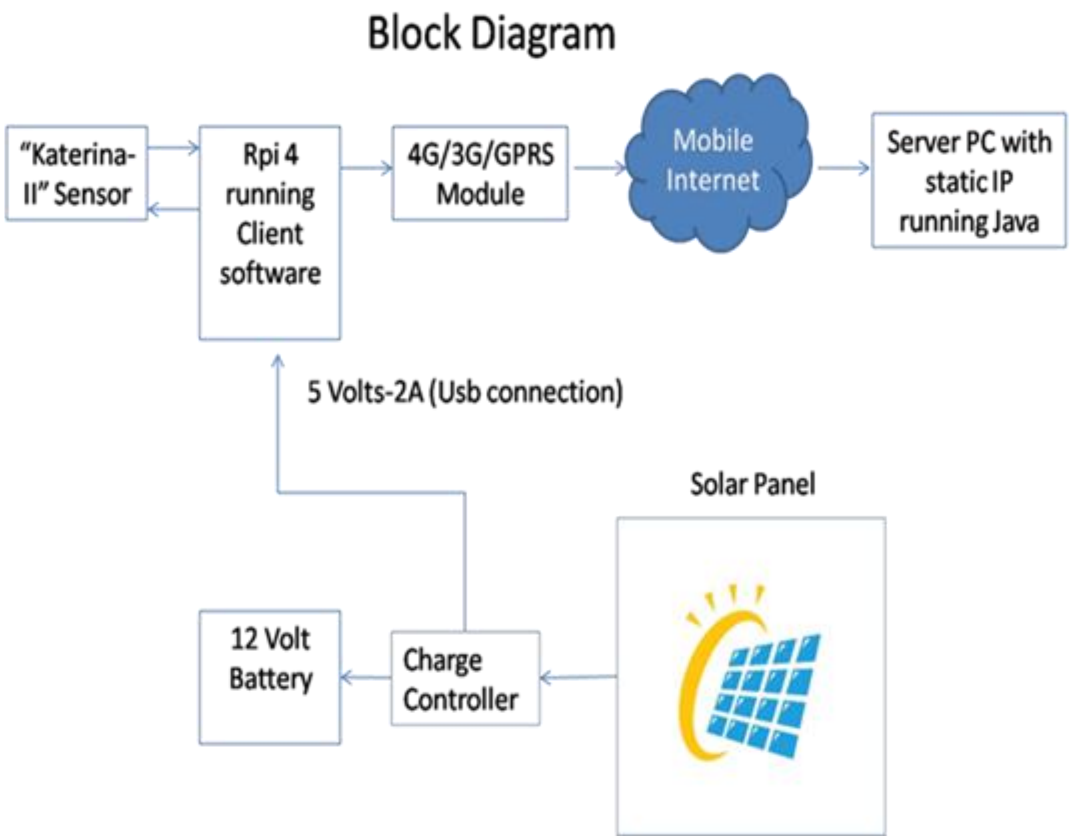
ROV

Aspect	*Advantages*	*Disadvantages*
Data Quality	High-resolution video and images Real-time observation	Jellyfish transparency affects visibility
Environmental impact	Non-invasive method with minimal jellyfish disturbance	Bright lights or propeller noise may still affect sensitive species
Integration	Can be combined with UAVs for surface + underwater coverage	Data synchronization across platforms requires extra planning
Data Processing	Frame extraction enables photogrammetry and detailed analysis	Processing is time-consuming With high storage requirements
Logistics	Portable and easy to deploy in small boats or coastal zones	Limited battery life Needs skilled operator
Cost	Long-term investment for repeated use across multiple projects	High initial cost and maintenance expenses

Further details on this study can be found in D5.5

SMART MARINE RADIOACTIVITY OBSERVATION TOOL (NEAR) REAL-TIME MONITORING

- Applied smart observation tools support services related to seawater quality and to the investigation of oceanographic processes using key radio-tracers such as 137Cs, 222Rn, 226Ra and 7Be.
- The smart observation tool for marine radioactivity provides key information for the trends of any potential pollution and subsequently can support MSFD implementation.
- The detection of marine radioactivity and the measurement of the specific isotope ratios (such as the mass 134 and 137 isotopes of Cs), are of high importance for studying the biogeochemical cycles of elements as well as the lifetime of the potentially detectable radio-pollution.

