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Module 4: Seagrass Mapping and Monitoring

Mapping and monitoring seagrass extent, cover and species composition is vital to understanding these complex and dynamic ecosystems. This process highlights areas of resilience and sensitivity, and helps predict responses to climate change-induced pressures.

Seagrass mapping and monitoring extends beyond direct measurements to include their benefits, processes and pressures relating to food regulation, fishery production, the global carbon cycle, biodiversity and climate change, among other aspects.

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Challenges in Global Seagrass Mapping

1 Diverse Habitats

Seagrasses are found across a broad depth range, from the intertidal zone to 80 metres deep, and grow in environments ranging from very clear to very turbid waters.

2 Variable Density

Seagrass beds vary in density, from single patches to square kilometres of homogeneous meadows, making consistent monitoring difficult.

3 Species Diversity

Species composition ranges from single species to mixed grounds of more than 10 species, requiring different monitoring approaches.

In order to achieve innovative and timely seagrass mapping and monitoring, a globally coordinated matrix approach is necessary to address these challenges.

A Matrix Approach to Seagrass Monitoring

Top-Down Methods

Remote sensing instruments including satellites, airplanes, drones, and sonars provide broad spatial coverage but may miss detailed ecosystem conditions.

Bottom-Up Methods

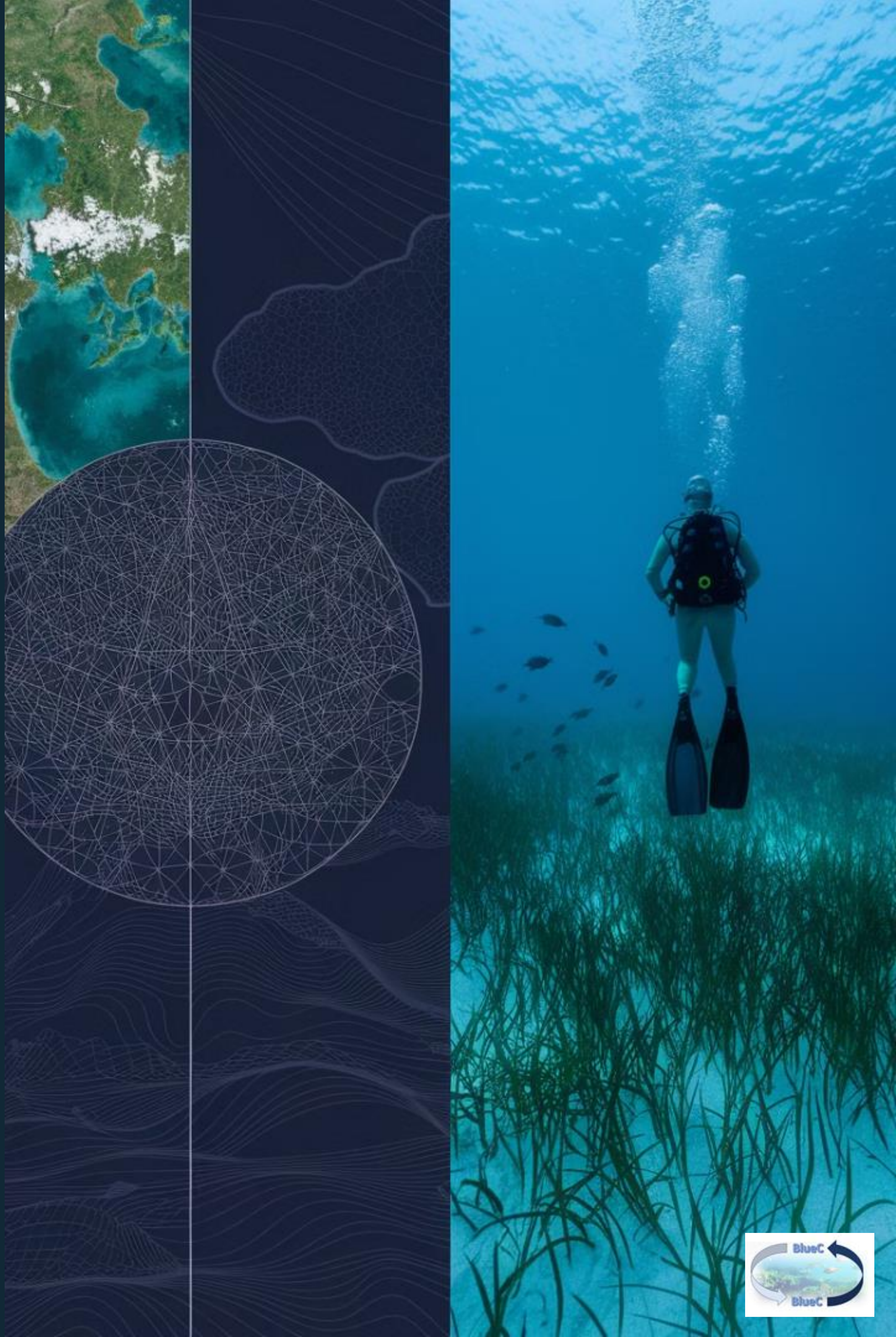
In situ sampling provides detailed information but is resource intensive and can vary in timing, consistency and methodologies.

Combined Approach

When combined, remotely sensed and in situ methods yield critical information on health and trends of seagrass ecosystems for researchers and decision makers.

The three main components of the matrix to perform mapping and monitoring of seagrasses at the global scale are: the techniques, the technology and the data.

