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GROOM II

GLIDERS FOR RESEARCH, OCEAN OBSERVATION & MANAGEMENT : INFRASTRUCTURE AND INNOVATION

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D.5.1

Glider Services for Public and Private Needs

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Executive Summary

This report provides a **description of specific data services** based on marine autonomous systems that meet the needs of public and private entities. These services are relevant to GROOM RI because they **require and will benefit from coordination** of European marine research infrastructure dealing with autonomous observing. An international network of ocean science and engineering experts and physical and digital MAS infrastructure is the most effective way to build these services, and **specific value propositions about the use of MAS and GROOM RI** have been provided. It is not practical, desirable, or cost-effective to collect marine data for these applications as a single entity or isolated consortium. Several "flavors" of services are identified, described, and prioritized in this report. They have been chosen because they are **important for society** in general (ocean and human health, economic growth), and they **require cooperation and coordination** across sectors of stakeholders (government, industry, academic, non-profit) and across disciplines (ocean sciences, marine technology, policy/management). The catalogue of services includes the following for each data service:

- Summary of External Services & Products
- Specific Benefits to Society
- Value Proposition
- SWOT Analysis
- Specific Recommendations for Modality and Implementations
- Prioritization based on the expertise of the GROOM II Working Groups, Industry Advisory Group for Marine Autonomous Systems (IAG-MAS), and ocean glider community.

Not explicitly identified in the catalog are **two types of marine data collection** that are already frequently carried out using the autonomous approach: **ocean observing** (described in D4.2 and D4.3) and **ocean research**. For the contribution to research, the technology and methods at the foundation of GROOM RI originated in scientific research groups for the academic pursuit of knowledge and will continue to enable scientific excellence by **improving data quality and efficiency of operation**. This idea was extensively examined during the predecessor project, GROOM FP7, and acknowledged during GROOM II, hence it is not developed further in this deliverable.

A section describing lower-level services among partners in the RI is also included, in order to make it more clear how and why the **higher-level services should be performed in a distributed way** in practice. In essence, these are "internal services" that one member may provide another to provide a result that is higher quality and more resource-effective (with respect to cost and/or time).

This deliverable also provides **recommendations for implementing these services**, according to the priorities foreseen in the market analysis of *D5.3 Ensuring Continued Evolution of Glider Services*. It is necessary to **build partnerships** between SMEs, the marine technology industry, academics, and NGOs as well as other public and private entities for GROOM RI to succeed. The services which GROOM RI enables will be the center of these partnerships.

As a first step, the **legal status of the GROOM RI** should be defined to provide a basis and access model(s) for exchanging the internal services described in this report. GROOM RI needs to be formally established, including the way it will manage membership and function internally. Once established, GROOM RI should **establish a suite of external services** one by one, based on the catalog in this report, each in cooperation with the relevant GROOM RI members and other external providers. Next, GROOM RI should **form a product portfolio** and present it to external parties for uptake and implementation. A cycle of evaluation and updating/improving should be implemented.

Connected Deliverables
Deliverable 2.1 Access Policy
Deliverable 2.3 Enhancing Skill and Building Capacities
Deliverable 3.1 Governance and Legal Aspects
Deliverable 3.2 Financial Sustainability at Regional, National, EU Levels
Deliverable 3.3 Financial Sustainability with Industry
Deliverable 4.2 Whitepaper on the GROOM RI position in EOOS
Deliverable 4.3 - Whitepaper the GROOM RI contribution to statutory monitoring frameworks and maritime/naval information
Deliverable 6.1 – GROOM RI Technical framework Roadmap
Deliverable 6.2 – Data Management Roadmap
Deliverable 6.4 – Interfaces and Methodologies for Mission Planning and Execution
Other documents
Task 5.1 Document - Key societal benefits of a sustained glider infrastructure
Task 6.1 Document - GROOM RI Use Cases
Task 6.1 Document - GROOM Services - FP7 vs H2020

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List of Abbreviations

AI	Artificial Intelligence
ASVs	Autonomous Surface Vehicles
AUV	Autonomous Underwater Vehicle
BCP	Biological Carbon Pumps
BGC	BioGeoChemical
BOON	Boundary Ocean Observing Network
CCP	Carbonate Counter Pump
CFP	Common Fisheries Policy
EC	European Commission
EEZ	Exclusive Economic Zone
EMB	European Marine Board
EMSO	European Multidisciplinary Seafloor and Water Column Observatory
ENVRI	Environmental Research Infrastructures
EOOS	European Ocean Observing System
ERA	European Research Area
ERCC	Emergency Response Coordination Centre
ERIC	European Research Infrastructure Consortium
EU	European Union
Euro-Argo	European Contribution to the Argo Programme
GCOS	Global Climate Observing System
GES	Good Environmental Status
Glider Task Team	GTT
GOOS	Global Ocean Observing System
HAB	Harmful Algal Blooms
IAG-MAS	Industry Advisory Group for Marine Autonomous Systems

JERICO	Joint European Research Infrastructure of Coastal Observatories
MAS	Marine Autonomous Systems
MRE	Marine Renewable Energy
MRI	Marine Research Infrastructure
MSFD	Eu Marine Strategy Framework Directive
MSFD	Marine Strategy Framework Directive
NRT QC	Near Real Time Quality Control
OCG	Observation Coordination Group
OTEC	Ocean Thermal Energy Conversion
PI	Principal Investigator
RI	Research Infrastructure
SWOT	Strength, Weakness, Opportunity, Threat
UVP6-LP	Underwater Vision Profiler 6 – Low Power
WP	Work Package

Table 1 – List of abbreviations

List of Definitions

Blue Growth	Increased or new economic activity related to marine and/or maritime products or services.
Core Services /Processes	Tasks & activities that GROOM RI partners perform for each other within the organization.
External Parties	Government agencies, research institutes, scientific and commercial entities that would possibly require or benefit from GROOM RI services - also referred to as third parties.
External Services	Work products GROOM RI partners provide for third parties. Some of these products may include analyses, datasets, live-stream data, and/or reports. These external services are the end result of cooperation between GROOM RI partners exchanging core services (and possibly supported by third party suppliers).
Services	General term for any work performed for various parties - internal or external to GROOM RI.

Table 2 – List of definitions

1. BACKGROUND OF GROOM RI and WP5 GOALS & OBJECTIVES

GROOM-II WP5 (*Services for Public policies, Market & Innovation*) has a broad goal to further define how a future, pan-European infrastructure of marine autonomous systems (especially gliding vehicles) could more generally and sustainably address stakeholders' needs across Europe far into the future.

Specific objectives include:

1. Evaluating key areas in which the RI can (uniquely) respond to and support societal needs.
2. Designing partnerships between SMEs providing services and developing innovative solutions, large industries that may commercialize or use those solutions, and public bodies that may support, regulate, or even require/benefit from the newly-developed services.
3. Identifying possible emerging markets and ways to use the RI to support Blue Growth and innovation in Europe.

The goal of this document, *D5.1 Glider Services for Public and Private Needs*, is to identify, characterize, and define MAS-related services that functionally define the RI. In other words, it should provide a description of specific new and existing marine autonomous system data services that meet the needs of public and private entities in key sectors and emerging markets. This deliverable will examine potential win-win partnerships that do just that.

This deliverable is situated on the current scientific, technical, and policy landscapes as understood through the methods described below, mainly carried out through two tasks of WP5: *T5.1: Key societal benefits of a sustained glider infrastructure* and *T5.2: Environmental services for industries (water quality management, offshore energy, mining, maritime transport)*. Together with this deliverable and the other two tasks of WP5, they also informed those working on *D5.2: Ensuring Continued Evolution of Glider Services*, which includes a market study. The present document is important to feed many other deliverables such as those for access modalities and planning (WP2), legal frameworks and financial sustainability (WP3), and technical implementation (WP6).

1.1 Catalogue of Services/Products

Section 3 of this Deliverable outlines these five key sectors of focus:

- Fishery Management and Scientific Support
- Marine Renewable Energies
- Climate Observations
- Statutory Ecosystem Monitoring/Assessment Ecosystem Stressors
- Operational Monitoring for Good Environmental Status (GES) and Emergencies in the Ocean

In general, work performed for various parties – both internal and external to GROOM RI – are services. Tasks and activities that GROOM RI partners perform for each other within the organization are designated as "Core Services" or "Core Processes." While work products GROOM RI provides for third parties are considered "External Services" or "External Products." We also refer to government agencies, research institutes, scientific and commercial entities that would possibly require or benefit from work products GROOM RI partners provide as third parties. Some of these External Services/Products may include analyses, datasets, live-stream data, and/or reports. These external services are the result of cooperation between GROOM RI partners exchanging core services (and possibly supported by third party suppliers).

Each catalogue entry of the Marine Autonomous Systems (MAS) Services and Products section includes a summary of the tailored external services and products, specific benefits to society, a value proposition, SWOT analysis, and specific recommendations for modality and implementation.

1.2 Recommendations for the Implementation of Services

Before describing specific external services that may be offered, it is worthwhile to briefly discuss a general vision for how they would be implemented, including access modes and models. A short listing of internal services here helps illustrate the types of activity being performed and makes it easier to understand what is behind the external services before going into detail in Section 3.

As a physically distributed yet administratively centralized Research Infrastructure (RI), GROOM RI will facilitate access between member-partners with their hardware, software, and expertise and users with their requirements. A user of GROOM RI may be a person or organization requesting access to GROOM RI's services. Since the number and type of GROOM RI member-partners may change, the access policy will be adapted to incorporate the changes to the structure and legal status model of the RI as a result.

As a facilitator between potential users and MAS services and related facilities, GROOM RI will need to help form contractual relationships among the involved parties. The final contractual relationship may be between the MAS user and the individual member facilities, or GROOM RI could contract with the user and generate sub-contracts directly with the individual facilities using pre-arranged agreements to meet the particular user's needs. In either case the technical support will be provided by the various RI nodes based on the individual nodes' capabilities, availability, and resources. Deliverable D2.1: Access Policy outlines the access models and rules for the physically distributed research infrastructure that defines how users from academia, business, industry, and public services are regulated, granted access, and supported throughout the project.

In general, services are work performed for various parties – both internal and external to GROOM RI. Core Services are the tasks and activities that GROOM RI partners perform for each other within the research infrastructure. The 14 Core Services / Processes are summarized below within Section 4 – they include (in alphabetical order):

- Best Practices Development and Sharing
- Capacity Building
- Data Management, Sharing, & Harmonization
- Environmental Monitoring
- Hardware Calibration & Integration
- Legal Frameworks
- Operations & Maintenance
- Outreach
- Pan European Coordination
- Piloting & e-Infrastructure
- Procurement
- Software Repositories
- Support to Innovation
- Training

From top to bottom, all of these are necessary for GROOM RI to enable the various External Services and Products that will be outlined below within Section 3 of this deliverable. Internal contractual relationships will also be needed to manage those interactions. The individual members may have established an agreement with GROOM RI prior to project bidding, so GROOM RI could call on the facilities to deliver the contract with clear mechanisms and minimal bureaucracy and quicker response time.