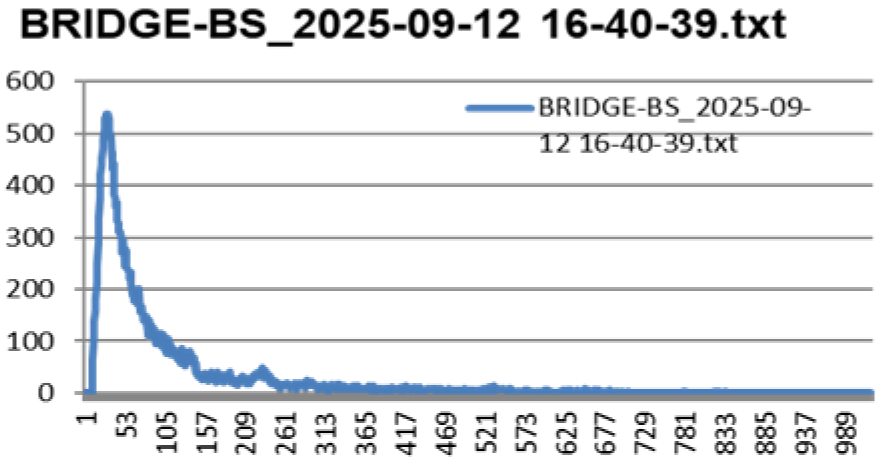


The system test (in terms of operation, communication and data transfer) at a fixed marine station in Varna Bay (PS2)

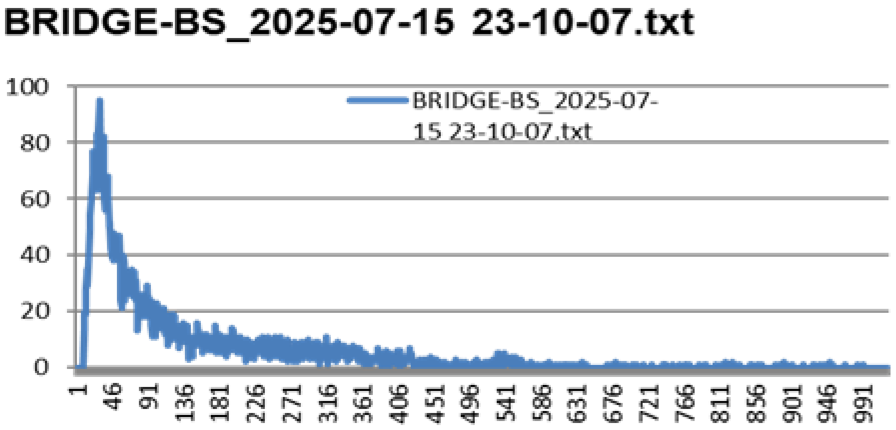
Further details on this study can be found in D5.5.