Mapping and Monitoring Techniques



Optical-based

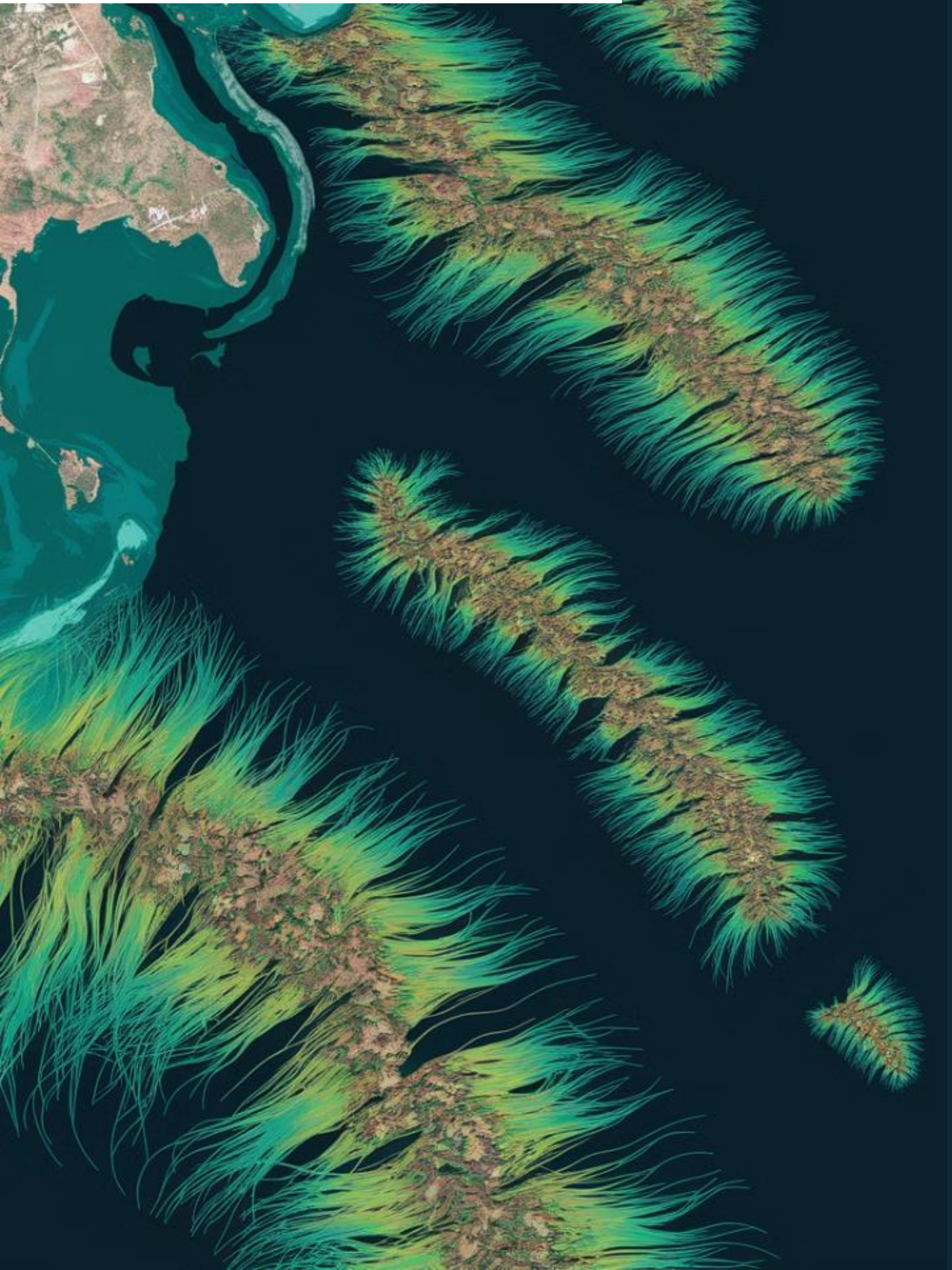
Using remote sensing instruments such as satellites and drones to capture imagery of seagrass beds from above.

Acoustic-based

Using remote sensing instruments such as sidescan sonars to map underwater seagrass distribution.

Field-based

Conducted through diving, snorkelling and ecological monitoring to gather detailed data on seagrass health.



Optical Techniques: Satellites and Drones

Satellite Capabilities

Satellite-based remote sensing can identify and map seagrass between spatial resolutions of 0.30 and 30 m, temporal resolutions between 1 and 17 days, and spectral bands between 400 and 700 nm – the visible spectrum.

Depth Limitations

Satellites can see seagrasses with satisfactory detail and frequency to maximum water depths of 40 m in many cases, depending on water clarity.

Advantages and Disadvantages

While satellites provide broad coverage, their effectiveness is limited by factors such as water clarity, cloud cover, and resolution constraints.

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Selecting the Right Satellite Sensor

1. **Project Scope**
   Scale and extent of mapping area
2. **Sensor Capabilities**
   Spatial and temporal resolution
3. **Available Funds**
   Budget constraints for imagery

The final decision on selecting the appropriate satellite sensor highly depends on balancing these three factors. Recent developments in lightweight drones, also known as Unoccupied Aerial Systems (UAS), have added valuable new tools to the Earth observation and remote sensing toolkit.

Advantages and disadvantages of satellite imagery in mapping seagrass meadows.

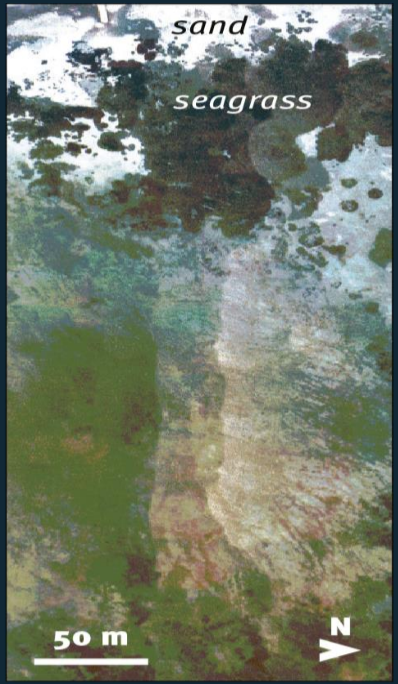
Advantages	Disadvantages/potential errors
• Enables differentiation between objects whose colour would appear identical to a photo-interpreter • High spatial resolution • Digital from acquisition • Large coverage, easy to georectify	• Photographic distortion • Photo-interpretation • The spectral output of seagrass beds may vary over very short distances due to: - growth of epiphytes - "health" of the grasses - water depth - optical properties of overlying water • Low radiometric resolution • Clouds are a big problem

Selecting the Right Satellite Sensor

Seagrasses from above - drones and satellites

Example images from Lesbos, Greece. 39°09'30.6"N 26°32'01.8"E

Drone



resolution: 4 cm

- (+) Very high spatial resolution, Low cost of acquisition, High flexibility of deployment
- (−) Small ground area coverage, Limited optical bands, Required laborious image pre-processing

WVII PAN

resolution: 50 cm

- (+) Very high spatial resolution, High spectral information, Direct and flexible sensor tasking
- (−) Commercial imagery, Very high cost of imagery

WVII MUL

resolution: 2 m

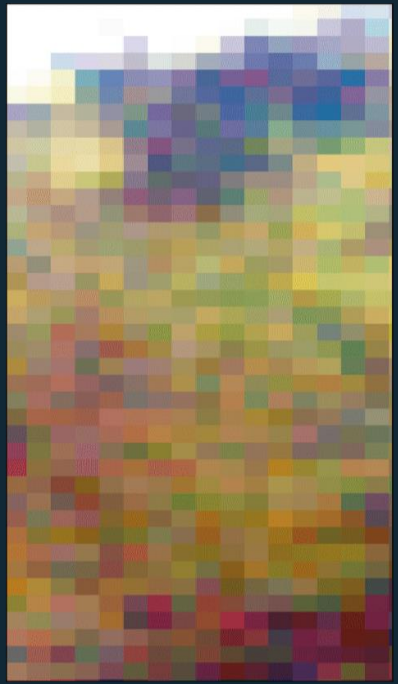
- (+) Very high spatial resolution, High spectral information, Direct and flexible sensor tasking
- (−) Commercial imagery, Very high cost of imagery