Access to MAS services, vehicles, and facilities by the scientific community and other interested stakeholders, including industries, civil protection institutions, educational institutions, and others is vitally important. GROOM II will increase the accessibility to all stakeholders including the research community and industry for trials and testing of new/novel technology, procedures, and materials. GROOM II will develop an Access Policy including rules of access and application procedures setting-up a system to collate access requests as defined in the principles of open access established by the European Commission and in line with the European Charter for Access to Research Infrastructures. Moreover, efforts in aligning access with other RI's and projects such as EMSO ERIC, EuroFleet+, EUMR and JERICO S3 are foreseen.

2. METHODOLOGY AND RESULTS

To determine the most valuable services for the potential users of the GROOM RI, it was necessary to collect information about their current and future interest in MAS. The methods used to collect that "market" information are discussed below: Industry Advisory Group formation and workshops, industry-wide survey, internal working groups, and attendance of international workshops related to gliders. The services in the following section were chosen based on that feedback, as well as the expertise and experience of the authors.

2.1 Workshops of the Industry Advisory Group for Marine Autonomous Systems (IAG-MAS)

GROOM II partners invited key developers, manufacturers, researchers, and users of marine robots, miniaturized sensors, and platforms to the Industry Advisory Group for Marine Autonomous Systems (IAG-MAS). The IAG-MAS was a temporary group within the GROOM II Project that discussed key challenges related to the integration of the future Marine Research Infrastructure (MRI) with industry. Members of IAG-MAS and their organizations benefitted from participation as they provided valuable feedback to the European marine robotics community.

IAG-MAS Objectives

- Establish a strong relationship between industrial and national/EU scientific and technical stakeholders.
- Develop a cooperative framework between researchers & MAS service providers for GROOM RI access.
- Identify and advance priorities for innovation in developing new MAS and products and applications.
- Exchange views on the industry's needs and the available assets and expertise.

Expectations of IAG-MAS Members

- Involvement in designing the workshop agendas and highlighting key challenges to be addressed.
- Identification and mobilization of key national and (preferably) European actors for these workshops.
- Identification of frameworks for effective, sustainable operation in receptive industrial sectors.
- Provide advice on financial targets and potential legal structure.
- Active participation during workshops.
- Identification of European funding opportunities related to priorities above.

By coordinating commercial involvement, IAG-MAS members were at the forefront of the potential MRI defining:

- high-impact services for new and emerging markets in the Blue Economy,
- environmental services for industries that benefit from marine robotic monitoring, and

- key societal benefits of a sustainable marine research infrastructure.

List of IAG-MAS Member Organizations

IAG-MAS Members Associated with these Organisations
Hefring
SCOOT
MRV
Saildrone
Offshore Sensing AS
Neotek SAS
ECA Robotics
Liquid Robotics-Boeing
Kongsberg Maritime
RBR
Sonardyne
4H-Jena
SBE
Hydromea
RS Aqua ltd
Akvaplan-Niva
VOTO-Ocean Knowledge pillar
NOC Innovations Ltd: Marine Robotics Innovation Centre
ProOceano (Brazil)-CLS (Toulouse contact)
MMT - Ocean Infinity

Table 3 – List of IAG-MAS Members Organizations

Partners conducted three online workshops between February and October 2022. Prior to each workshop, GROOM II organizers prompted participants to prepare to discuss a particular challenge within the marine autonomous technology space. The IAG-MAS members gathered for these three online workshops where they discussed three main topics of interest to identify priorities to ensure future collaborations between the RI and IAG-MAS members. The highlights of each of the workshops are included within the Appendix. There was a limited number of key stakeholders to ensure a focused discussion regarding the future GROOM RI.

2.2 Internal Working Group: Task 5.1 Team

As members of the GROOM II Project, we organized a working group to explore and subsequently provide an analysis of the societal benefits of a sustained Glider Research Infrastructure. A working group authored a report titled, "GROOM II - Key societal benefits of a sustained glider infrastructure" (https://www.groom-ri.eu/wp-content/uploads/2023/10/key-societal-benefits-of-a-sustained-glider-infrastructure-.pdf), and it is summarized below. They focused on three main types of benefits of the GROOM RI:

1) Reducing the number and/or impacts of environmental emergencies (e.g., preventing, predicting, mitigating harmful algal blooms, geohazards, extreme meteorological events) and operational monitoring in general (addressed in section 3.6).

2) Improving the quality, reliability, interoperability, availability, and findability of marine data products and services; Forming dedicated services for climate studies and model assimilation. (addressed in section 4.3)

3) Helping public authorities to establish policies and EU Marine directives with relevant observational data. (addressed in section 3.5)

As a sustained long-term Research Infrastructure (RI), GROOM RI is designed to provide ocean observations, knowledge, and innovative solutions to science and society through the use of Autonomous Underwater Vehicles (AUV). GROOM RI will contribute to European Research Area (ERA), and in general, the knowledge and technological solutions facilitated by GROOM RI will have a global impact.

By evaluating the needs of AUV users, GROOM RI will tailor its output to the services requested by stakeholder groups as well as coordinate processes with them to provide greater benefits. Since scientists will be the major users and service providers, society will not directly use or access GROOM RI. Consequently, societal benefits are mostly indirect. Therein lies the difficulty of identifying, describing, and estimating any anticipated indirect benefits and impacts of GROOM RI on society. As opposed to national or PI only operations, GROOM RI, as a European RI, opens up ocean observation data and infrastructure to a wider global community for them to access and improve their data products.

To be a valuable European RI, GROOM RI will provide trusted and interoperable ocean observational data that follows the Findability, Accessibility, Interoperability and Reusability (FAIR) Data Principles. As such, GROOM RI's operations will assist scientists European-wide in their research. Since GROOM RI will provide innovative services, products, and universally available data, a monetary value for the entire spectrum of economic and societal benefits is immeasurable and not calculable through a financial cost-benefit analysis that provide "metrics" such as revenue earned or costs saved as a result of a decision to pursue a project. Since GROOM RI is only in its design study phase, the full and precise data sets and services to be provided by the GROOM RI (outputs) have yet to be completely investigated, which impedes an accurate calculation of the benefits.

Both the estimated capital expenditures (CAPEX) and operation expenditures (OPEX) of a glider RI network have been categorized in a previous project. This report, in particular, categorizes the potential benefits of ocean observation activities that help improve ocean and atmosphere predictability from:

- multiannual to multidecadal prediction,
- seasonal to interannual predictions,
- monthly to seasonal predictions, &
- daily to weekly forecasts.

This report also addresses the numerous benefits of better ocean science for the private sector. They include cost savings, operational efficiency, increased market shares, predictable and stable supply chains, enhanced relationships with stakeholders, improved access to markets and customers, as well as attracting new investments.

The bulk of this report addresses the six types of societal benefits following a conceptual framework of research infrastructures:

1) Technological externalities

GROOM RI's mission is to provide access to platforms and services to the broadest range of scientific users, as well as ocean observing RIs. It will maintain a unique centralized provision of cyber-infrastructure, data, and knowledge for the optimized use of MAS to study climate and marine environments, and to support operational services, and the Blue Economy.

2) Human capital formation

GROOM RI will provide means to train the next generation of European scientists and career-minded individuals looking to upskill.

3) Demand and value of knowledge output

GROOM RI will enable standardized high-quality long term ocean data and bring together different ocean datasets from different countries and distinct types of platforms. The data produced by GROOM RI will support decision-making for ocean management and climate actions, in addition to stimulating scientific studies, modelling, and forecasting.

4) Outreach and cultural impact of the RI

Members of a future GROOM RI will increasingly continue communicating science-based knowledge to the public and through the increased means of a European-wide RI -- including providing material for educational programs.

5) Services provided by the RI to third parties and consumers

Since GROOM RI aims to provide high-quality ocean observation data to the broadest range of scientific and industrial users, GROOM RI will also offer the public sector, private sector, and NGOs data for their specific applications.

6) Non-use value of Discovery: a pure public good.

In addition to "use-benefits" of GROOM RI, the future RI will also provide "non-use benefits" – the possible effects of any discovery. The pure value of knowledge as a result of these discoveries are a public goods.

Compared to many other investments in European research infrastructures, the return on investments of GROOM RI is very likely to be positive and rapidly achieved considering the large and long lasting potential societal impacts and the relatively low level of investment required to develop the already existing national glider infrastructure into a European Research Infrastructure Consortium.

2.3 Internal Working Group: Task 5.4 Team

A survey was conducted targeting members of IAG-MAS, including industry leaders from manufacturers of marine autonomous platforms and instrumentation to data software developers to providers of marine services. This survey was titled 'Expectations from industrials regarding the future GROOM RI', and its objective was to define the priorities of GROOM RI. In particular, it collected data regarding the types of services the future research infrastructure should deliver, markets it could target, and its potential legal structure. The survey questions were designed to ensure the data collected guides GROOM II partners to design and develop the future RI so it aligns with the needs of the marine technology sector.

The questionnaire was disseminated from the 3rd of October to the 10th of November 2022 to more than 60 companies including 18 companies from 6 European countries (Cyprus, France, Germany, Norway, United Kingdom, and Spain) and 2 non-European countries (Canada and the USA) answered the survey.

The results of the survey demonstrated a significant interest from industry leaders to join or work with the future GROOM RI. The survey defined certain conditions to ensure a sustainable involvement of the marine technology industry and confirmed findings and discussions from the three IAG MAS workshops.

Regarding target markets, focusing the future GROOM RI on ocean observation services is aligned with industry. In addition, other traditional markets such as defense and maritime surveillance as well as emerging markets such as offshore renewable energy and deep-sea mineral extraction are also important areas to target. These markets are supported by innovative technologies developed and/or commercialized by these companies. In the future, these markets may be at the heart of GROOM RI – from advanced autonomous navigation and planning of missions using AI to passive and active real time acoustic sensor monitoring to data acquisition and treatment.

For more information about the survey process and results, please consult Deliverable *D5.2 Ensuring Continued Evolution with Industry.*

2.4 Internal Working Group: Use Case Task Force

The use cases were developed by an interdisciplinary team of GROOM project partners, using the ocean observing value chain proposed in Pearlman et al. (2019) and in alignment with European blue economy priorities. This exercise helped us to identify and imagine realistic situations on how the GROOM RI could be used in practice. The Use cases document clusters the services that could be offered by a future GROOM RI, into six use cases. For each use case, potential users, methodologies, and outcomes are outlined and then explained through an example. A summary of the use cases is provided in the table below.