SMART MARINE RADIOACTIVITY OBSERVATION TOOL (NEAR) REAL-TIME MONITORING

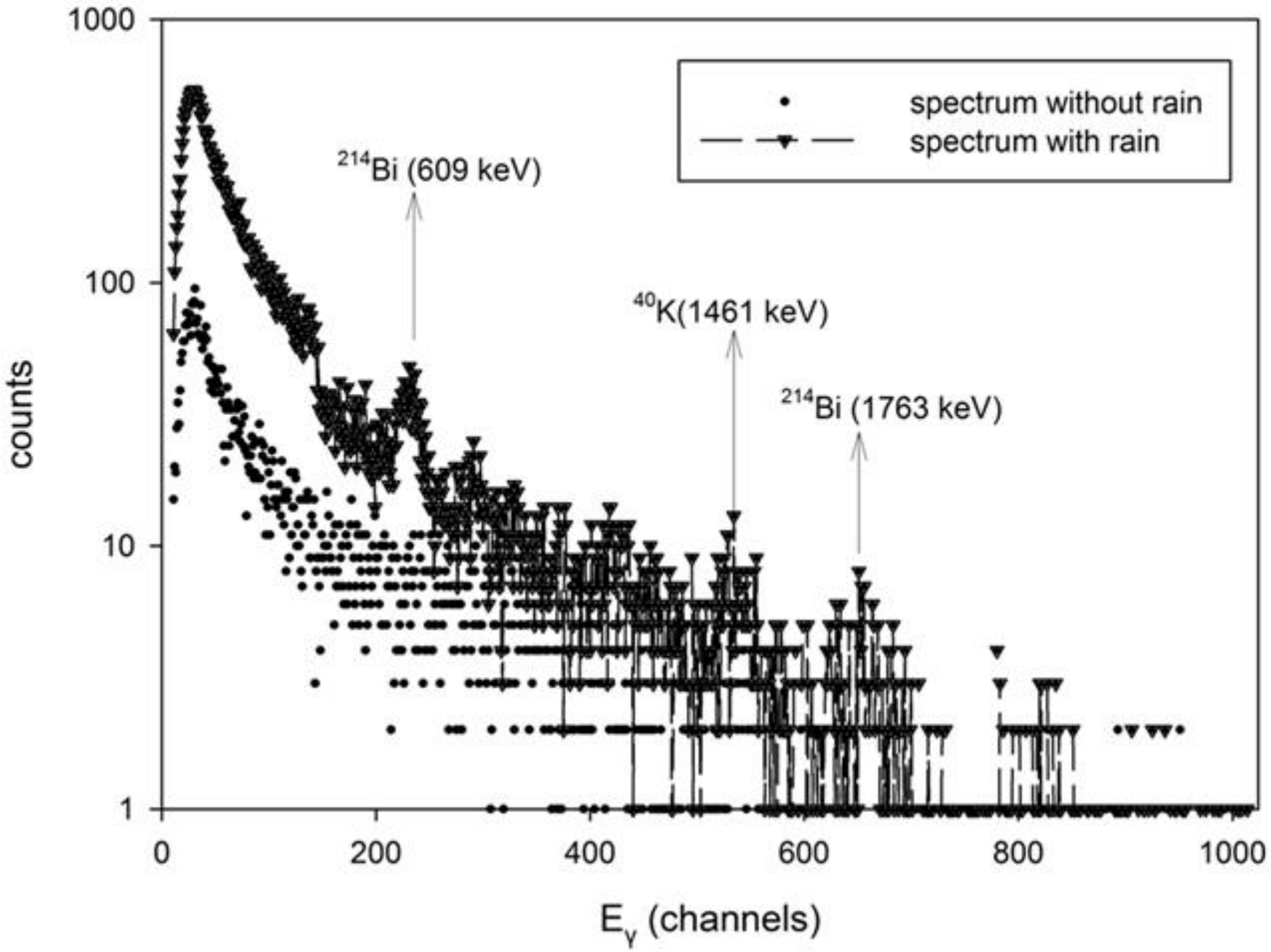
Spectrum under heavy rain



Spectrum without rain



Acquired γ spectra with and without rain



Imaging Flow Cytometry

- Combines microscopy and flow cytometry to image individual phytoplankton cells in real time
- Enables rapid, automated identification and quantification of species based on morphology and fluorescence
- Supports early detection of harmful algal blooms and enhances routine ecosystem monitoring