PlanetScope

resolution: 3 m

- (+) High spatial resolution, High temporal resolution, Free under a scientific license
- (−) Radiometric differences betweem, Low spectral information

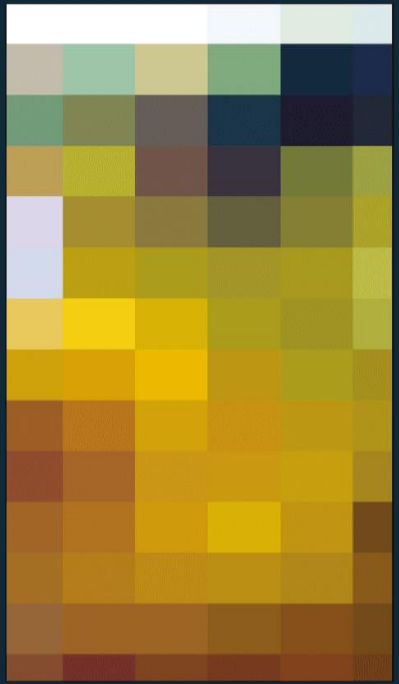
Sentinel-2



resolution: 10 m

- (+) High spatio-temporal resolution, Open, free and public datasets, Archive between 2015-2029
- (−) Multiple spatial bands, Spectral technological-related artifacts over seagrass areas

Landsat-8



resolution: 30 m

- (+) Large area coverage, Free datasets, Historical archive back to 1972
- (−) Low spatial resolution, Low temporal resolution

Sources: Topouzelis, K. University of Aegean (2018); … data (2018); Lansdat-8 (2018) U.S. Geological Surve…

	Landsat Thematic Mapper*	SPOT XS *	CASI (Compact Airborne Spectro-graphic Imager)	Aerial photography
Accuracy of the map (%)	<60	<50	<90	<70
Coverage per scene (km)	185 x 185	60 x 60	variable	variable
Cost (€ km^{-2} $scene^{-1}$)	0.12	0.71	8.11	16.07

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Advantages and disadvantages of mapping seagrasses with aerial photography.

Advantages	Disadvantages
• High spatial resolution • Spatial resolution (as determined by the scale) can be selected based on project objectives • Flexible acquisition – imagery can be planned captured at the most optimal time of day and under the best environmental conditions • Low technology information extraction – seagrass maps can be made from aerial prints or diapositives with little technical hard- or software resources, but in most cases aerial photos should be digitised and rectified before mapping. • Stereometry can greatly enhance mapping.	• Cost – The fine spatial resolution provided by the photographs comes at the cost of obtaining a large number of frames • It is produced in an analogue format and must be scanned if any computer enhancement, image processing or rectifying is anticipated • Distortion – The nature of the camera lens and position, roll, yawl and tilt of the plane introduces some distortion into the imagery. A problem if not corrected by rectifying. • Lack of light can make interpretation difficult in deep and turbid waters • Highly variable sun-glint reflection from all directions in image. • Clouds.

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Drone Applications in Seagrass Monitoring

<10cm

Resolution

Drones provide subdecimetre spatial resolution, capturing fine details of seagrass beds.

$

Cost

Relatively low cost compared to other remote sensing methods.

100%

Flexibility

High flexibility in deployment capabilities and customization for specific monitoring needs.

Drones have been used in a series of intertidal seagrass monitoring studies demonstrating their effectiveness for high-resolution mapping. The cost and accuracy considerations vary significantly between satellite and airborne sensors, with drones offering a middle ground solution.

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Synergy Between Drones and Satellites

1

Drone Collection

Drones collect high-quality, high-resolution reference data at lower altitudes (usually no higher than 300 m).

2

Validation

This data validates the lower-resolution, satellite-derived seagrass mapping products.

3

Cost Reduction

This approach reduces costs associated with collecting field validation data in situ (by means of snorkelling and/or diving).

4

Increased Feasibility

The combined approach increases the feasibility of seagrass mapping projects.

The ability to fly drones on the same route repeatedly and collect data as necessary has made them a very useful tool in the routine monitoring of seagrass ecosystems, despite requiring special permissions and licenses.

Acoustic Mapping Techniques

Side-scan Sonars

1

Used since the 1970s in the Mediterranean Sea to map seagrass beds, though it is difficult to measure densities and canopy heights.

Multibeam Echosounders

2

One of the most effective acoustic tools, creating three-dimensional images of seagrass meadows with detailed structure.

Single Beam Echosounders

3

Useful for mapping the lower depth limit of seagrass distribution, though they do not provide full coverage of the sea floor.

Acoustic sensors are commonly used to map seafloor physical and biological properties. Using ultrasound techniques, it is possible to map seagrass meadows using an acoustic apparatus, usually towed from or installed on a boat. The size of the surveyed area generally falls between that of in situ methods and satellite imagery.

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Field-based Monitoring Approaches

Percentage Cover Assessment

The best established and most commonly used variable for seagrass monitoring, referred to as 'the horizontally projected foliage covers of the canopy'.