Table 4: GROOM RI Use Case

	Name/ Users	Description/Background	Services
1	Contribution to Discovery Science Users: Scientists/Researchers	GROOM RI will act as a central access point to European MAS facilities for discovery science collecting data on a broad range of temporal and spatial scales, as well as measurement types and frequency.	FAIR Data, MAS training, identification of collaborators and synergies.
2	Contribution to the GOOS, GCOS, EOOS and another international initiative (UN Decade) Users: regional or international initiatives	GROOM will help to design and implement a fit for purpose system to provide sustainable net zero MAS observations to regional and international projects and networks.	Pan European Coordination, capacity building, outreach, legal frameworks, software repositories, piloting e-infrastructures.
3	Contribution to the regulatory Monitoring of marine systems Users: European national environmental/ marine monitoring agencies	European countries have the mandate to perform monitoring of biodiversity on the European seas. These mandatory activities are sometimes expensive and difficult to sustain.	Develop and maintain a catalogue of consistent services and capabilities provided at national level allowing European users and stakeholders to identify providers that could perform the monitoring for them

4	Contribution to Operational Oceanography/Ocean Forecasting Users: National Met Offices and Mercator Ocean	GROOM RI will improve operational forecasts with data from MAS, enabling collaborative cross-country observations leading to enhanced ocean forecasts at the European level	Model validation, fill data gaps, digital piloting infrastructure that includes automation and AI tools, consistent transnational MAS use, FAIR data center
5	Contribution in response to emergency situations Users: Emergency Response Coordination Centers	Provide help to the local institution/agency in charge of the emergency response by monitoring the event conditions through a rapid and coordinated deployment of emergency support with MAS platforms.	Decision support tool, bespoke data products, high-level command platform, fast MAS response solution.
6	RI role as a technology Assessment Centre Users: Start-ups, Universities and research organizations, Research and development departments of sensor companies, MAS manufacturers.	Provide a continuous assessment of new platforms and sensor integrations to deliver world-class observational capability, bringing together users of MAS and stakeholders innovating in the technology space	Standardized Quality control and quality assessment procedures for new sensors and MAS, link research to engineers and manufacturers, support new MAS users, advice on instrumentation and sensor integration.

2.5 Workshop: 2022 U.S. Underwater Glider User Group (UG2)

The international buoyancy glider community met at the 2022 U.S. Underwater Glider User Group (UG2) workshop. The UG2 Workshop was held at the University of Washington in Seattle, WA from September 20-22, 2022. This workshop was part of a continued effort to unite the international glider community and build on the work done since the previous workshops in 2017 at the Mississippi Infinity Science Center and in 2019 at Rutgers University.

The 2022 U.S. UG2 Workshop brought together an established glider community with the overarching goal of facilitating the sharing and coordination of glider missions and mission output both in the U.S. and internationally within areas of ocean monitoring, operational reliability, and data management.

As outlined in the UG2 Workshop Seattle '22 Final Report (UG2, 2022), the objectives of the workshop were to:

1. **Harmonize Glider Efforts:** Data management, leveraging partnerships, documenting best practices, collaboration within U.S. and international community.
2. **Share New Developments:** Sensors, gliders, emerging requirements, novel glider applications.
3. **Explore Extreme Operating Environments:** Sea ice, currents, severe weather conditions.
4. **Share/Refine Operational Activities:** Sustained observing, reliability, sampling strategies, ocean modelling impacts (physical and biological), connecting coastal to open ocean biogeochemical observations; and
5. **Ocean Decade and OceanObs'19:** Strategy for the next decade of regional, national, and global ocean observing using glider technologies.

The UG2 Workshop consisted of working groups (WG) that focused on these six topics:

- Sustained Observing

- Biogeochemical (BGC) Sensors
- Biological Sensors – Acoustics
- Collaborative Science
- Modelling Impacts
- Data Management

In particular, the Sustained Observing WG discussed plans for sustained, glider-based observing along ocean boundaries. The group continued previous efforts made by the Ocean Gliders Boundary Ocean Observing Network (BOON). This group succinctly summarized the importance of the ocean boundaries within the UG2 Workshop Seattle '22 Final Report.

> Ocean boundaries are where society experiences most effects of ocean variability. Societally relevant topics include climate, weather, fisheries, pollutants, transportation, and recreation. As an ocean observing platform, underwater gliders are particularly well suited to providing observations in boundary regions, connecting the coastal waters to the deep ocean. Gliders can measure essential physical, biogeochemical, and biological parameters with high spatial resolution, which is necessary to resolve the sharp gradients that typify ocean boundary regions.

Underwater gliders are well suited to connect measurements from the coastal to open ocean. With a growing suite of biogeochemical (BGC) sensors integrated onto gliders, there is a growing opportunity to connect coastal to open ocean biogeochemical observations. The glider community is currently working to standardize methods to calibrate and quality control O2, nitrate, pH, Chlorophyll-a fluorescence, optical backscatter, and downwelling irradiance measurements – with the goal of interoperable datasets.

In addition to BGC sensors, an ad-hoc working group focused on acoustic biosensors formed during the workshop. Due to the high interest and increased use of passive and active acoustical sensors, this ad-hoc WG acknowledged the real opportunity to collect biological data on ecosystem structure and function using underwater gliders. These gliders are necessary to monitor ocean health. Acoustic backscatter from Acoustic Doppler Current Profilers (ADCPs), broadband, and/or narrowband scientific echosounders integrated onto gliders provide data stream(s) to develop ocean health as well as manage living marine resources.

While these working groups discussed the growing opportunities to utilize underwater gliders to collect critical measurements to monitor ocean health, they also acknowledged that there are several challenges that need to be met - from instrument calibration, target validation to data management and need for standardized data formats.

It was definitively determined that many societal needs can be met through gliders. In addition, scientists, engineers, students, and industry members at the 2022 U.S. UG2 Workshop developed plans to sustain glider observations, foster collaborations, coordinate best practices, and importantly, determine standards for biogeochemical (BGC) sensing and data processing, and aligning data management practices.

3. MARINE AUTONOMOUS SYSTEMS (MAS) SERVICES & PRODUCTS

GROOM II Project members identified five key sectors to focus marine autonomous systems (MAS) External Services over a time span from present day to 5 to 10 years into the future.

Based on the results of the three Industry Advisory Group for Marine Autonomous Systems Workshops, GROOM II Project's Internal Working Groups, and independent Workshops of the Glider Community, the five key sectors identified include:

- Fishery Management and Scientific Support
- Marine Renewable Energies
- Climate Observations
- Statutory Ecosystem Monitoring/Assessment Ecosystem Stressors
- Operational Monitoring for Good Environmental Status (GES) and Emergencies in the Ocean

The main result of this report is a catalog describing each of these sectors. The structure of each entry is described below, followed by the catalogue itself.

3.1 Structure of Catalogue Entry

3.1.1 Summary of External Services / Products

For these five key sectors, this section for each of the catalogue entries contain descriptions of the respective sector as well as specific new and existing marine autonomous system (MAS) data services and products. With the goal of identifying potential win-win partnerships, these external services and products will meet the needs of public and private entities in both key and emerging markets.

3.1.2 Specific Benefits to Society

This section of the catalogue entry contains specific benefits to society provided by GROOM RI's External Services and Products tailored to the respective key sector.

3.1.3 Value Proposition

An effective value proposition is a clear statement that communicates the unique benefits that a product and/or service provides to its customers. The value proposition solves their specific needs or problems and answers the fundamental questions of why customers should choose your product and/or service over others in the market.

Some things to consider:

- Customer-centric: It focuses on the customer's needs, desires, or problems that the product or service solves.
- Unique: It highlights the unique aspects of the product or service that sets it apart from its competitors.
- Clear and concise: It communicates the value proposition in a simple and easily understandable language with no room for ambiguity.
- Specific: It provides clear and measurable benefits that the customer will receive from using the product or service.
- Compelling: It evokes an emotional response and creates a sense of urgency that motivates the customer to act.

3.1.4 SWOT Analysis

A SWOT Analysis is a strategic planning tool. It helps organizations such as GROOM RI identify their strengths, weaknesses, opportunities, and threats. Here is a template with descriptions of what each quadrant may include for this planning tool.

Strengths This section should identify the internal factors that contribute to the success of an organization.	**Weaknesses** This section should identify the internal factors that hinder the success of an organization.
Opportunities This section should identify external factors that present opportunities for an organization to grow or improve.	**Threats** This section should identify the external factors that pose a threat to an organization's success.

The SWOT analysis should be reviewed and updated on a periodic basis as market conditions and the organization changes. For the purposes of this deliverable, we will identify the most pertinent strengths and weaknesses of the future GROOM RI as well as the current opportunities and threats that the network faces in the near future, with respect to each specific service.

3.1.5 Specific Recommendations for Modality and Implementation

This section includes technical requirements, some of which may not exist yet. Some technical services can be provided by the GROOM RI immediately or in the future after investments, and some can be expected from the community (glider manufacturers, sensor manufacturers, R & D teams in commercial and academic settings). Reports from WP6 describe the technical developments needed for implementation.

3.2 Service 1: Fishery Management & Scientific Support

3.2.1 Summary of External Services / Products

Fishery management is the process of regulating the harvesting of fish and other aquatic resources. This process ensures the sustainability and productivity of the seas and oceans over the long term since effective fishery management balances the need to preserve fish populations and their habitats with the needs of fishers and fishing communities.

Marine autonomous systems (MAS) contribute to effective fishery management by providing critical high-quality ocean observation datasets that inform scientifically valid reports and analyses to help fishermen, industry, and government agencies make informed decisions about the use of fisheries resources, including, but not limited to, setting quotas and catch limits, implementing gear restrictions, establishing protected areas, and managing fishing fleets.

As autonomous underwater vehicles (AUVs), ocean gliders are especially well suited for long term monitoring in demanding marine environments. They use variable-buoyancy propulsion and hydrofoils allowing the vehicle to glide forward while descending or ascending through the water. Traditional measurements of water quality are standard on underwater gliders: temperature, salinity, dissolved oxygen, fluorescence of chlorophyll and colored dissolved organic matter, and optical backscatter. Photosynthetically Available Radiation (PAR) is often measured as well. As *in situ* sensors for water quality and biomass characteristics improve (lower size and power requirements, increased processing and storage capacities), integration with gliders is more attractive and opens new perspectives for comprehensive observations in coastal and deep seas. Examples of current state of the art include BIOGLIDER: Autonomous Exploration and Monitoring of Marine Ecosystems Project and Zooglider (https://zooglider.ucsd.edu), which include both scientific echosounders and optical imaging payloads for characterizing size distribution and nature of small particles in the water (plankton, detritus, sediments, larvae, and crustaceans). Other sensors shedding light on ecosystem processes have been proven on gliders like pH, pCO2, and passive acoustics. Finally, cutting edge MAS sensors for addressing European monitoring needs are being developed in the TechOceans project (https://techoceans.eu). These include an improved optical imaging device for plankton, an improved cytometer, biogeochemical sensors for nutrients (Lab On Chip), microsamplers, genomics technologies, and phytoplankton primary productivity sensor.