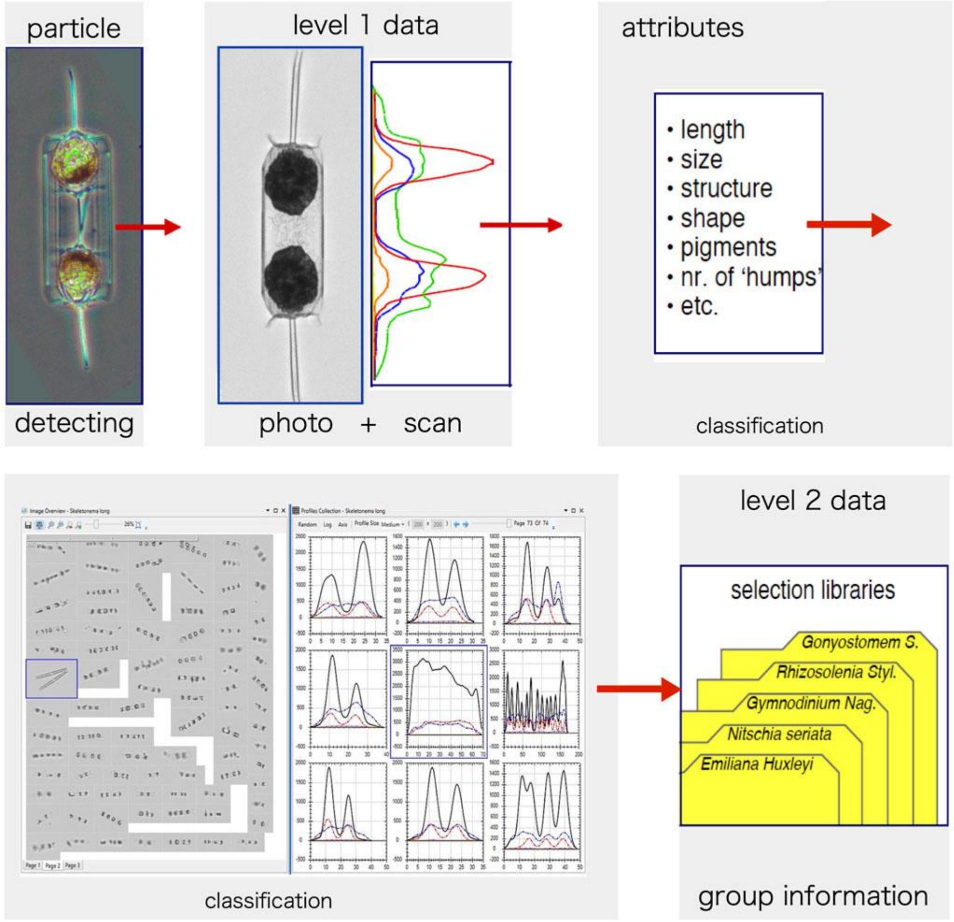


Figure: https://www.cytobuoy.com/

ADVANCED METHODS FOR PHYTOPLANKTON MONITORING

Imaging Flow Cytometry

AI & Machine Learning in Imaging Flow Cytometry

- ***Automated Classification:*** ML algorithms analyze thousands of cell images per second, identifying phytoplankton taxa without manual labeling.
- ***Feature Extraction:*** AI models learn morphological and fluorescence patterns (shape, size, texture, pigment signatures) directly from images.
- ***Unsupervised Clustering:*** ML groups cells with similar features, enabling discovery of novel or rare taxa and improved community structure analysis.
- ***Adaptive Learning:*** Models improve over time as new training data are added, increasing taxonomic accuracy and robustness.
- ***Real-time Monitoring:*** Onboard AI enables near real-time recognition of harmful algal species and rapid response to bloom events.
- ***Integration with Environmental Data:*** Combining IFC-derived classifications with physical and chemical parameters supports predictive ecosystem modeling.