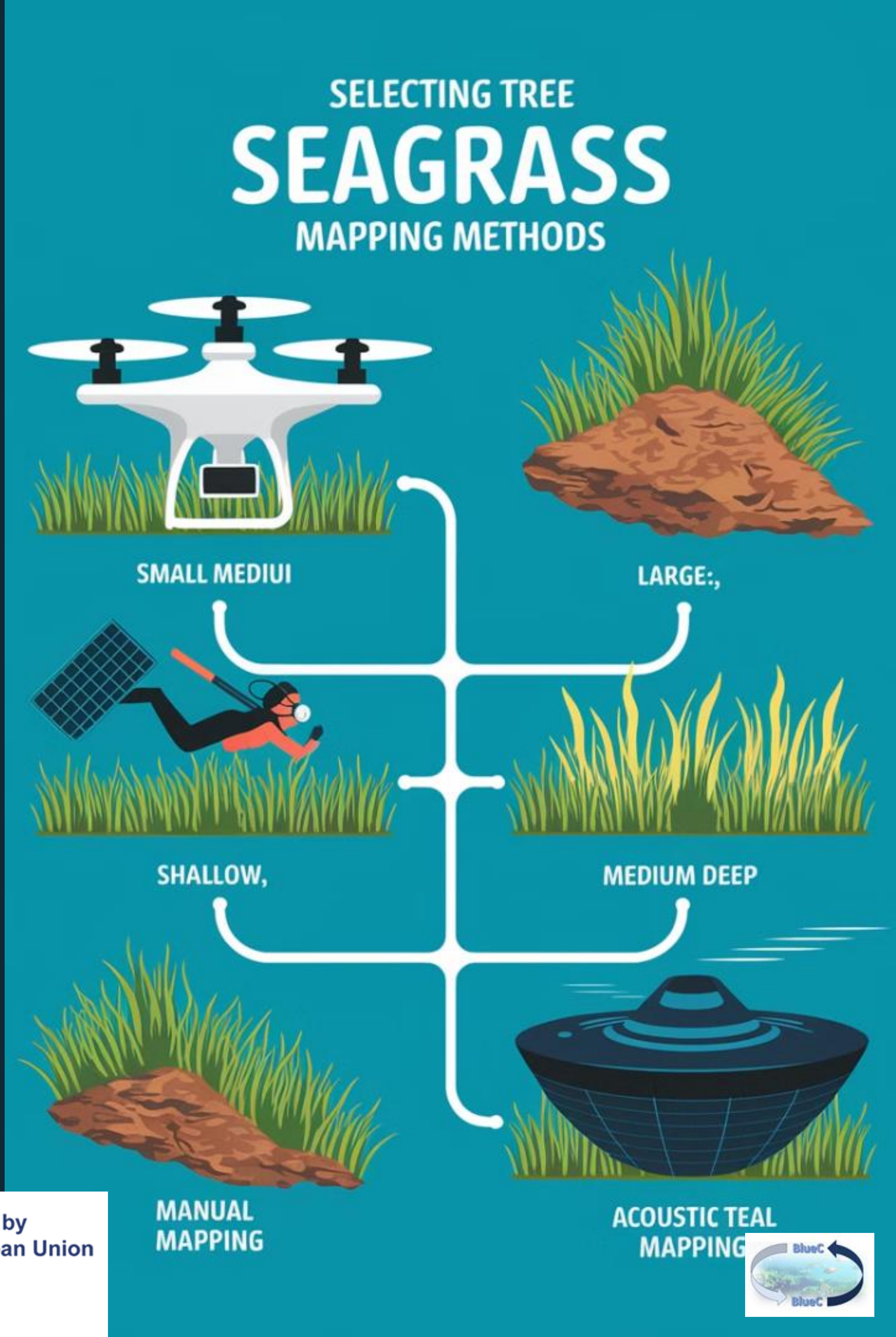
Additional Measurements

Collection of shoot density, canopy height, biomass and species composition data at a fine scale.

Quality Control

Using common reference cards and quality assurance/quality control (QA/QC) procedures to improve accuracy.

Field-based monitoring can provide detailed information on the health status (ecological status) of seagrass meadows as a number of variables are collected at a fine scale. While estimating cover can be subjective, proper training and standardized methods can greatly improve the method's accuracy.



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BlueC

Coordinated Monitoring Networks

Standardized Protocols

Common methods across sites

Data Collection

Comparable measurements

Reporting

Shared results and insights

Analysis

Cross-site comparison

Networks provide an excellent and cost-effective method of obtaining standardized and comparable data on seagrass change and related drivers over several different locations worldwide through time. A recent global assessment identified 19 active long-term seagrass monitoring programmes, the largest being Seagrass-Watch and SeagrassNet.

Both networks aim to provide up-to-date online data submission systems, as well as resources to support monitoring, such as manuals or protocols, field guides and data sheets, news, details of seagrass sites and participants.

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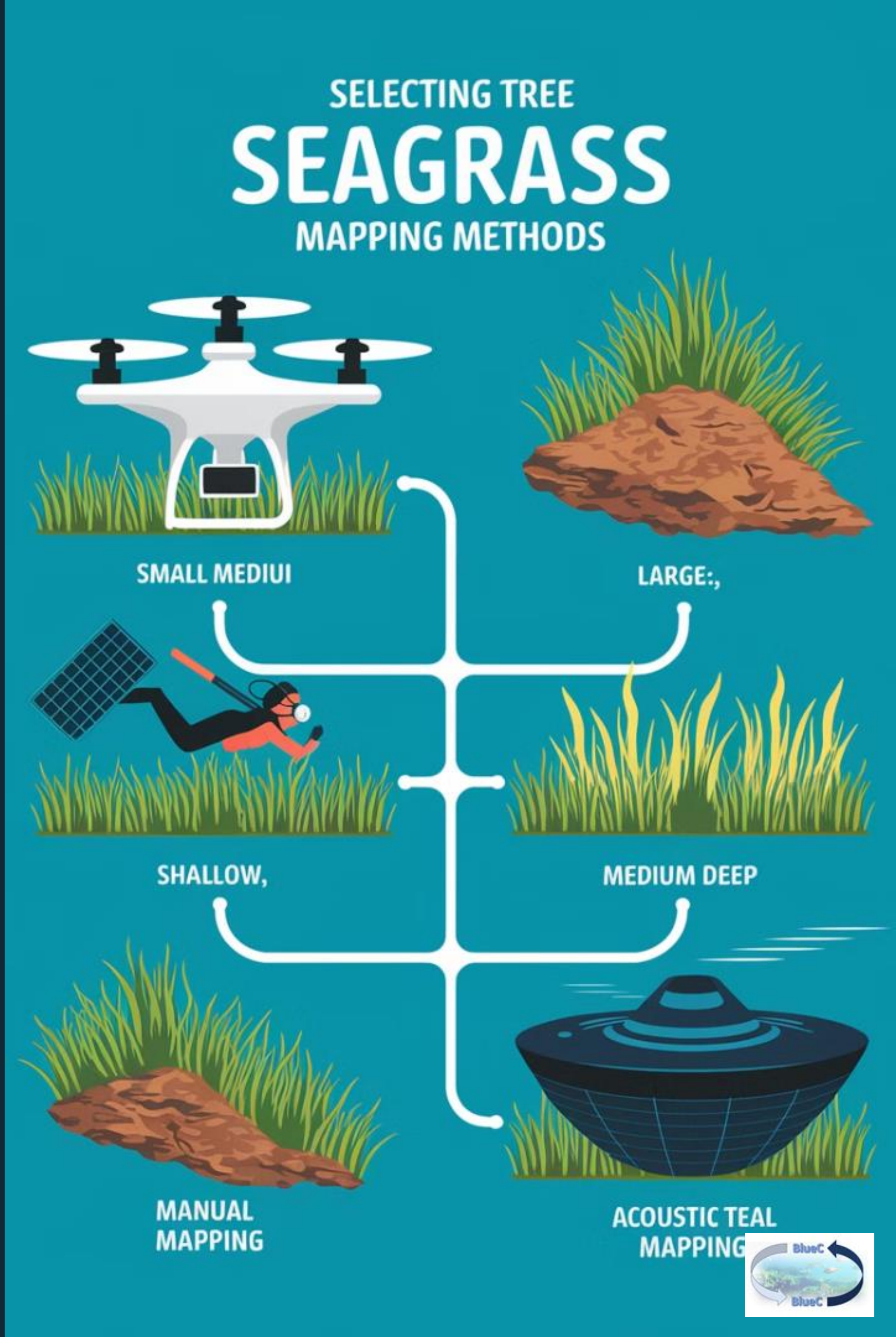
Choosing the Right Mapping Method

Method	Area Size	Depth Range	Advantages
In-situ (diving)	Small (<1km²)	0-30m	High detail, species ID
Video camera	Small-Medium	0-50m	Good coverage, less labor
Aerial photos	Medium-Large	0-15m	Wide coverage, archival
Satellite imagery	Very Large	0-10m	Global coverage, repeatable

The depth intervals are only indicative as the ability of remote sensing methods to distinguish seagrasses depends on water clarity rather than absolute water depth. Digital aerial photos have higher sensitivity than ordinary film and are recommended when water clarity is low.