In addition, for those organizations that own marine autonomous system assets such as gliders, GROOM RI provides a wide range of services to procure, operate, maintain, calibrate, integrate, deploy, pilot, and recover these innovative systems. GROOM RI partners also coordinate and support mission planning as well as data sharing and harmonization to ensure proper collaboration with other national data centers and EU data aggregators. From the management of software repositories to implementing established best practices, GROOM RI partners have the expertise to facilitate environmental monitoring. Partners have extensive experience coordinating and implementing baseline environmental surveys on water properties for clients around the globe.

The extensive network of GROOM RI partners have not only developed and demonstrated these services, but they are also on the forefront of developments in miniaturized sensor systems, edge processing, and artificial intelligence that ensure long-term fishery management. Many of the partners in the projects above are linked to GROOM II.

3.2.2 Specific Benefits to Society

Protecting the EU's seas and oceans will reverse biodiversity loss and increase fish stocks among other interrelated benefits including important contributions to climate mitigation and resilience. In fact, European countries have the mandate to monitor the biodiversity of European seas and oceans. European public policies and the EU Marine Strategy Framework Directive (MSFD), in particular, have been implemented to protect the marine ecosystem and biodiversity upon which our health and marine-related economic and social activities depend. The MSFD assesses the impact of all human activities and drives new research and legal initiatives related to Europe's four marine regions (5,720,00 km2).

Marine autonomous systems help EU countries achieve a good environmental status (GES) and meet a number of the directives set out within the 11 illustrative qualitative descriptors. From *Descriptor 1. Biodiversity is maintained* to *Descriptor 3. The population of commercial fish species is healthy* to *Descriptor 4. Elements of food webs ensure long-term abundance and reproduction*, these qualitative illustrations can be effectively and efficiently achieved through rigorous, quantitative evidence in the form of well-managed, valid, calibrated, and standardized datasets collected by marine autonomous systems.

In addition, to GES, the Common Fisheries Policy (CFP) is a set of rules for sustainably managing European fishing fleets and conserving fish stocks. This comprehensive legal framework features fish stock management at maximum sustainable yield, among other dimensions of fisheries. By balancing a healthy marine environment with the profitability of the fishery sector, the CFP critically supports the revitalization of coastal communities and improves the economics of fishery management with more innovation and technology.

Innovative marine autonomous systems as well as the products and services GROOM RI provides contribute to the long-term sustainability of the fisheries sector. Since the EU is actively seeking solutions to facilitate climate neutral fisheries and aquaculture by 2050, MAS by their very nature do not require energy intensive propulsion to collect high-resolution datasets in coastal waters and the open sea. GROOM RI partners have the capacity, experience, and expertise to provide critical datasets to ensure the fulfillment of national obligations to meet the EU MSFD and CFP and achieve GES.

3.2.3 Value Proposition

GROOM RI is committed to collecting and analyzing high-quality data through innovative marine autonomous systems. The international partnerships we have established ensure that as a group, we have a deep understanding of MAS platforms, sensing technologies, and a scientific approach to integrating and proving the validity of their use. This understanding enables us to provide the highest quality data to inform your decision-making and lead to sustainable fishery management.

By using advanced data collection techniques, we can gather accurate information about fish populations, their habitats, and the effects of fishing practices on the ecosystem. This allows regulators to make informed decisions about fishing quotas and other regulations that ensure the long-term sustainability of fish stocks. Our dedication to data-driven decision-making drives us to provide our customers with trusted, high-quality data to ensure they have their seafood products sourced from healthy and sustainable fisheries. These validated datasets also provide EU countries with the required observations and analysis to determine whether they have achieved a good environmental status (GES) and meet rules set out in the Common Fisheries Policy (CFP).

GROOM RI will be able to help protect the oceans and livelihoods of our fishing communities.

3.2.4 SWOT Analysis

As a strategic planning tool, this SWOT Analysis for the fisheries management market identifies GROOM RI's strengths and weaknesses as well as those opportunities and threats the RI faces in the near future.

Strengths	**Weaknesses**
• Marine Technology Experts & Marine Scientists • Talented MAS engineers & operators • Constant developments in innovative sensor integrations and artificial intelligence • Systems to deliver a wide range of services and products have been established and continue to grow • MAS approach to data collection has much lower carbon footprint than traditional technologies	• Limited availability of skilled labor to design, create & operate fishery-specific MAS • Novelty of the RI will involve growing pains • Low TRL of some sensing technologies will require scientific validation before widespread use
Opportunities	**Threats**
• Urgency to fulfill Marine Strategy Framework Directives (MSFD), including achieving good environmental status (GES) • Growing requirements to meet Common Fisheries Policy (CFP)	• Other Marine RIs in the space • Legal challenges or regulations related to permission to use or the validity of autonomous systems and AI. • Technological complexity of autonomous operations increases risk of unsuccessful mission

3.2.5 Specific Recommendations for Modality and Implementation

The most advanced MAS specifically designed for fisheries management is probably the Bioglider, which integrates an innovative marine ecology sensing system on underwater gliders. This solution is applicable to fish ecology and involves a vision profiler and a scientific echosounder integrated onto commercially available gliders (Seaglider and Slocum). It carries a Hydroptics UVP6-LP optical sensor and Kongsberg Maritime Simrad EK80 WBT Mini Echosounder and have demonstrated effectiveness during missions in the Norwegian Arctic. In May 2022, for example, the Bioglider (Seaglider version) participated in a scientific cruise to help characterize the Polar Front. This glider collected important data about the ice algae and phytoplankton population and density during the spring bloom. These species, in turn, provide a basis for food for a number of predatory zooplankton species and fish that migrate north, which in turn are food for whales, seals and seabirds. The EK80 is a high-precision scientific echosounder designed to quantify and monitor underwater ecosystems which is capable of operating several different transceiver and transducer combinations. The Underwater Vision Profiler, or UVP, is designed to study large (>100 µm) particles and zooplankton simultaneously and to quantify them in a known volume of water. These sensors have been adapted to return data in near real time to shore. GROOM RI partners are part of Bioglider, a collaboration between research and industry partners in Cyprus, France, Norway, and Poland. For this service to become part of GROOM RI, certain technological advances need to be made around data processing, interpretation, and quality control. Agreements will need to be made between sensor manufacturers, vehicle manufacturers or their representatives, operators and the scientific experts needed to properly qualify the results. Only then could a non-GROOM RI entity be provided with a reliable, valid service for fishery management. Other MAS with relevant payloads would need to go through a similar process.

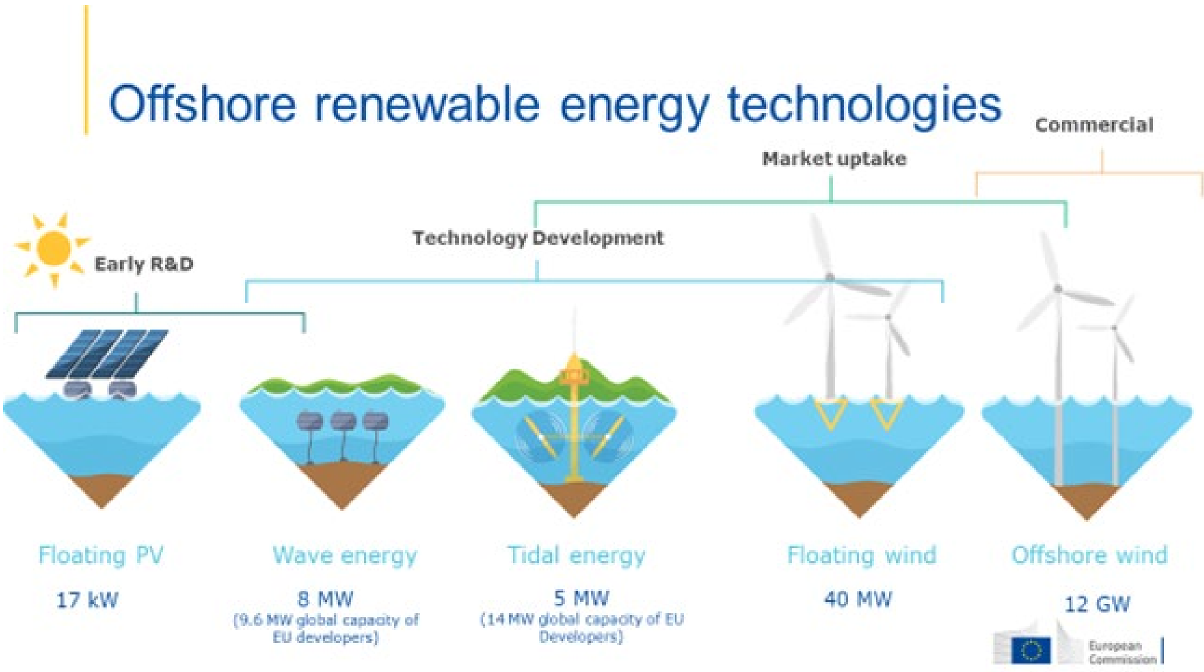
3.3 Service 2: Marine Renewable Energies

3.3.1 Summary of External Services / Products

The EU is a global leader in Marine Renewable Energy (MRE). MRE includes offshore wind energy (bottom-fixed and floating offshore wind notably) and ocean energy (wave and tidal energy). These technologies are at various stages of maturity: large commercial scale bottom-fixed offshore wind projects are already operating in Europe, whereas large commercial floating wind projects are being announced and installed (European Commission, 2020). Although the EU industry is also a global leader for wave and tidal energy technologies development, with 70% of the global ocean energy capacity developed by EU27 based companies, the sector struggles to create an EU market (European Commission, 2022). Other promising ocean technologies such as salinity gradient energy and ocean thermal energy conversion (OTEC) are still at the development stage (European Commission, 2020).

If we refer to the following value chain of marine renewable energy (wind, waves, and tides), it breaks down in seven main areas:

1. Project development and siting
2. Assembly and installation
4. Foundations
5. Design and manufacturing of converters
6. Grid connection
7. Operation and maintenance
8. Support and services



Offshore renewable energy technologies (European Commission, 2020)

Among these areas, the 1, 2, 6 and 7 can concern the use of MAS that GROOM RI could provide:

- In the project development phase, MAS can be used for environmental assessment and monitoring. For instance, MAS can collect data about the nature of the seabed and the characterization of biological species, as well as the current level of acoustic noise and presence of marine mammals. Autonomous Surface Vehicles (ASVs) are particularly well-suited for the high-precision bathymetric mapping required before installation, as well as met-ocean characterization of shallow shelf-seas.
- In the installation phase, MAS could help to monitor water quality and noise levels, and survey the process of anchoring, assist the establishment of dynamic electrical submarine cables and also their connection to the main electrical substation.
- During Operation, a continuous met-ocean, water quality and noise survey of the marine exploitation site will be necessary to guarantee the security and safety of the production. It will be efficient and cost effective to use MAS to do that, in particular ASVs. Mapping for seabed changes such as scour or new foreign objects could be carried out on a regular basis by ASVs as well.
- In terms of support and services: for each marine renewable energy commercial farm, a fleet of MAS could be mobilized when needed. Training people to use MAS will become a service to offer. The MAS could be also used for existing test facilities or in construction in Europe (i.e.: Open-C in France, ORE Catapult in the UK).

