Project Number: 902504

Project Start: Jan. 1, **2025**[1] **Project Duration (in years):** **5 years**[1]

Please indicate if proposal includes requests for any of the following (mark all that apply).

[X] Ship Time	[X] ROV	[ ] AUV	[ ] Wave Glider	[X] Mini ROV

Please indicate what type of project is being proposed (mark only one).

[ ] Feasibility/Scoping [<100 days effort]	[ ] Development[2]	[X] Research	[ ] Infrastructure[2]	[ ] Education	[ ] Time Series	[ ] Institute Initiative

Project Manager[3]: Sebastián Rodríguez
Principal Investigator: Giancarlo Troni
Lead Scientist: Aaron Micallef, David Caress
Lead Engineer: Eric Martin

Project Title: Scalable Semantic Mapping and Monitoring

Please indicate which category best describes the project theme (mark only one).

[ ] Ocean biogeochemistry	[ ] Ecosystem dynamics	[ ] Ocean visualization	[X] Exploration & discovery

Please indicate percentage of effort on this project anticipated for 2025 toward these three highest institutional goals from the Strategic Roadmap (percentage total should equal 100%).

Goal	Innovate and Build	Explore and Protect	Inspire and Engage[4]
Percentage	40%	40%	20%

[1] This date and number should remain the same for the duration of the project. If your project start date for 2025 is not January 1, please indicate the start date in the first cell of the milestone chart. Format for duration example: "Year 2 of 5".
[2] Development and infrastructure projects must complete the risk matrix (see end of the proposal form).
[3] Not all projects will require all four titles to be filled in. Please indicate individuals only for those titles that are appropriate for your project.
[4] This category includes transfer of hardware, know-how, publications, presentations, etc.

1) ABSTRACT (all projects)

The main goal is to **collect and analyze field data** for semantic mapping and monitoring. This will enable the identification and analysis of environmental changes over time.

This project focused on demonstrating the technology developed within the "Scalable Marine Robotics" (902204) project by employing it to collect and analyze field data to facilitate semantic mapping in collaboration with other MBARI. This collaborative effort is linked to other internal projects, such as the "Seafloor Processes" (902312) and "Seafloor Mapping" (901101).

In the first year (2025), this project will focus on collecting seafloor data. Two significant instances of this data collection effort include (i) using the MiniROV in the Canadian Arctic on the Korean icebreaker Araon as part of the "2025 Arctic Expedition" (902505) and (ii) conducting data collection activities in Antarctica aboard the Falkor Too. This "2025 Antarctica Expedition" is part of an external proposal titled "Exploring the Cascading Effects of Climate Warming in the Southern Ocean Seafloor and Subseafloor: Impacts on Hydrogeology, Geomorphology, and Ecology (ECSOS)" (under review).

2) PROPOSAL (all projects)

Background

The main goal is to **collect and analyze field data** for semantic mapping and monitoring. This will enable the identification and analysis of environmental changes over time.

This project seeks to leverage the research and development (R&D) efforts done in previous years with the Scalable Marine Robotics project (902204) to collect and analyze field data for semantic mapping and monitoring. This effort will enable the identification and analysis of environmental changes over time.

MBARI is a leader in high-resolution seafloor mapping, but high operational costs and limited analysis tools limit its current operations. However, we want to utilize our navigation and mapping developments to collect data from multiple locations using a portable system, such as onboard the MiniROV or integrated on other platforms like the SuBastian ROV on board the SOI Falkor Too. By collecting more data, we aim to enable semantic benthic mapping and monitoring, which allows for better representation of the environment by adding identifying labels to spatial maps. Semantic maps contain high-level features that allow us to understand the environment better and enable novel representations for autonomous robotics platforms for science.

We plan to leverage the research and development work done in creating a portable mapping system to start collecting and analyzing data for semantic mapping. The portable mapping system has stereo cameras, a multibeam echosounder sonar, a forward-looking imaging sonar, and a navigation system. Additionally, it has a software infrastructure for simultaneous localization and mapping. These sensors work together in real-time to provide accurate mapping data. We aim to collect and analyze this data by employing machine learning techniques to automatically extract characteristics and label features such

as biology and geology. This will significantly enhance the mapping process and allow for a semantic terrain representation. Such a representation will be helpful for scientists and will enable us to improve our navigation methods based on those labels instead of the raw sensor information in the future.