Technological Advances in Seagrass Mapping

1

Cloud Computing

Enables processing of massive datasets

2

Artificial Intelligence

Automates analysis and classification

3

Machine Learning

Improves accuracy and detection

In the last decade, technological advances in computation have enabled two cornerstones of today's mapping and monitoring via satellite and drone imagery: cloud computing platforms and artificial intelligence (AI), which includes machine learning and deep learning.

This technology sets the stage for highly scalable, repeatable and accurate techniques that can facilitate seagrass mapping and monitoring at unprecedented scales and resolutions.

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Cloud Computing Platforms

Google Earth Engine

Cloud-based platform offering storage, processing, analysis and visualization of Earth observation data, used successfully for mapping Posidonia oceanica across Greek coastlines.

Amazon Web Services

Provides cloud environment for storage and processing of large-scale Earth observation datasets.

European Commission's Copernicus

Data and Information Access Services offering tools for analyzing satellite imagery for environmental monitoring.

The last five years have seen the establishment and growth of cloud computing platforms, which represent an unprecedented 'big data' approach to science and management. These platforms emphasize data-intensive analyses, time- and cost-efficient data access, huge computational resources and high-end visualization.

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Artificial Intelligence in Seagrass Monitoring

1

Machine Learning

Programs that use input data to build and employ predictive models for seagrass identification and classification.

2

Deep Learning

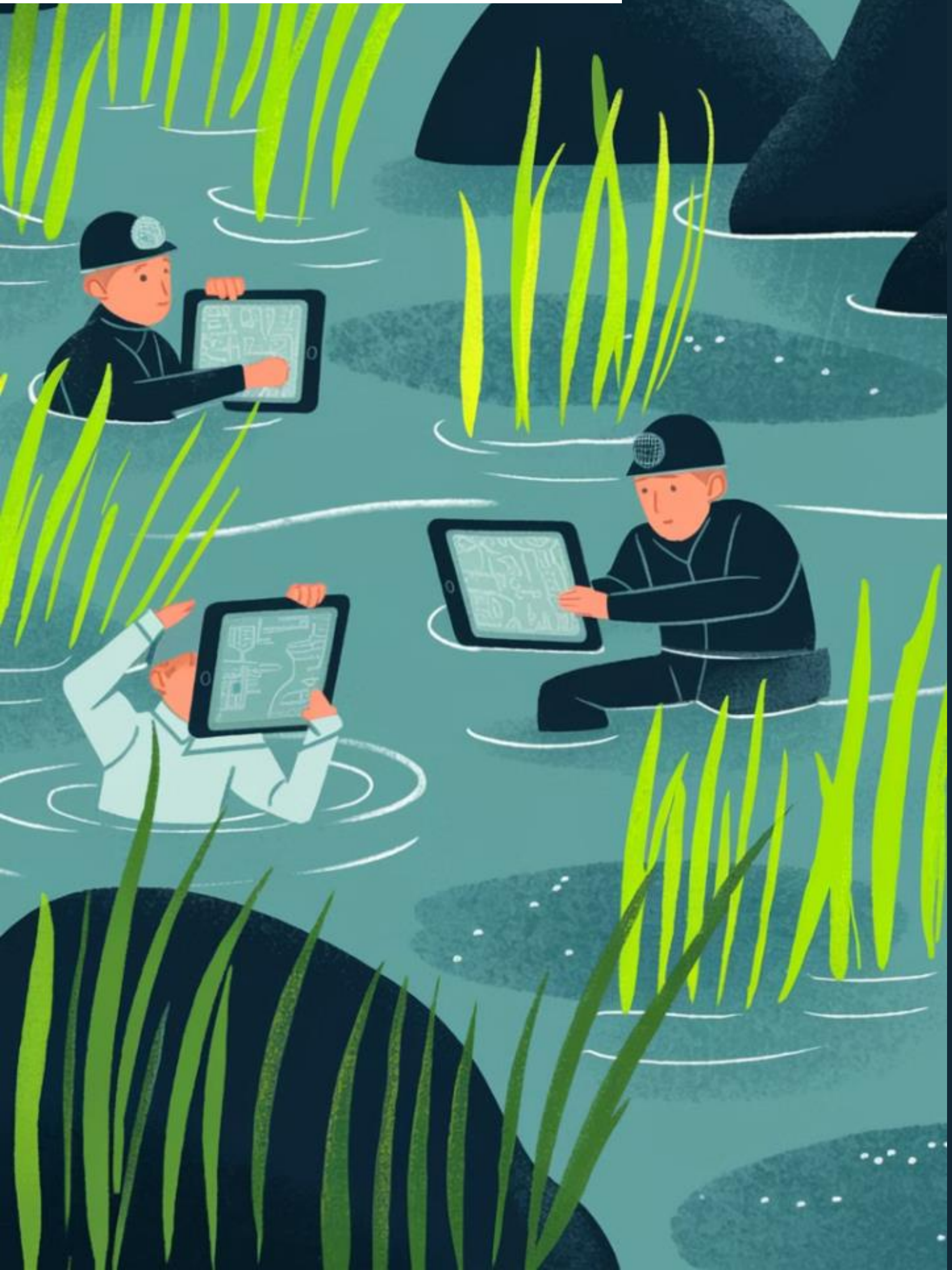
A broader member of the machine learning family based on artificial neural networks that mimic brain structure and function.

3

Automated Analysis

These algorithms lead to breakthrough innovations in data-driven seagrass monitoring, especially within cloud environments.

AI technologies could significantly advance seagrass monitoring through improved classification accuracy, increased automation of data processing and analysis, and development of automated change detection of seagrasses over time.



Reference Data Requirements

1 Training Data Collection

High-quality training data for the calibration of algorithms can be collected by field campaigns with GPS or via customized mobile applications.