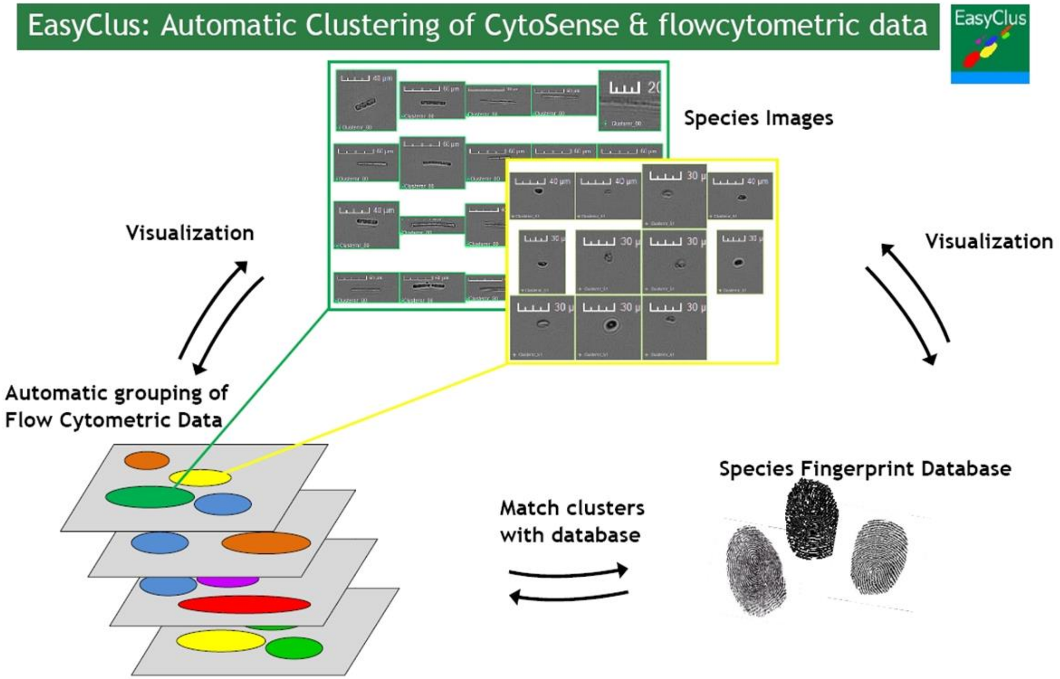
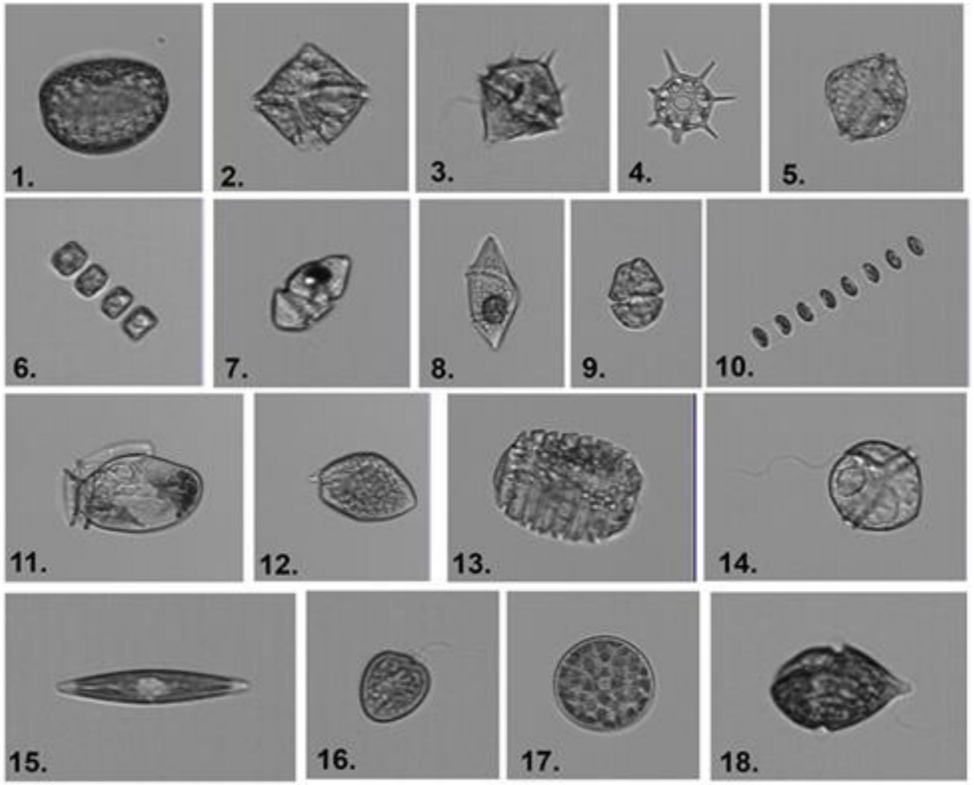


Figure: https://www.fytoplankton.nl/easyclus/

ADVANCED METHODS FOR PHYTOPLANKTON MONITORING

Pilot Site Case Study from the Black Sea

Regional Black Sea Phytoplankton Image Library: **over 8,000 curated photos covering 160 taxa**.