In summary, GROOM RI could set up a bundle of services for the MRE market in dedicating MAS systems to this market for the distinct phases of the value chain of this new industrial sector.

3.3.2 Specific Benefits to Society

In Europe, the Maritime Spatial Planning Directive (MSP) requires the 22 coastal Member States to develop a national maritime spatial plan at the latest by 31 March 2021, with a minimum review period of 10 years.

The main objectives are:

- When establishing and implementing maritime spatial planning, Member States shall consider economic, social, and environmental aspects to support sustainable development and growth in the maritime sector, applying an ecosystem-based approach, and to promote the coexistence of relevant activities and uses.
- Through their maritime spatial plans, Member States shall aim to contribute to the sustainable development of energy sectors at sea, of maritime transport, and of the fisheries and aquaculture sectors, and to the preservation, protection, and improvement of the environment, including resilience to climate change impacts.

The requirements of data use and sharing prescribe that Member States shall organize the use of the best available data and decide how to organize the sharing of information, necessary for the definition and implementation of maritime spatial plans.

The MRE, as mentioned above, are at the heart of many of these national maritime spatial plans.

We must keep in mind that MSP will apply in the frame of the European public policies and the EU Marine Strategy Framework Directive (MSFD), which were implemented to protect the marine ecosystem and biodiversity upon which our health and marine-related economic and social activities depend. The MSFD assesses the impact of all human activities and drives new research and legal initiatives related to Europe's four marine regions (5,720,00 km^2).

MAS systems and especially gliders will be essential to make the environmental assessment (biological analysis in the water column than on the seabed) before selecting the best area to implement MRE infrastructures. An analysis of the geological seafloor also has to be done for the safety of the future installation (anchoring).

The use of MAS during the installation on site could also answer to the descriptor 11: (introduction of energy, including underwater noise, does not adversely affect the ecosystem) of the MSFD. The capacity to move undersea quietly allows gliders to measure the level of noise and will help to monitor it over time.

3.3.3 Value Proposition

This service will rely on the availability of MAS systems with environmental sensors, sonar systems, video cameras and hydrophones. It will address several needs of the MRE sectors:

- Environmental assessment before installation of MRE offshore farms through the deployment of MAS on site and the collect and treatment of relevant data. This service will also be dedicated to the national public authorities in charge of the planification of MRE area than to the major energy players (Large companies) who will build and operate MRE farms
- Supervision and monitoring of the installation phase. Most operations will be underwater notably for anchoring and electrical connections. The customers will be the contractors within the Energy Industry
- Security and surveillance on site underwater and on; surface with AUV and ASV, on behalf of operators
- For inspection related to biofouling during the exploitation phase

Advantage of MAS

- Potential permanent presence at sea with use of smaller ships or a reduced fleet size.

- Capacity to be remotely controlled and operated and or/ even reprogrammed.
- Capacity to communicate and send data directly from the operation site.
- Capacity to pre-treat the data onboard, saving time also in operation.

The future RI could take advantage of this important market in making available MAS equipment when possible, helping to design and develop MAS adapted to the above needs, certifying new MAS and sensors, and offering specific training courses.

3.3.4 SWOT Analysis

Strengths	**Weaknesses**
● Marine scientists with relevant expertise (existing partners) ● Talented MAS engineers & operators ● Capacity to gather and treat environmental data ● Expertise in innovative sensor integrations and artificial intelligence	● Capital costs to maintain enough operational MAS equipped with up-to-date sensors too high for most members ● Typical response time of RI may be too slow ● Potentially limited availability of skilled labor to design, create & operate MAS
Opportunities	**Threats**
● Member states need assistance to fulfill Marine Strategy Framework Directives (MSFD) and MSPD ● The market MRE on the European coasts is significant and growing ● Few options currently available for use of MAS compared to traditional solutions as diving and support/supply vessels	● Legal challenges or regulations related to permission to use or the validity of autonomous systems and AI. ● Rapid development of MAS by European and foreign industries for the MRE market ● Technological complexity of autonomous operations increases risk of unsuccessful mission

3.3.5 Specific Recommendations for Modality and Implementation

For this MRE service, we can take two parallel approaches with:

- Public authorities of European countries which have national development plans for MRE.
- Major energy players to present the objectives of GROOM RI and available capacities.

GROOM RI will seek to establish long term partnerships with them, if possible, to plan the availability of means and, in some cases, the development of specific sensors and MAS itself.

3.4 Service 3: Climate Observations

3.4.1 Summary of External Services / Products

Climate observations can be considered as either direct or indirect in scope: monitoring and understanding long-term changes or contributing to studies of poorly understood processes integral to the climate system, respectively. Direct monitoring programs are designed to characterize large spatial and temporal scales, while process studies typically examine smaller scale processes for improved conceptual understanding of the larger climate system, with the goal to improve modelling and forecasting (through improved parameterizations or approximations of the unresolved processes). The observing programs currently in place are driven by foundational or "discovery" science supported by international coordination and national or regional public funding. Commercial entities are minimally involved in funding or carrying out the programs. The programs consist of moorings/buoys, monitoring cruises, dedicated research cruises, and some glider missions. Very few long term/sustained glider stations are in place with the most extensive work along these lines reported by Rudnick et al. (2017). ASVs are involved in studying ocean-atmosphere interaction (meteorological, oceanic, and biogeochemical payloads) and have proven their value as contributors to the ocean observing system in general (Meinig et al., 2019). This program has been sustained for a few years by NOAA. This work also provides a possible model for how a cross-sector partnership can be set up. The authors "consider the potential for a coordinated international effort to establish a global network of USVs that ultimately could contribute to the Global Ocean Observing System (GOOS) and the Global Climate Observing System (GCOS)." At the same time, there is a call and well-described vision for more sustained observations from the community, in which autonomous fleets are mentioned as one important factor (Weller et al., 2019).

Through our investigations, we believe that MAS could play a much bigger role in sustaining both direct and indirect types of climate observations. As shown in the GOOS OceanGliders task team BOON (Boundary Ocean Observing Network), gliders are well-suited for climate observations because not only is it possible to repeat hydrographic lines at a fraction of the cost of a vessel over a long period, but they can also resolve high resolution processes. When sustained, this results in a long-term high resolution 3-D data set resolving seasonality and interannual processes needed to both detect long-term changes but also understand processes (Rudnick). In the boundary regions from shelf to deep sea, underwater gliders fill a gap not easily maintained by fixed or drifting platforms when it comes to hydrographic, hydrodynamic changes. For example, the mixed layer and the interface between air-sea are can be observed at the temporal resolution required using gliders (Thompson et al., 2016), which is important since they play an important role in the ocean heat and freshwater balance and the carbon cycle. Another example is the difficulty of traditional means to capture exceptional/short term events such as hurricanes and marine heatwaves with traditional means (Miles et al., 2021). The next section describes more fully MAS services related to this issue.

Other state-of-the-art approaches utilize greenhouse gas sensors on MAS to directly measure components of the carbon system in coastal shelf regions (Hauri et al., in prep). Gliders have been able to demonstrate the near-real-time measurements of dissolved pCO_2 and pCH_4 in high resolution coastal sections, which could be scaled up for improved understanding and parameterization of the processes that store/release inorganic carbon in the ocean. Coupled with hydrographic lines along ocean boundaries, greenhouse gas observations will provide a much richer picture of the interaction between the coastal and global ocean, where horizontal and vertical exchange of heat, fresh water and carbon are critical to understanding the global climate.

3.4.2 Specific Benefits to Society

By using MAS for climate observations, society benefits in a number of ways:

- More climate data (improved coverage in time and space, higher resolution) for less environmental and financial cost.
- A scalable, adaptable approach to collecting climate observations. There is the ability to target specific areas to maintain repeated observations (glider lines), which can form the basis for future expansion or improvement as sensor and platform technology improves or budgets change. As other platforms develop, MAS platforms can easily be re-deployed or re-programmed to better complement them, ensuring a more complete observing network.
- Better foundational science: the improved ability to understand and predict the global climate will result from the above. Improving predictions will improve our ability to mitigate and

adapt. One example is the role of Blue Carbon ecosystems[1], which is the concept of natural carbon storage and/or sequestration via coastal and open ocean processes (EMB, 2023). While not a "silver bullet" solution to mitigating or offsetting increased atmospheric greenhouse gas emissions, these processes have a significant net effect on the global carbon balance and are also sensitive to climate change themselves. How these natural processes can be protected, supported or enhanced will have an impact on how the climate evolves, yet our fundamental understanding of the magnitude of various components is severely lacking. If the effects of conservation and restoration efforts can be quantified using MAS, then these efforts can be monetized and encouraged in a responsible manner. Most of the recommendations in European Marine Board (2023) are relevant to MAS (either gliders or long-endurance ASVs):

- *Fund further research to reduce uncertainties about the amount of carbon removed and stored by Blue Carbon ecosystems.*
- *Fund the development of more tailored monitoring and continuous observations of carbon stocks, fluxes, and process rates across various time and space scales to improve our understanding of the global Ocean carbon budget, the biological carbon pumps (BCP, CCP) and sedimentary carbon storage. This requires an optimally designed network of observatories and sensors in a diverse range of environments to monitor the long-term carbon sequestration of Blue Carbon ecosystems, which will be needed for credible carbon accounting. This could be complemented by the extension of current monitoring programmes to include carbon parameters, providing added value to regular environmental monitoring surveys run by government agencies.*
- *Support sustained observations to better parameterize processes (e.g. remineralisation, fragmentation, sinking) in carbon cycle models. These models will provide a better understanding of the impact of possible future geoengineering or technological options to capture and store greenhouse gases, or to increase the uptake of atmospheric CO2 and remove it for long enough to provide climatic benefits.*
- *Fund research to understand the dynamics of offshore carbon stocks and sequestration, and the possible impact of human activities, such as trawl fishing and deep-sea mining.*

Specifically, MAS carrying payloads relevant to carbon parameters (pCO2, pH) in addition to the fundamental oceanographic parameters (temperature, salinity, dissolved oxygen, turbidity, fluorescence of chlorophyll and colored dissolved organic matter, currents) in and around the coastal shelf, shelf-break, and adjacent deep seas will be able to shed light on processes related to the BCP and the CCP and sedimentary carbon storage.