2 Algorithm Development

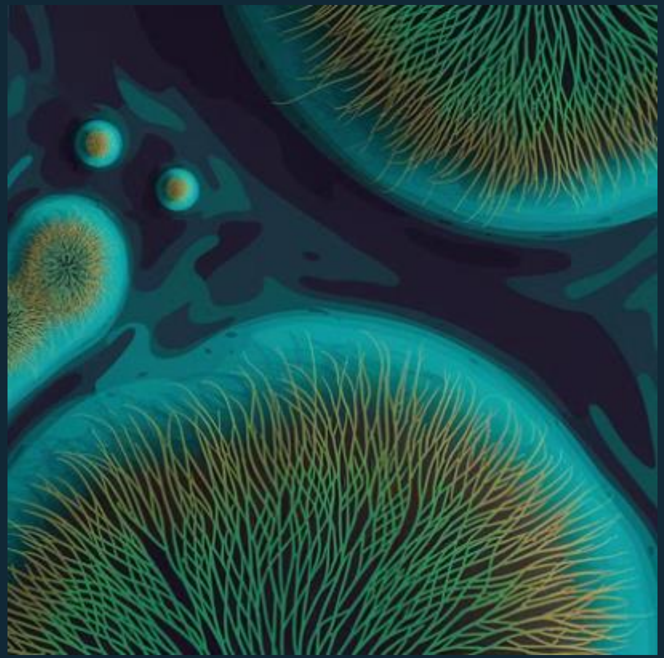
Machine learning methods require extensive training data to accurately identify seagrass in Earth observation imagery.

3 Validation

Data validation or ground-truthing evaluates the accuracy and quality of the classified image, ensuring reliable results.

Analysis of Earth observation data using machine learning methods requires high-quality training data for the calibration of algorithms. The validation data should be representative of the population, with all the classes sampled (same number of classes as used for classification and training data).

Sources of Validation Data



Validation data sets can be obtained from various sources such as existing maps and inventories, images from high-resolution satellites or drones, and in situ methods (diving, snorkelling or on foot in intertidal seagrass areas).

Satellite and drone-based, georeferenced and high-resolution images, when available, can be used as basemaps by experienced users who design training data sets in the form of spatial points or polygons.

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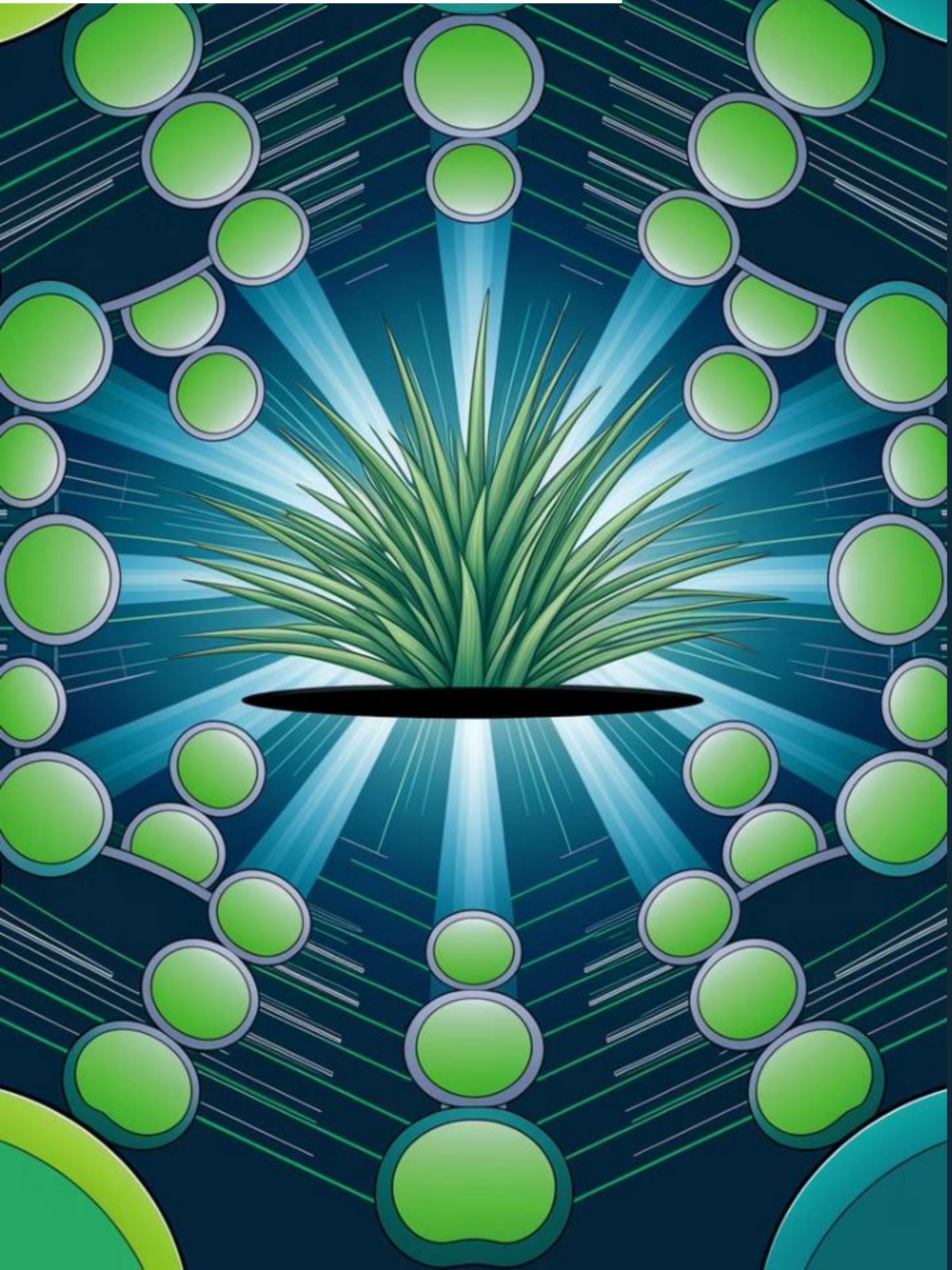

The Importance of Metadata

1 Documentation Standards

Global and regional standards exist, such as ISO 19115 and the INSPIRE Directive, to ensure consistent documentation of data.

2 Data Platforms

Platforms like the Dynamic Ecological Information Management System (DEIMS-SDR) help document available in situ data sets.

3 Biological Standards

Metadata standards commonly used for biological and ecological data include the Ecological Metadata Language (EML) and Darwin Core standards.

Rigorous metadata are an essential but often overlooked requirement for the future use of the collected data, following the 'collect once, use many times' principle. Metadata provide details on the source, location, time frame, version and methodologies used for each data record, enabling meaningful comparison between records.

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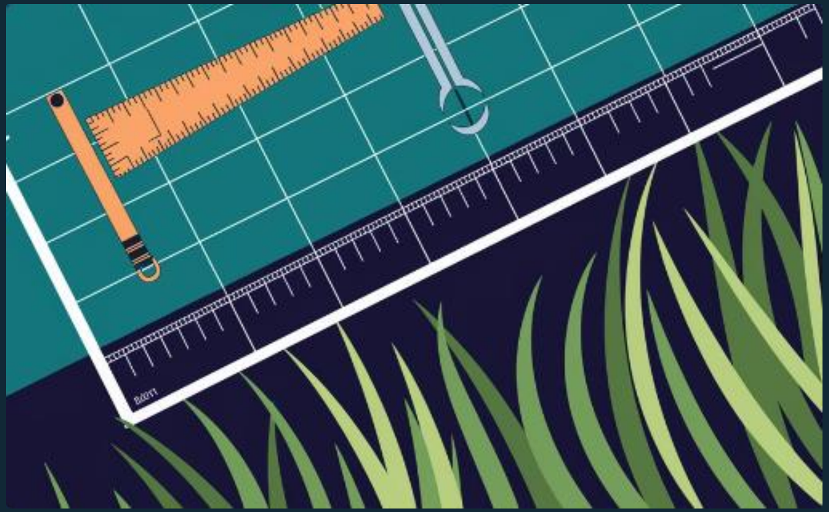
Seagrass-Watch Global Monitoring Program



Community Participation

A global participatory scientific monitoring and science-based education programme established in 1998, operating across 408 sites in 21 countries.