1. Coscinodiscus granii 2. Protoperidinium subinerme 3. Blixaea quinquecornis 4. Octactis speculum 5. Alexandrium 6. Cyclotella choctawhatcheeana 7. Nematodinium 8. Gyrodinium spirale 9. Gymnodinium aureolum 10. Skeletonema 11. Dinophysis acuminata 12. Prorocentrum micans 13. Polykrikos kofoidii 14. Oblea rotunda 15. Navicula 16. Prorocentrum cordatum 17. Thalassiosira eccentrica 18. Scrippsiella

Automated data and classification pipeline test

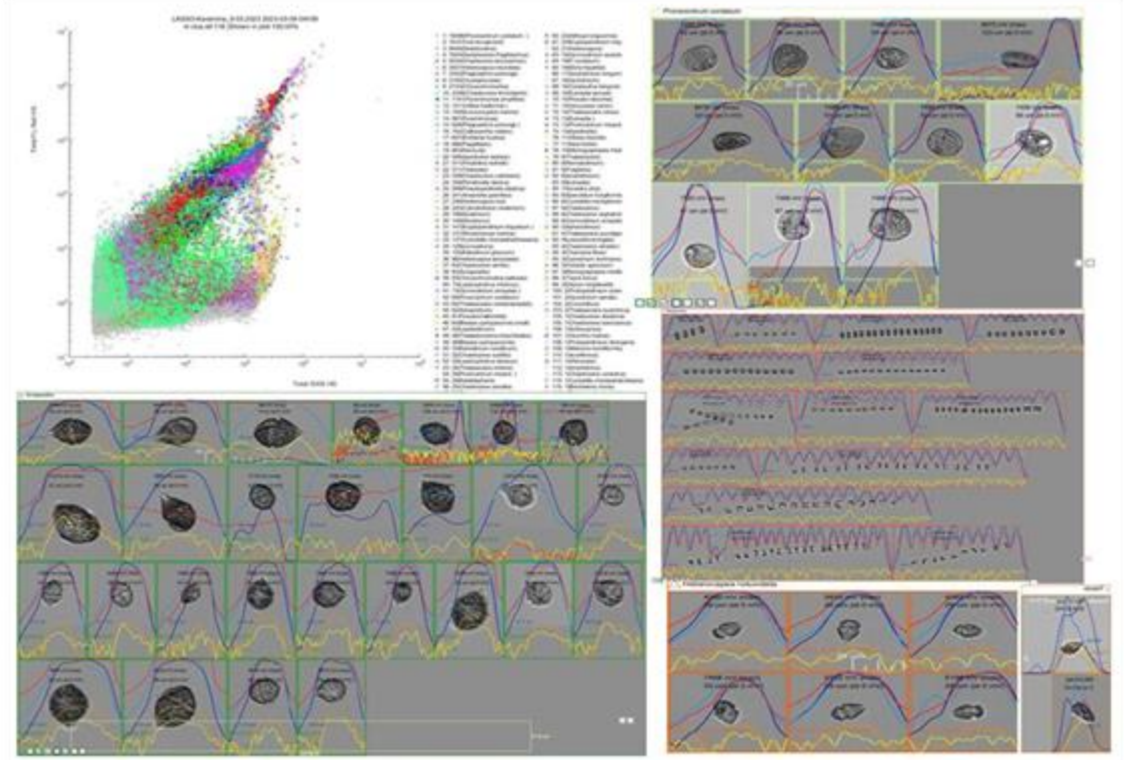


Image library and classification pipeline show strong potential for operational monitoring.

Further details on this study can be found in D5.5.

CONCLUDING REMARKS

- Smart observations play a crucial role in safe, sustainable and innovative Blue Growth.
- Tools such as eDNA, acoustics, UAV/ROVs, imaging flow cytometry, and radioactivity sensors provide faster, more accurate, and non-invasive data collection.
- These innovations strengthen early-warning capabilities, support evidence-based management, and create opportunities for new services in the Blue Economy.
- Integrating advanced tools with traditional methods ensures more reliable ecosystem assessments and better-informed decisions.
- By combining technology, science, and collaboration, we can detect risks earlier, act faster, and manage marine resources more responsibly.

THANK YOU!

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