3.4.3 Value Proposition

As mentioned above, the use of MAS in and of itself has a clear value proposition for collecting more/better/different climate observations at lower cost when compared to the alternatives. Fixed point methods cannot resolve the spatial processes that need to be understood and parameterized for more accurate predictions of global climate. Vessel-based operations are very costly financially, and in terms of carbon emissions, so should be minimized to only provide the necessary baseline and physical samples needed to reference MAS observations. Vessels of opportunity carrying flow-through systems for carbon parameters and other oceanographic parameters play a very important role in the carbon observing system but are limited to surface observations along well-travelled routes, for the most part. Drifting platforms are not able to maintain the valuable repeated, coastal transects that compose the high resolution 3-D, long-term time series offered by gliders. The capacity of MAS for near-real-time

[1] According to EMB (2023), Blue Carbon ecosystems are coastal vegetated ecosystems with rooted vegetation (organic carbon) and marine coastal, continental shelf and offshore sediments (inorganic carbon).

data transmission, operator control, and very long endurance over remote, inhospitable regions adds value to the climate observing system. Enhancing payloads to include greenhouse gas parameters is already happening and adds further value.

At the same time, the GROOM RI has a value proposition as the evolution of a clearly established, connected, international network, which is needed to address climate observations: climatic changes have no borders. The GROOM RI will allow greater accessibility to infrastructure, data and knowledge provided by MAS. For example, GROOM RI will be able to provide specific services associated with the climate observations such as:

- Workshops on standard operating procedures and best practices
- Smooth integration with data management organizations
- Scientific expertise on data quality and interpretation methods
- Interface with OceanGliders (GOOS) and the international coordination of MAS observations for society's benefit in general, including climate.

3.4.4 SWOT Analysis

Strengths	**Weaknesses**
• Marine scientists with expertise in climate (existing partners) • Talented MAS engineers & operators • Constant developments in data management, including data QC. • Expertise in innovative sensor integrations • Infrastructure and logistics to run training workshops • MAS approach to data collection has much lower carbon footprint than traditional technologies • Ability to measure in adverse conditions • Lower financial cost than traditional *in situ* measurement methods	• Individual centers not currently coordinated (difficult to acquire permits to operate across boundaries like EEZ and national waters). • Novelty of the RI will involve growing pains • Lack of funding to coordinate and operate climate quality observations • Low TRL of some sensing technologies will require scientific validation before widespread use
Opportunities	**Threats**
• Demonstration of gliders towards a net zero monitoring capacity • Can address the needs of carbon accounting with respect to Blue Carbon ecosystems, and possible carbon capture and storage.	• Legal challenges or regulations related to permission to use (EEZ permits) or the validity of autonomous systems. • Technological complexity of autonomous operations increases risk of unsuccessful mission or coverage gaps, in particular when covering global regions requiring very high longevity or under-ice navigation.

3.4.5 Specific Recommendations for Modality and Implementation

One of the main objectives of GROOM RI should be the formation of a unified statement between interested authorities/governments, towards a "shared border" for MAS. While this is not easy, and will certainly have limitations on what MAS with which capabilities are included, it is critical for forming and sustaining a climate observing network. Climate observing should be linked to wider environmental monitoring (statutory, for example) in order to share infrastructure and expertise (hardware, data management, vessel support, permitting) as well as close cooperation for training and operating procedures and best practices. Long-term funding is not easily secured or kept, so it will be important to be flexible enough to adapt to availability of resources and coordinate with observational efforts of all types.

3.5 Service 4: Statutory Ecosystem Monitoring/Assessment Ecosystem Stressors

3.5.1 Summary of External Services / Products

The European Union (EU) requires the systematic collection of marine data and regular assessments of the health, status, and trends of marine ecosystems. EU statutory marine ecosystem monitoring refers to legally mandated monitoring programs by regulatory frameworks and EU legislation. The monitoring methodologies, data collection, and reporting standards vary across regions and marine ecosystems which necessitates a cooperation between local experts and a broad network of expert scientists and engineers with access and expertise to state-of-the-art technology and methodology. Statutory ecosystem monitoring involves a wide range of organizations including EU member states, scientific institutions, research organizations, and environmental agencies. These groups are animated by a combination of motivations from environmental protection to conservation to sustainable management of marine resources.

Marine autonomous systems (MAS) fit into the matrix of statutory ecosystem monitoring by providing critical high-quality, lower-cost ocean observation datasets that inform scientifically valid reports and analyses. GROOM RI will have the capacity to systematically collect data using standardized methods and protocols. Through physical measurements and remote sensing, GROOM RI's partners will be able to provide information on the status and functioning of marine ecosystems and impacts of human activities.

As noted earlier, GROOM RI provides a wide range of services to procure, operate, maintain, calibrate, integrate, deploy, pilot, and recover MAS. GROOM RI partners also coordinate and support mission planning as well as data sharing and harmonization to ensure proper collaboration with other national data centres and EU data aggregators. From the management of software repositories to implementing established best practices, GROOM RI partners have the expertise and tools to facilitate continuous environmental monitoring to meet MSFD and achieve and maintain GES. GROOM RI partners have extensive experience coordinating and implementing baseline marine environmental surveys for clients around the globe.

Since the 11 descriptors of GES need continuous monitoring of the marine environment for assessments and regular updates of targets, MAS should collect parameters over extended periods and large spatial scales. MAS offer cost and operational efficiency compared to traditional manned data collection methods of doing this. MAS operate autonomously for extended periods, cover larger areas, and reduce human resource and vessel requirements, especially when survey areas are challenging or dangerous for humans to access. GROOM RI partners currently collect large datasets on water quality, temperature, salinity, nutrient levels, and other parameters over extended periods of time and large spatial scales all around the globe. Suites of sensors integrated on marine autonomous vehicles collect and transmit data in near-real time to observers on shore.

In addition to marine data collection, GROOM RI partners have the capacity to analyse and process the collected data to generate meaningful information and assessments. Through statistical analysis, modelling techniques, and other analytical tools, partners will interpret the data to derive insights about ecosystem health, trends, and stressors. By quantifying stressor impacts, GROOM RI will provide valuable data and the necessary insights to inform EU and member state policymakers and other stakeholders as they develop effective marine management strategies including targeted conservation actions.

Through the use of innovative MAS and the expertise of its many partners, GROOM RI will have the capability to make recommendations for policy adjustments and management actions. Datasets, reports, statistical analysis, and modelling provided by GROOM RI partners will aid regulatory agencies as they meet their monitoring and enforcement obligations. In addition to ensuring compliance, statutory monitoring with the operational expertise of GROOM RI will feed into adaptive management approaches – improving marine conservation and effective management strategies in the EU.

3.5.2 Specific Benefits to Society

The EU Marine Strategy Framework Directive (MSFD) was implemented to protect the marine ecosystem and biodiversity upon which our health and marine-related economic and social activities depend. The MSFD assesses the impact of all human activities and drives new research and legal initiatives related to Europe's four marine regions (5,720,00 km2). These directives require member states to establish monitoring programs, set environmental objectives, and implement measures to achieve and maintain good environmental status (GES) in their marine waters.

Marine autonomous systems improve the capabilities of EU countries to achieve GES and meet several of the directives set out within the 11 illustrative qualitative descriptors. Marine autonomous systems collect well-managed, valid, calibrated, and standardized datasets to provide rigorous, quantitative evidence that ensure the integrity of those descriptors.

In order to achieve GES and meet particular directives within the MSFD, various stakeholders must have accurate datasets, reports, statistical analysis, and modelling to assess ecological health and the integrity of marine ecosystems, including the quality of water, biodiversity, habitats, and the functioning of ecosystems. The monitoring data and assessments provided by a future GROOM RI will help identify and quantify any degradation or changes occurring in these ecosystems. Monitoring systems focus on evaluating the main environmental pressures and stressors affecting marine ecosystems including chemical contaminants, marine litter, climate change, overfishing, habitat destruction, and invasive species. A monitoring program that scientifically tracks indicators including parameters like water quality, nutrient levels, species abundance, biodiversity indices, and ecosystem functioning can assess the effectiveness of conservation measures and policy actions.

GROOM RI will ensure future policy development has more information to develop and implement legislation, regulations, and management measures to protect and conserve marine ecosystems, promote sustainable fisheries, and address environmental challenges, all of which benefit society directly through improved quality of life and management of marine resources.

3.5.3 Value Proposition

GROOM RI is dedicated to collecting scientifically valid marine data and providing officials within these monitoring programs high-quality data analysis through innovative marine autonomous systems. Those agencies and institutions required to seek data-driven decision-making can rely on the expertise of the internationally renowned scientists and engineers with decades of experience operating marine autonomous systems around the world. GROOM RI partners have extensive knowledge and operational experience to acquire accurate datasets, generate informative reports, conduct rigorous statistical analysis, and generate up-to-date models to assess ecological health of coastal and deep seas. The integrity of marine ecosystems, including the quality of ocean waters, marine biodiversity, habitats, and the functioning of oceanic ecosystems is of utmost importance to GROOM RI and its many partners across Europe.

By using advanced data collection techniques with underwater autonomous vehicles (AUVs) and autonomous surface vehicles (ASVs), GROOM RI can gather accurate information for long term monitoring in demanding marine environments more effectively than traditional sampling methods in many cases. Fleets of ocean gliders can cover large expanses of coastal areas to collect immense datasets that previously were not operationally feasible. Not only can this be a cost-effective solution, but the time frames to collect these datasets will be considerably shorter than more traditional methods.

GROOM RI will have the capacity to systematically collect data using standardized methods and protocols. Through physical measurements and remote sensing, GROOM RI's partners will be able to provide information on the status and functioning of marine ecosystems and impacts of human activities. In addition to data collection, GROOM RI has the expertise and network to properly manage and analyze these large quantities of data collected by MAS. The network of scientists partnering with GROOM RI have the expertise to generate assessments including reports, statistical analysis, and models to assess ecological health of coastal and deep seas.

3.5.4 SWOT Analysis

Strengths	Weaknesses
• Marine Experts & Scientists • Talented MAS engineers & operators • Constant developments in innovative sensor integrations and artificial intelligence • Systems to deliver a wide range of services and products have been established and continue to grow	• Limited availability of skilled labour to design, create & operate MAS • Novelty of the RI will involve growing pains and delays as partners tease out issues with the institutes' governance
Opportunities	**Threats**
• Monitoring obligations to meet Marine Strategy Framework Directives (MSFD) • EU countries attempting to achieve good environmental status (GES) • Greater awareness of climate change and the growing need to monitor the increasingly warming oceans	• Other Marine RIs in the space • Legal challenges related to robots & autonomous & artificial intelligence-based systems • Technological complexity of underwater operations

3.5.5 Specific Recommendations for Modality and Implementation

For implementation of MAS for statutory monitoring to be realized, it is recommended that the agencies at the member state level (who implement MSFD and other directives) work directly with GROOM RI member partners in their country. This will smooth the research permit application process and the exchange of information, expertise, and hardware through coordination with GROOM RI members from other countries who may contribute.