Standardized Methods

Seagrass condition is assessed from 33 quadrats (50 cm × 50 cm) within permanent and replicated monitoring sites (0.25–5.5 ha), established in representative meadows.

Quality Control

To ensure data accuracy, assessments are predominantly conducted by experienced scientists and environmental practitioners, in partnership with the wider community.

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Seagrass-Watch Measurement Parameters

1 Primary Measurements

Seagrass percentage cover and species composition, canopy height, epiphyte cover, macroalgae cover and sediment grain size.

2 Additional Parameters

Depending on local capacity: seagrass flowers/fruits, seed densities, meadow seascape (fragmentation), herbivory, leaf tissue nutrient concentrations, temperature and light.

3 Assessment Frequency

The frequency depends on local capacity and can be quarterly (every three months), biannual, annual or ad hoc.

4 Reporting

Status reports on seagrass condition are provided on the programme website, with results used at local and regional levels to support conservation objectives.

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SeagrassNet Global Monitoring Network

Global Reach

Established in 2001, SeagrassNet investigates and documents the status of seagrass meadows by monitoring 126 sites in 33 countries.

Standardized Protocol

Each monitored area has three permanent 50-metre transects with 12 replicate sampled positions, with sampling predominantly conducted by local government and environmental practitioners.

Comprehensive Parameters

Biological parameters include species, cover, canopy height, biomass and flowers/fruits, and meadow expansion/retraction, measured along with temperature, light, salinity and sediment characteristics.

Coordinating Global Seagrass Monitoring Efforts

GOOS Coordination

The Global Ocean Observing System (GOOS) works to coordinate global seagrass monitoring efforts within the context of essential ocean variables (EOVs).

MBON Integration

The Marine Biodiversity Observation Network (MBON) helps integrate seagrass monitoring with other marine biodiversity observations.

National Standards

The SeagrassNet protocol (adapted) has been taken as the national standard in Brazil, demonstrating its effectiveness and adaptability.

SeagrassNet results reveal seagrass change over timescales relevant to management, while also informing scientifically supported statements about the status of seagrass habitat and the magnitude of the need for management action.

The goal of the biological essential ocean variables (EOV) approach, including the seagrass EOV, is to develop communities of practitioners around the globe to measure key biological variables in a globally coordinated and inter-comparable way.

Best Practices in Seagrass Monitoring

Methodology Standards

Developing standardized monitoring approaches that can be applied consistently across different regions and ecosystems.

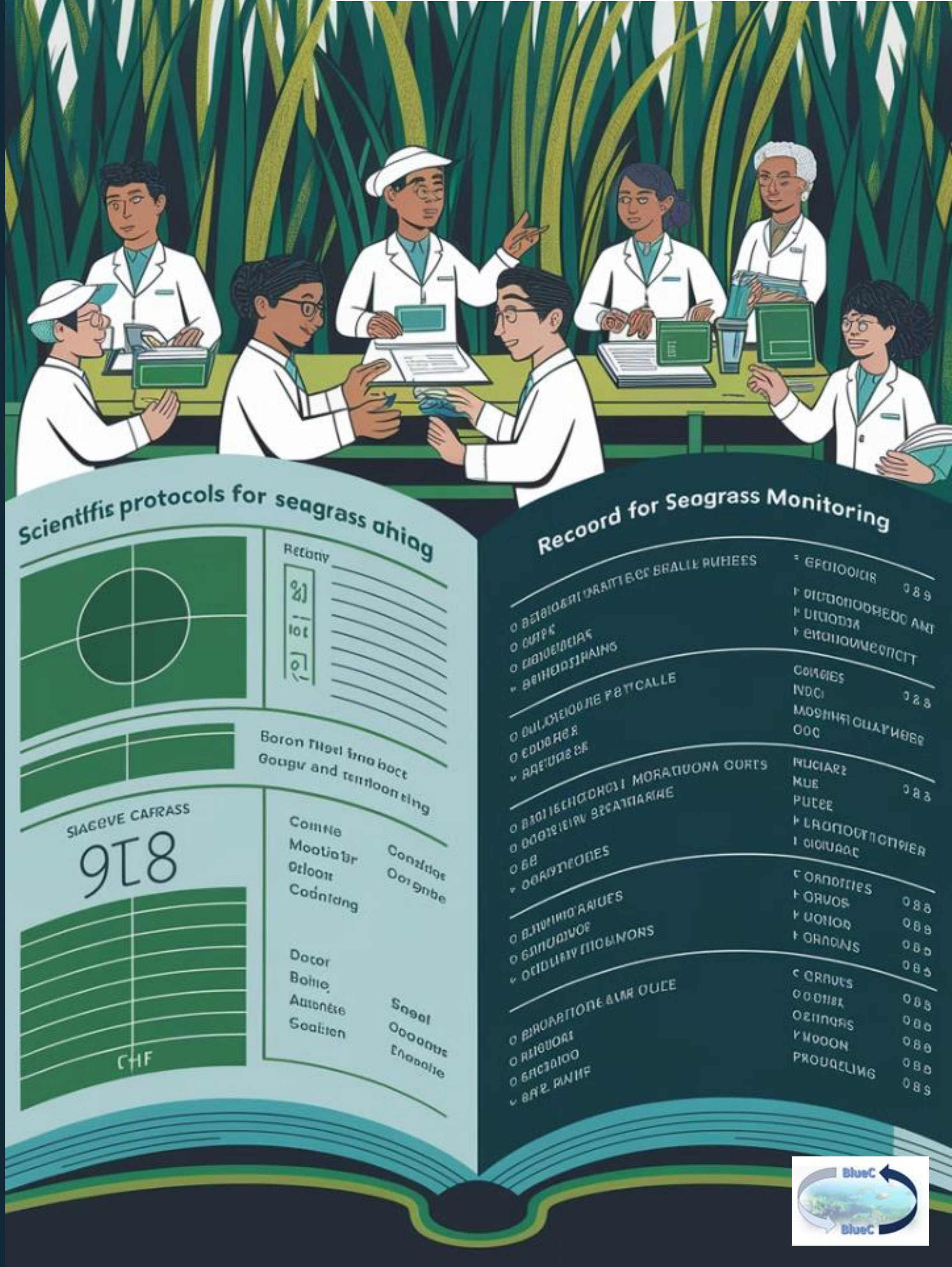
Metadata Protocols

Establishing clear guidelines for documenting data collection methods, timing, and conditions to ensure comparability.