Relevance to MBARI: The current proposal directly supports the MBARI Strategic Roadmap 2022—2032. Its central core helps address the **seafloor imaging** and **data analytics challenges** (onboard and onshore) and supports the technology development challenge. It complements the challenges associated with ocean science and engagement. In addition, all are relevant to the Packard Foundation's goal of improving our understanding of the ocean.

Internal and external project links: This project focused on demonstrating the technology developed within the "Scalable Marine Robotics" (902204) project by employing it to collect and analyze field data to facilitate semantic mapping in collaboration with other MBARI. This collaborative effort is linked to other internal projects, such as the "Seafloor Processes" (902312), "Seafloor Mapping" (901101), and "2025 Arctic Expedition" (902505).

Nature and Scope of the Proposed Project

This is a medium effort, with some less intense engineering development efforts and more focus on data collection and analysis. Depending on the fieldwork expedition, the effort level will likely be similar over the coming years.

Does this activity relate to one or more 2025 proposals your team is submitting?

This project focused on demonstrating the technology developed within the "Scalable Marine Robotics" (902204) project. A summary of additional projects:

- Seafloor Processes (902312, Micallef).
    - Seafloor mapping of complex terrain and high resolution to monitor changes.
    - Antarctica Expedition 2025
- Seafloor Mapping (901101, Caress).
    - Data processing tools and calibration work.
    - Support field work and system development.
- Antarctica Expedition 2025: "Exploring the Cascading Effects of Climate Warming in the Southern Ocean Seafloor and Subseafloor: Impacts on Hydrogeology, Geomorphology, and Ecology (ECSOS)" (SOI, Micallef, Troni, Caress)
    - The mapping sled sensor system is to be mounted on the Subastian ROV.
    - Support with our research 6DOF platform and the uncrewed surface vessel.
- Arctic Expedition 2025 (902505, Paul, Caress, Micallef, Troni).
    - MiniROV navigation and mapping for Arctic fieldwork.

Anticipated Shared Resource Needs

We estimate ~1,600 hours of shared engineering for 2025. Shared resource needs are anticipated to be similar or lower in the coming years.

Anticipated Expenses

For 2025, we request about $76,000 for the required hardware and $21,000 for travel and shipping for the Antarctica expedition. The cost of the Arctic expedition will be included in a separate proposal.

Intellectual Property (IP) Considerations

None. Since data collection is the focus of this effort, there are no expected IP requirements. However, these requirements may be addressed in our other research and development projects.

Data

We anticipate generating image and range sensor data from all the engineering dives 10-40 TB per year. Data will be stored in the project's shared Google Drive and Atlas/Titan, and all team members will manage it. We have included some time allocated to improve the analysis and visualization tools of the data and the vehicle status.

Anticipated Impact

We are targeting internal and external ocean science users interested in accessing the mesopelagic zone, but we believe the technology can be expanded to include similar efforts.

Anticipated Outreach Needs

Modest outreach needs are anticipated to highlight some of the field expedition efforts when they are completed.

Continuing Projects Only: Status Report

This project plans to demonstrate the developments made under the Scalable Robotics Foundations project (902204), focusing on deploying systems in the field to support science goals.

Current status of the project and results to date for 902204

Field program status and results

- *FLS Surveys at Sponge Ridge (R/V Rachel Carson, January 18 and February 9, 2024):* We collected data using the ROV Ventana for our developments, which focused on using AI-based methods for navigation and bathymetry using forward-looking sonar data. In both expeditions, we successfully collected the data for its later processing.

- *Unexplored Seamounts of the Salas and Gómez Ridge Falkor(too) Expedition*: We participated in an expedition aboard R/V Falkor (too) from Schmidt Ocean Institute (SOI), which sailed from Valparaiso, Chile, to Easter Island, Chile, for 40 days. During this expedition, we deployed a hyperspectral and stereo camera system integrating navigation and a hyperspectral imaging package. Two developed systems were deployed during the expedition:
    1. **Visual Mapping and Navigation System**: A sled adapted from a previous expedition with the MiniROV, equipped with navigation and vision sensors to support our real-time visual-based simultaneous localization and mapping (SLAM). This system utilizes feature-based visual information from stereo cameras to integrate with attitude, velocity, and depth measurements, enhancing navigation and reducing drift, a common issue in long underwater surveys.
    2. **Hyperspectral System**: A hyperspectral camera, spectrometer, and pair of stereo cameras for novel seafloor mapping across a hundred contiguous spectral bands.

    Integrating both systems enables the creation of spatial reconstructions using hyperspectral and photogrammetry data. The team deployed these systems on 12 dives across multiple seamounts, where many new species were discovered.