3.6 Service 5: Operational Monitoring for Good Environmental Status (GES) and Emergencies in the Ocean

3.6.1 Summary of External Services / Products

The health of the ocean is continually endangered by human-directed actions. Some of these actions have been defined as "emergencies" that occasionally happen such as oil, gas, and radioactive spills as well as navigation incidents. Solving these emergencies usually requires a considerable amount of time. For instance, spills may take weeks, months, or even years to clean up. On the other hand, marine litter in all sizes, shapes, and compositions is generating pollution continuously. This pollution directly affects flora and fauna of our oceans and indirectly affects the human population. The total amounts of plastics and other man-made debris in the ocean are currently unknown and continue to increase. Furthermore, we do not know the degradation processes or the residence time scales.

Additionally, natural phenomena such as volcanic eruptions, major storms, and cyclones along with harmful algal blooms (HABs) generate changes in the marine ecosystems that impact the economy and society in general. These phenomena are also considered "emergencies". All of these impacts on the world's ocean require continuous observation to ensure the good health of these ecosystems.

To provide a legal framework to respond to phenomena, incidents, or continuous sea impacts, the 1982 United Nations convention agreed on the Law of the Sea – the obligation to protect and preserve the marine environment among the signatory countries of the agreement. These countries have the shared responsibility to respond effectively in a timely manner to any phenomenon or incident. In addition, they must provide continuous surveillance by having the necessary equipment along with qualified personnel as and when needed both in territorial and international waters.

The European Community also echoes this need to protect the marine environment and under the EU Marine Strategy Framework Directive (MSFD) which establishes a set of descriptors that seek to guarantee good environmental status (GES) of our seas and oceans. This directive is mandatory for all member states. A 2020 report on the implementation of the MSFD highlights that it needs to better address the ongoing anthropogenic impacts – even as one of the most ambitious and comprehensive regulations in the world.

In recent years, MAS fleets have helped with monitoring good environmental status and generating exceptionally good prospects when collaborating with the responsible agencies. Autonomous underwater vehicles (AUVs) as well as those platforms that navigate on the surface (ASVs) are contributing to GES with high-quality data sets and improved spatial and temporal resolutions. By covering a wide spectrum of essential variables, MAS allow surveillance of protected areas and facilitate the work of monitoring in emergency situations, thus helping officials take immediate decisions. The future autonomous vehicle infrastructure will coordinate a set of distributed resources belonging to the national institutions that already have these vehicles. This will make it possible to cover large areas of the European seas and oceans and respond immediately to those emergency events that may occur.

3.6.2 Specific Benefits to Society

Currently, affected countries and their institutions/agencies or consortium of institutions are responsible for responding to emergency situations and the surveillance of protected areas at sea. In the case of the emergencies, responses are defined by the nature of the event or incident. In addition to the direct response to the emergency, quick and continuous monitoring during and after the event is necessary. This monitoring can help in decision-making for response management as well as in monitoring the effects caused by both the emergency and response determined by the institutions in charge. In recent years, MAS fleets contribute to ongoing monitoring. Below are illustrative cases.

Oil spills usually have significant consequences for the environment and a strong impact on society. After an oil spill, the recovery time scale of the environment is affected the type and volume of oil spilled, meteorological, and oceanographic conditions. Monitoring how and where oil is moving through the water column is crucial to successful remediation since spills may take weeks, months, or even years to clean up. One of the most important events where gliders were involved responding to an oil spill occurred in 2010 in the Gulf of Mexico (Mullins-Perry et al., 2013). Several gliders helped during the cleaning duties. These gliders produced subsurface observations of temperature, salinity, and velocity to determine where oil was likely to be swept by currents. Real time data were made available on a central database for all interested parties to freely access. Fluorometers integrated on gliders acted as sentries for subsurface plumes of hydrocarbons.

More recently, damage to the Nord Stream pipeline released a high quantity of greenhouse gases in the ocean and ultimately some fraction to the atmosphere. With no observing system in place, it was not possible to assess the amount of greenhouse gasses released and impact on the local marine ecosystem. This case is an example of a situation where rapid response capacity to deploy an observing system would have been beneficial for environmental monitoring.

Harmful algae blooms (HABs) have been increasing during the last decades. The main causes appear to be eutrophication and warming (O'Neil et al., 2012), in addition to others. The principal effects on the population include respiratory irritation, poisoning, and even death by consuming contaminated organisms (Backer et al., 2010). They also usually produce massive marine fish and mammal mortality events (Gannon et al., 2009). To mitigate the effects of HABs, the scientific community suggests continual monitoring established by the authorities in the affected areas. MAS with suitable sensor payloads can help in the detection of HABs and complement other observational platforms such as remote sensing and moorings. The existing program for HAB detection in the southwest Florida Shelf in the last decade (Turley et al., 2022) is a good example where remote sensing, mooring, and MAS fleet collaborate.

Storms and cyclones are meteorological phenomena that usually cause major disasters in coastal infrastructure and the most extreme life and deaths scenarios in the population (https://en.wikipedia.org/wiki/List_of_European_windstorms#Since_2019). With the development of new observation technologies that provide numerous new data, forecasting models have vastly improved, and the predictions of these meteorological phenomena have advanced significantly in recent decades. MAS technologies are currently improving knowledge about the interaction between the atmosphere and ocean during phases of formation and propagation of storms. There are several examples of MAS inside these particular weather structures showing the evolution in the temperature and salinity of the upper ocean (e.g., Le Hénaff et al., 2021, Miles et al., 2021). The Atlantic Oceanographic and Meteorological Laboratory (AOML) is currently working in the 2022 Hurricane Field Program with the goal of improving hurricane forecasts with upper ocean observations. MAS are essential during these observations because they permit the monitoring of these hazardous weather structures without any risks to the operators.

Since 2015, the topic of marine geohazards has been discussed at the EMB. This Board is the unique strategic pan-European Forum for seas and ocean research and technology. Its aim is to direct political attention to the topic at European and international level by highlighting the impacts on society and the Blue Economy while also advocating for more knowledge on processes, triggers, and precursors of marine geohazards.

Marine geohazards are generated from diverse geological conditions ranging from broad to local scale. At any time, they may develop into a situation that poses a direct threat and disaster risk to coastal communities and the Blue Economy. Historically, marine geohazards impacted on coastal communities affecting livelihoods and causing loss of lives. Three examples of earthquakes and tsunamis occurred in 1755, 1908, 1999 in Lisbon, Sicily, and the Eastern Marmara, respectively. Currently, marine geohazards can cause severe problems along the shoreline as well as at offshore facilities of vital importance to socio-economic activities such as handling shipping, refineries, communication, and transportation infrastructures, wind farms, etc.

An EMB report (Kopp et al., 2021) suggested how science can transform geohazard assessment in Europe by proposing the statistical characterization of past geohazards events and assessing their frequency, monitoring active processes to understand their dynamics and mechanisms, recording and recognizing precursors to geohazards, and defining them through numerical and physical modelling. Among these suggestions, the report included fleets of MAS to be of vital importance to monitor active processes. These platforms are essential due to their capacity to carry out underwater missions without operators constantly controlling the vehicles as well as the variety of sensors that can be integrated onto these platforms. Environmental monitoring using these vehicles augmented with remote sensing and data assimilation will improve spatial and temporal resolution to study these phenomena and events.

As mentioned above, the affected country (national waters) or the nearest countries (if the emergency or incident occurs in the international waters) respond to emergencies at sea. Marine emergencies are those mainly caused by navigation incidents, oil spills, or ones requiring protecting the population. The responses usually involve various institutions – from civil protection to scientific institutions to even the navy or army depending on the protocols of each one of the affected countries. The EU established the European Civil Protection Pool to progress European cooperation in civil protection with the aim to activate a faster, better-coordinated, and more effective European response to human-induced disasters and natural hazards. These capacities cover a wide range of services, such as search and rescue, medical treatment, and forest fire fighting. They are coordinated from the Emergency Response Coordination Centre (ERCC). This type of organization is made up of collaborating countries and demonstrates the capacity for a rapid aid response when a country is overwhelmed by an emergency. However, of the various services that ERCC manages, those aimed at marine emergencies are scarce. ERCC can mainly carry out rescue services and help against marine pollution, but it is only in some national nodes.

GROOM RI could offer operational monitoring services in support of ERCC through the use of fleets of MAS with specific sensors according to the emergency. A distributed European infrastructure in coordination with the ERCC through access protocols will generate a specific benefit for the society.

3.6.3 Value Proposition

GROOM RI will provide a coordinated monitoring service for both the surveillance of European marine protected areas and assistance to various emergency events at sea. The use of a MAS fleet will reduce risks in those cases of emergency where there are impediments to proximity from ships since MAS navigate autonomously and are remotely piloted. They help to cover observation and surveillance needs by contributing to the fleet of scientific vessels and improving spatial and temporal resolutions. In addition, MAS facilitate data sets in real and delayed time with quality control to facilitate decision making.

To facilitate decision making, a distributed national infrastructure network with its own resources will own and operate fleets of marine autonomous systems coordinated from a coordination center. In the case of a national infrastructure unable to respond to a specific emergency, GROOM RI will coordinate with another national node to provide a response in a timely manner. The data sets provided by GROOM RI will maintain the quality controls and formats established by international data harmonization agreements. GROOM RI will contribute to the harmonization of resources of the national nodes as well as support the training and capacity building strategies that contribute to improving the distributed infrastructure.

GROOM RI will promote technological knowledge of new developments that are aimed at covering and improving social requirements in the sustainability of the good environmental status and emergencies at sea.

3.6.4 SWOT Analysis

This SWOT Analysis for marine monitoring using MAS fleets for environmental surveillance and marine emergencies response identifies GROOM RI's strengths and weaknesses as well as those opportunities and threats the RI will face.

Strengths	**Weaknesses**
• Marine Experts & Scientists • Talented MAS engineers & operators • Distributed national nodes with their own resources and capable of quickly contributing to the requirements of the MSFD or emergency events. • Constant developments in innovative sensor integrations and artificial intelligence. • Training and capacity building program to sustain and improve the skills of infrastructure members and Scientific community.	• Current imbalance of capacities among the national nodes. • Continuous requirements for qualified personnel and technological means to provide a good service to society.
Opportunities	**Threats**
• Quick support for the development of the Marine Strategy Framework Directives (MSFD) • Expansion of European emergency services at sea by using existing national resources to support observation during and after such events.	• Legal challenges related to robots & autonomous & artificial intelligence-based systems • Technological complexity of underwater operations

3.6.5 Specific Recommendations for Modality and Implementation

The start up of GROOM Research Infrastructure would facilitate the implementation of this service provided that the national nodes already exist. The coordinating center generated by the RI will establish the coordinated operating standards for the different national nodes. This center would act as a link to establish collaborations with European and national institutions responsible for the good environmental status (GES) of the oceans and seas. Thus, in this way, the operating capacities of each national node as well as their closest complementary nodes will be determined to ensure the necessary response for any emergency event. Also, economic means will be sought to provide the nodes with the most appropriate technology to sustain the required observations in each case. Finally, a training and capacity building program will be established to help maintain and improve knowledge and good practices within the staff of the national nodes.