Data Management

Creating systems for storing, sharing, and analyzing seagrass monitoring data across different platforms and organizations.

In addition to developing partnerships and a community of practitioners, this community is working to develop best practices for monitoring, metadata, and data management. For example, the Ocean Best Practices repository (**www.oceanbestpractices.net**) has been developed to collate and archive the best practices in ocean research, observation, and data and information management.



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Existing Seagrass Monitoring Programs

Numerous established monitoring programs exist worldwide, including Posidonia oceanica Monitoring Networks in the Balearic Islands, Cataluña, and Comunidad Valenciana (Spain), GIS-Posidonie in France, the Danish National Monitoring and Assessment programme, the Estonian Environmental Monitoring Programme, and the Cooperative Monitoring in the Baltic Marine Environment (COMBINE).

Global networks like Seagrass Watch and SeagrassNet provide coordination and standardization across these regional efforts, helping to create a more comprehensive global understanding of seagrass ecosystems.

Open Seagrass Distribution Data

1 **Global Distribution Dataset**

Efforts to collate seagrass distribution data have led to the development of the Global Distribution of Seagrasses data set.

2 **Regional Inventories**

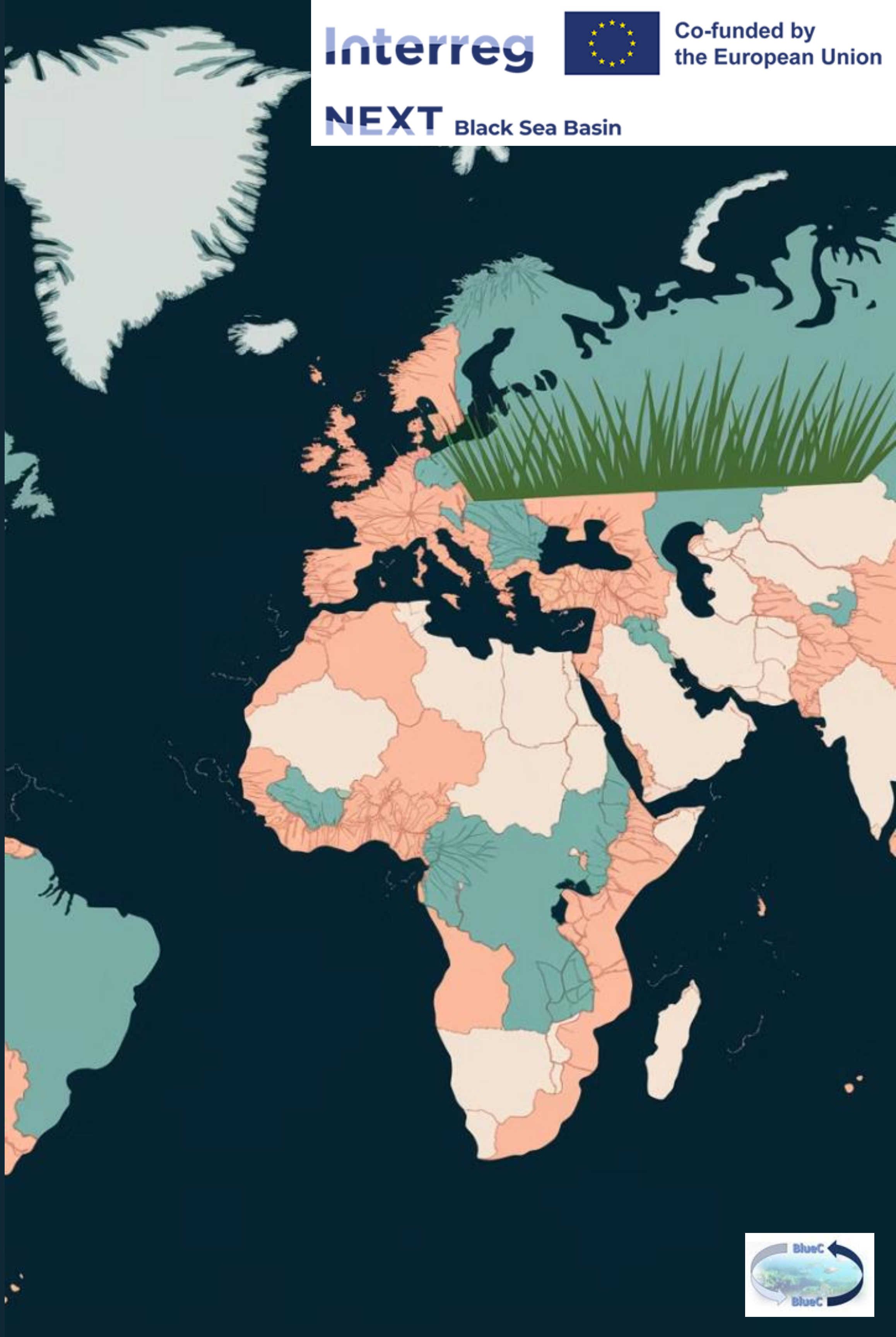
Regional or national inventories held by intergovernmental, governmental and non-governmental organizations provide detailed local data.

3 **EMODnet**

The European Marine Observation and Data Network's broad-scale map of seabed habitats includes recently launched seagrass, macroalgae and live coral EOV data sets.

4 **GBIF and OBIS**

Individual point records are available through the Global Biodiversity Information Facility and Ocean Biogeographic Information System.



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Challenges and Future Directions

1. **Knowledge Gaps**

   While efforts are continuing to strengthen understanding of seagrass locations, there are still significant gaps in knowledge, particularly in remote or understudied regions.

2. **Time Series Scarcity**

   Comprehensive, large-scale time series on the state of seagrasses remain scarce, limiting our understanding of long-term trends.

3. **Technology Limitations**

   Emerging technologies face challenges in capturing the variety of seagrasses that exist globally and can be expensive to use on a regular basis.

4. **Standardization Efforts**

   IOC-UNESCO GOOS is developing essential ocean variables for seagrass to help standardize data collection worldwide.

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The Future of Seagrass Monitoring

Integrated Approaches

Combining multiple techniques

Advanced Technologies

AI and cloud computing

Open Data Sharing

Accessible repositories

Global Coordination

Standardized protocols

The future of seagrass monitoring lies in the integration of multiple approaches, from satellite remote sensing to in-situ measurements, all supported by advanced technologies like artificial intelligence and cloud computing.

Global coordination through standardized protocols and open data sharing will be essential to build a comprehensive understanding of seagrass ecosystems worldwide, supporting conservation efforts and policy decisions in the face of climate change and other anthropogenic pressures.