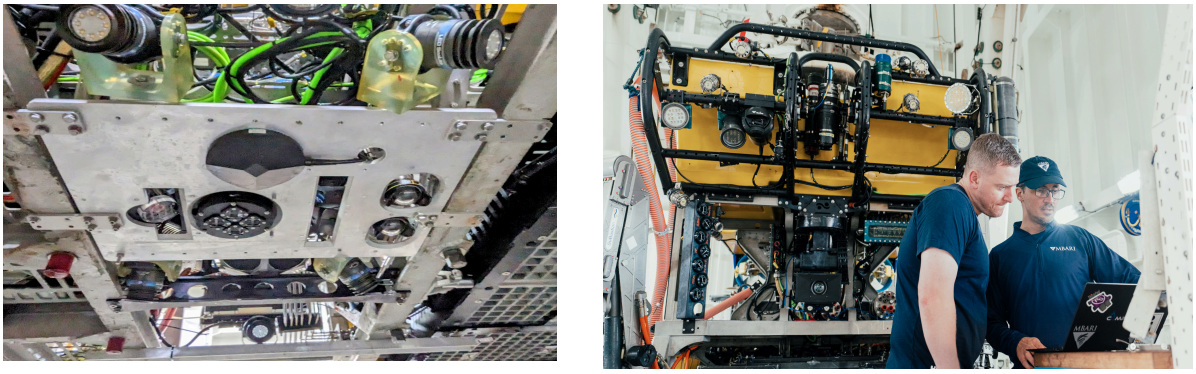

Figure: Compact sled adapted from CoMPAS MiniROV Mapping sled mounted on ROV SuBastian (left) thanks to a collaborative effort with SOI ROV pilots (right).

- *MiniROV Surveys at Sponge Ridge (R/V Fulmar, June). Canceled due to ship unavailable.*

Still to come this year:

- LASS Surveys at Sponge Ridge (R/V Rachel Carson, August 27 - 29, 2024)
- MiniROV Surveys at Sponge Ridge (R/V Rachel Carson, October 29 - 31, 2024)

All Projects: Specific Plans for 2025

Research Activities

In 2025, this project will cover integration needs, deployment, and testing of developments by the Scalable Robotics (902204) lab to support the efforts for the Arctic expedition led by Charlie Paull and the Antarctic Expedition in collaboration with Aaron Micallef. These significant external efforts will require integration and testing that leverage MBARI resources as well in 2025.

Activity 1: Antarctic Expedition (ECSOS, R/V Falkor (too), SOI, February 2025 (TBD))

A proposal to SOI is still under review to explore the Antarctic Peninsula based on our novel mapping sensors on ROV Subastian onboard the Falkor (too). This effort will build on a previous development of a sensor payload that took place in early 2024. We will demonstrate the ability of this technology to help chart areas undergoing change driven by fluids in the Antarctic Peninsula, such as groundwater, permafrost, and methane.

We will iterate on 2024's integration of the scalable mapping sensor suite on the ROV Subastian for the proposed Antarctic expedition. Improvements to the previous integration will include the Norbit WBMS and a change to the vehicle's mounting location so that it can address the seafloor at better angles and lighting. We expect limited improvements to the existing hyperspectral imager, which will also be tested here. To meet the likely tight schedule, we will have to begin some of this work in late 2024.

Please see proposal 902312 (Seafloor Processes) for more information on the overall area of study and its motivations.

Activity 2: Preparation for the Arctic Expedition (R/V Araon, KOPRI, Fall 2025)

To maximize data collection during benthic exploration and data collection, the MiniROV will be configured with a single configuration based on the sled, including sensors from our previously developed MiniROV Mapping Sled. A newly acquired compact multibeam sonar from Norbit will be used for low-altitude mapping. The objective is to generate surveys of permafrost boundaries aboard the R/V Araon. Detailed maps will allow for geological interpretations despite the navigational challenges of the Arctic environment. The team plans to use camera and laser systems to determine the properties of exposed permafrost. A novel Waterlinked 3D sonar will be integrated into the platform, replacing a heavier sensor from Blueprint subsea and providing a point cloud for future terrain following and path planning applications. Field use of this sonar is expected to be minimal in 2025 due to a 180-day lead time. See proposal 902505 (2025 Arctic Expedition) for more information on the overall study area and its motivations.