4. CORE SERVICES / PROCESSES

In general, services are work performed for various parties – both internal and external to GROOM RI. Core Services are the tasks and activities that GROOM RI partners perform for each other within the organization. These Core Services are necessary for GROOM RI to enable the various External Services and Products outlined within Section 3 of this deliverable. While these External Services and Products are meant for government agencies, research institutes, Science, and Industry, Core Services are processes internal to GROOM RI. The completion of various combinations of Core Services result in work products GROOM RI partners provide for these third parties. Some of these end-products may include an analysis, datasets, live-stream data, and reports.

(Core Services/Process are in alphabetical order.)

4.1 Best Practices

GROOM RI will facilitate and take part in the establishment and evolution of best practices on the operations of MAS to incorporate them into the Ocean Best Practices System (OBPS). The RI will establish a repeatable process to endorse new best practices and incorporate them into the OBPS for continual improvement. The development of GROOM RI's best practices and Ocean Gliders' best practices are closely related and inform each other. Although, while there will be more specific EU best practices in the future, so GROOM RI's best practices may not applicable globally.

4.2 Capacity Building

GROOM RI will identify gaps of capacity and capability in the GROOM network. The RI will facilitate and foster collaborations among its partners and external institutions to fill those gaps by developing new ways of operating innovative technology and new legal frameworks. All these activities will then feed back to new best practices and training programs for the new capability to further strengthen the marine RI landscape.

4.3 Data Management, Sharing, & Harmonization

GROOM RI will coordinate and support efforts to manage, harmonize, and standardize metadata, evolving data, and new formats. The RI will collaborate with national data centres, global DACs, and EU data aggregators to assist with the uptake of gliders' observations by these wider user communities (NRT QC and FAIR data dissemination into GOOS, EOOS, & ENVRI communities). The coordination by the RI will assist with adoption of gliders and other MAS observations from wider user communities, thus making those observations as efficient and accessible as possible.

4.4 Environmental Monitoring

GROOM RI will facilitate the coordination and implementation of baseline environmental surveys on water properties, operational met-ocean studies, and monitoring services for national governments. The RI will have the capacity to estimate the environmental conditions of direct influence on coastal or offshore engineering projects and select appropriate solutions to facilitate goal achievement (e.g., implementation of marine infrastructures, sustainability of marine protected area, etc.).

4.5 Hardware Calibration & Integration

GROOM RI will develop standardized protocols for instrument testing, integration of new instruments into MAS and sensor calibration. This may be in the form of providing expert services and connecting with the best practices of GROOM RI.

4.6 Legal Frameworks

GROOM RI will support and facilitate diplomatic clearances and other legal matters (e.g., shipment regulations) involving the operations of MAS. The research infrastructure's support and depth of experience will make the whole administrative process of deploying gliders and other MAS in water frictionless and efficient from drafting contracts, providing templates for diplomatic clearance, and requesting Marine Scientific Research. The RI will provide expert services and connect with the best practices developed by the RI.

4.7 Operations & Maintenance

GROOM RI partners will have the full range of capabilities from the preparation and maintenance of MAS instruments to the deployment and recovery of MAS. Throughout this process, GROOM RI will collaborate with fellow partners to implement all necessary protocols to ensure the optimal operation of these systems.

4.8 Outreach

GROOM RI will coordinate a joint approach to disseminating the work done by the RI and its partners. These efforts will help the partners better communicate with the public while also saving resources through this common approach. GROOM RI will leverage its position in the European landscape to collaborate with other Ris and networks (Ocean Observation integration).

4.9 Pan European Coordination

GROOM RI will be a key actor to ensure that European leadership strengthens and consolidates the global OceanGliders coordination activity with direct links to the GOOS and GCOS via the Observation Coordination Group (OCG). The RI will assist partners coordinate within other frameworks (e.g., EuroGOOS GTT) and connect with other European stakeholders as well as global Ris. By being at the centre of all these activities, GROOM RI will effectively navigate the complex landscape of marine Ris and best represent the partners while benefiting all the different stakeholders involved.

Some of the activities to coordinate:

- An online portal for access as part of the e-infrastructure
- Access to the glider facilities vehicles, sensors, & pilots
- Access to geographically dispersed facilities for launch & recovery.
- Technology & engineering services
- Sensor integration & testing
- Glider servicing
- Sensor calibration
- Procurement
- Cruise programmes for launch & recovery support (with necessary links to ship operators)

4.10 Piloting & e-Infrastructure

GROOM RI will provide a catalogue of e-Infrastructures including electronic services, networks, archives, databases, and databanks at the partners' level. In addition, the RI will deploy and grant external users access to piloting e-infrastructures of the RI partners. The RI will facilitate joint collaborations and access to unique capabilities to support operations. GROOM RI will contribute to the development of software needed by the partners. This software will also be maintained on open repositories following best practices in software development. Other potential tools to be developed include risk assessment and mission simulation and rehearsal tools.

4.11 Procurement

GROOM RI will coordinate purchases on behalf of the partners to get more competitive offers from marine system hardware manufacturers and distributors (e.g., gliders, sensors, etc.) and services (e.g., Iridium, Argos, AIS, etc).

4.12 Software Repositories

GROOM RI will provide resources to help manage open-source software repositories with software version control tools. These tools will also be used to converge on best practices. The connection between these best practices and code will become very natural. These resources will also support the prioritization of issues and moderate online debates, giving consistency to the entire system.

4.13 Support to Innovation

GROOM RI will foster cooperation with Industry by providing data, dedicated services, and experimental facilities to the private sector. In addition, the RI will support innovation by organizing training opportunities for industry stakeholders. Lastly, the RI will collaborate with the private sector to develop and evaluate new components, instruments, and capabilities.

4.14 Training

As a central hub, GROOM RI will facilitate and organize those training activities among the GROOM RI partners. GROOM RI will maintain and increase its partners' skills by organizing targeted technical training on MAS, metadata and data handling, mission planning, and other skills as the need arises. The RI will also scan the marine research landscape for training opportunities with external bodies to both offer and receive training. When receiving training, the RI will capitalize on the economies of scale to potentially receive better pricing and higher quality offers for each of the partners.

5. CONCLUSIONS & OVERALL RECOMMENDATIONS

This report has described the **role of Marine Autonomous Systems in providing services** to organizations or sectors of society who require or will benefit from ocean environmental observations, but who do not collect data themselves. **Specific types of data services have been identified** as the most important for a future research infrastructure to provide (GROOM RI). They have been chosen because they are **important for society** in general (ocean and human health, economic growth), and they **require cooperation and coordination across sectors** of stakeholders (government, industry, academic, non-profit) **and across disciplines** (ocean sciences, marine technology, policy/management). An international network of ocean science and engineering experts and physical and digital MAS infrastructure is the most effective way to build these services, and specific value propositions about the use of MAS and GROOM RI have been provided.

As a first step, the **legal status of the GROOM RI should** be defined to **provide a basis and access model(s)** for exchanging the internal services described in this report. GROOM RI needs to be formally established, including the way it will manage membership and function internally. Members must form detailed **internal agreements** about which members provide exactly what internal services to other members, under what conditions, including type and amount of compensation. See Deliverable 2.1 Access Policy, Deliverable 2.3 Enhancing Skill and Building Capacities, and Deliverable 3.1 Governance and Legal Aspects.

Once established, GROOM RI should establish a **suite of external services** one by one, based on the catalog in this report, each in cooperation with the relevant GROOM RI members and other external providers (e.g. private companies who specialize in a relevant technology or method). The parties should **negotiate a well-defined contractual basis** for roles, expectations, and obligations which defines the service.

Next, GROOM RI should **form a product portfolio**, including rates, and present these to external parties for uptake and implementation. A **cycle of evaluation and updating/improving** should be implemented.

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7. ANNEXES

7.1 T5.1 Report: GROOM II - Key societal benefits of a sustained glider infrastructure

Please see: https://www.groom-ri.eu/wp-content/uploads/2024/01/groom-ii-key-societal-benefits-of-a-sustained-glider-infrastructure-_v.final_.pdf

7.2 Highlights of the three IAG-MAS Workshops

Workshop #1: Introduction & Environmental Services

Workshop #1 emphasized that GROOM RI will play the role of facilitator connecting service companies with technology and operations providers. Members discussed a potential access policy developed in D2.1 RI Access Policy and Rules. Members of the RI may also contribute to the final environmental service with clear rules on how and what the member is offering offsets the value the member is receiving.

- Attractive Environmental Services as identified by private sector organizations:
    - Baseline environmental surveys on water biogeochemistry, currents, waves, cetaceans
    - Meeting regulations during offshore activities like drilling: water quality, noise
    - Providing monitoring services for national governments using MAS: MSFD noise, oxygen, chlorophyll levels, others
    - Real-time current mapping with glider data merged with model, HF Radar, drifters.
    - Operational environmental information during operations: currents, waves

    - Second Tier Environmental Services:
        - Decommissioning: evaluation of water quality
        - Seeps from seafloor, pipelines, derelicts: HC, CH_4, CO_2, noise
        - Energy potential from wind, waves, currents (doppler, passive acoustics)

Workshop #2: GROOM RI's Benefits to Industry

- Sensor-Related Companies:
    - RI may provide access to test and demonstrate new sensors.
    - Understanding the needs of users in terms of sensor and/or system integration.
    - Link with science
- Platform-related companies:
    - Infrastructures for launch and recovery all kinds of vehicles
    - Interface with regulators of autonomous navigation systems
    - Adapt technology to user requirements with an understanding of their needs
    - Reduce the development time
    - Link with science

- Service-related companies:
    - Access to data & availability to codesign data collection rather than technical operations
    - Reduce cost investment in equipment & technicians

Workshop #2: Priority Emerging Sectors for the RI

- Impact on coastal ecosystem of offshore marine renewable energy infrastructure
- Underwater communication
- Cooperation between several MAS
- Greenhouse gas monitoring (CO_2, CH_4)

- On board decision-making
- eDNA (invasive species, biodiversity)
- Real time PAM (Passive Acoustic Monitoring)
- On-board AI (imagery, sound)
- Advanced coordinated automatic missions (USV)
- Water Sampling (Pollution- including microplastics and drug molecules)
- Real-time echosounders for fishery and ecosystems
- Nutrient sensors

Workshop #3: Attractive Services to IAG-MAS Members

- Mission planning/piloting
- Access to the glider facilities, vehicles, sensors, and pilots
- Shared planning campaign coordination, piloting, and e-infrastructure tools (including risk assessment tools and missions planning)
- For hardware maintenance/development:
    - scientific validation
    - sensor integration and testing
- For engineering:
    - glider servicing
    - sensor calibration
- Regarding data management:
    - FAIR Data dissemination into GOOS, EOOS, ENVRI communities
    - An online portal for access as part of the e-infrastructure
    - Data management
    - NRT QC
- For capacity building/training:
    - coordination deployments between platforms of distinct types
    - building & dissemination of best practices