A critical fieldwork plan on Monterey Bay is proposed to validate the solutions to satisfy the science objectives as follows:

- *MiniROV Mapping in Monterey Bay - January 2025:* Before the MiniROV is shipped to the Arctic Expedition (expected in April 2025), we would like to test the new developments on the platform on board the Carson. We would also like to visit challenging vertical terrain to test the control systems needed for the Arctic Expedition better. To maximize the bottom time, locations like Extrovert Cliff or even Sponge Ridge will be used for test locations.

- *ROV Doc Ricketts Forward-Looking Mapping - May/June 2025:* Using Doc Ricketts will allow longer survey and testing days in the appropriate areas to validate our methods for forward-looking mapping. We plan to visit remote but shallow areas of Extrovert Cliff and Sur Ridge, which offer both attractive biology and geology that are of interest to our collaborators. This will be the ideal time to develop the next generation of control and perception systems to be tested before the Arctic Expedition. Four days will allow us to test the system more thoroughly than single days at those locations without staying overnight. If the dates can be combined, we can collaborate with Aaron Micallef's Seafloor Processes cruise (902312) for a shared expedition when deploying the DAS system.

Activity 3: Forward-Looking Sonars and Scalable Semantic Mapping from ROV Ventana

This project focuses on developing the infrastructure to gather a large amount of data. This data will enable us to utilize machine learning techniques to navigate, map, and characterize the seafloor using our Forward-Looking Sonar (FLS) and the Low-Altitude Survey System (LASS). Due to a limited number of interfaces with the ROV, testing will occur on different dates.

We plan to collect FLS data from the ROV Ventana to validate our new navigation and mapping methods. We will also focus on integrating our new 1.2-2.1 MHz Blueprint Subsea FLS to significantly enhance navigation and mapping performance. Furthermore, we are set to integrate our Norbit Multibeam sonar to validate this approach further.

By collecting data from the ROV Ventana with the LASS, we can continue to improve our Sonar-based SLAM methods. To reduce integration overhead, those dates will be contiguous with Caress (901101) days.

Engineering/technology development

This project aims to demonstrate the tools and algorithms developed inside the Scalable Robotics Lab's core project (902204), so developments specific to this project will focus on integrating, visualizing, and validating those technologies.

Activity 4: Scalable ROV Mapping and Data Management and Visualization

As we continue collecting large amounts of data, we aim to develop a robust framework to handle the increasing volume of data from various ships of opportunity. This framework will manage data and visualize it in real-time and offline. Furthermore, we aim to adapt our vehicle status visualization tools for use in the Antarctic and the Arctic later this year.

In addition, some minor efforts will be required to make the payload compatible with all proposed platforms for the activities mentioned above. The control system for the ROVs Ventana and Doc Ricketts will require some effort and improvements. For physical integration, we will need mechanical bracketry designed and manufactured by François Cazenave to make it compatible with ROV Ventana and Doc Ricketts. We will modify the existing sensor plate for new cameras and a better location on Subastian.

Field programs (detail ship requirements/deployments/diver requirements)

To be brief and avoid duplication, we will only outline the requests made for MBARI Resources that are unique to this project.

MiniROV Mapping in Monterey Bay (Activity 2: Arctic Prep)

- Vessel: R/V Rachel Carson
- Platform: MiniROV with Mapping Sled
- Duration: 3 days consecutive, 10 hours,
    - will require normal mobilization/demobilization resources
- Target Dates: January/Early February
- Scheduling Constraints: MiniROV will be shipping in April, and the Antarctic Expedition can conflict with resource availability.

ROV Doc Ricketts Forward-Looking Mapping (Activity 2: Arctic Prep)

- Vessel: R/V David Packard
- Platform: ROV Doc Ricketts w/ Benthic Sled
- Total days requested: 4 days (shared with 902312 Seafloor Processes)
- Target Dates: May
- Scheduling Constraints: Avoid other activities

Forward-Looking Sonars and Semantic Scalable Mapping from ROV Ventana (Activity 3)

- Vessel: R/V Rachel Carson
- Platform: ROV Ventana:
    - Three days: Benthic Sled w/ imaging sonars and mapping plate
    - Two days: Low Altitude Survey Sled contiguous with Caress (901101) days
- Total days requested: 5 days
- Target Dates: Spread the year starting in May, August, and November
- Scheduling Constraints: Resources are unavailable in late August through September due to the Arctic expedition.

Piloting/Watchkeeping

- *MiniROV:* Frank Flores and Johann Voigtlander's hours of operation on the requested R/V Rachel Carson days have been increased.
- *Scalable Mapping Payload:* This complex set of equipment and the ROV stationkeeping applications will be operated by a combination of Giancarlo Troni, Sebastián Rodríguez, Kevin Barnard, and Eric Martin.

Specific deliverables

Activity 1: Antarctic Expedition

- Multimodal ROV-based maps of areas of interest.
- Subastian Integration of mapping payload

Activity 2: Arctic Expedition

- MiniROV-based maps of the seafloor. Vertical maps of permafrost seafloor boundary layers.
- MiniROV Updated Controls
- SLAM-generated maps of Extrovert Cliff are for use in future semantic mapping developments from all available platforms.
- Further testing of control systems for high-relief terrain for the Arctic Expedition.

Activity 3: Forward-Looking Sonars and Scalable Mapping

- Further validated and refined models for navigation and mapping from forward-looking sonars taken from available platforms.
- Keep improving our sonar-based SLAM for high-resolution mapping with LASS.

Activity 4: Scalable ROV Mapping and Data Management and Visualization

- A data management framework for stereo images, sonar, and navigation data enables AI-based post-processing.
- Visualization tools for ROV vehicle health, status, and situational awareness can be valuable for other ROV/AUV users at MBARI.

Milestones and required personnel (see personnel classification list for staff classifications)

2025 Project Start Date: 1/1/2025	**Milestone 1**	**Milestone 2**	**Milestone 3**	**Milestone 4**	**Total Resources[5] (in hours)** for each resource category for all milestones listed here
Milestone Date	**3/1/2025**	**9/1/2025**	**10/1/2025**	**11/1/2025**	
Milestone Description	**Antarctic Expedition**	**Arctic Prep Cruises**	**FLS**	**Data Management & Viz**	
Electrical Engineer	**EM – 86**	**EM – 146** **JV – 40**	**EM – 50**	**EM-40**	**EM – 322** **JV – 40**
Software Eng-Embedded		**KH – 50** **MR – 140**	**KH – 10**		**KH – 60** **MR – 140**
Software Eng-Info Eng	**KB – 20** **CR – 20**	**KB – 190** **CR – 60**	**KB – 10**	**CR – 400**	**KB – 220** **CR – 480**
Mechanical Engineer	**FC – 80**	**FC – 30**			**FC – 110**
Mechanical Eng-Division					
Mechanical Eng-Mfg					
Associate Engineer					
Electrical Tech	**TBD – 20**				**TBD – 20**
Software Tech					
Mechanical Tech	**TBD – 20**	**FF – 40** **TBD – 20**			**FF – 40** **TBD – 40**
Machinist					
Divers					
Video Lab	**LL – 80**	**LL – 80**			**LL - 160**
(Add other categories/rows as needed)					

[5] This number should be the same number you entered on the web budget resource requests for this particular resource.

Budget justification

Task	Expense
Antarctic Expedition - Omicron Fiber Bulkhead	$6,000
Antarctic Expedition - Shipping to Punta Arenas Vehicles and Cameras	$18,000
Arctic Expedition - Waterlinked 3D Scanner - Acquisition	$30,000
Arctic Expedition - Waterlinked 3D Scanner - Integration Components	$3,000
Core - Cabling Spares	$15,000
Core - Computer Hardware (SSDs, NUC, etc)	$5,000
Core - Mola AUV Spares	$10,000
Core - Shipping Cases	$3,000
Core - Spare POE Cam Build	$3,500
Core - Tools - Flyaway	$3,000
David Packard Expedition - Doc Ricketts Mounting Hardware	$1,000
Grand Total	**$97,500**

Project team

- Giancarlo Troni: PI
- Sebastián Rodríguez: PM, Research Engineer
- Eric Martin: EE, Lead Engineer, Operational Support
- Carlos Rueda: SEI, Data Management and Visualization
- Kent Headley: SEE, Sonar Drivers
- Mike Risi: SEE, Controls support
- François Cazenave: ME, Integration Mechanical Design
- Frank Flores, Johann Voigtlander: MT, EE, MiniROV Pilots
- Lonny Lundsten: ITD, Video Labeling & ML

External consultants/contractors

There are no external consultants required by this effort.

Project lab and office space requirements

We are beginning to accumulate more shipping cases, and soon, we will need space for deep storage in the tin shed or Castroville.

Risk matrix (development and infrastructure projects only)

	Technical Risk	Organizational Risk	Tech Transfer Risk	Labor Estimate Risk
High				
Medium	X		X	
Low		X		X

Compliance and Planning Considerations

All responses must be recorded in the Google form linked below. A form must be submitted for every project.

Link to Google Compliance and Planning Considerations form ***-OR-***
https://forms.gle/mRYKKEztAPYaiTz7A