The Impossible Things Workshop 2025: A Review

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Forty individuals with diverse skill-sets and backgrounds from twelve countries spanning Europe, the Americas, Africa and Asia, joined together for two and a half days in Madeira Island to share knowledge and ideas for how to reduce the costs of deep-sea research. The event was organized by MARE-Madeira with partners GEOMAR and NTNU as part of the EU project TWILIGHTED – TWInning Laboratory for an Innovative, Global Hub To Explore the Deep – and endorsed by the United Nations Decade of Ocean Science for Sustainable Development as a Decade Activity.

This review is a record of the workshop's aims, format and outputs. It is designed to aid 1) other marine research institutes with limited funding that are aspiring to develop deep-sea research programs; 2) marine research institutes already working in the deep sea but seeking ways to be more efficient or creative to increase the rate at which they can conduct research; 3) other organizations within or beyond marine science interested in applying this model of workshop to their own impossible challenges.

I. Context

MARE-Madeira, a non-profit marine research institute in Madeira, Portugal, is developing a deep-sea research program that takes advantage of Madeira's easy, year-round access to deep waters and is trying to do so in a more globally-accessible way. This ambition aligns with sustainable development goals (SDGs) 9, 14 and 17[1] and a more inclusive future for deep-sea science – for Madeira is not the only place with access to the deep sea yet with limited local financing that makes state-of-the-art deep-sea research technologies impractical or unattainable. The more we can reduce the cost of doing deep-sea research, then the more research institutes will be able to develop their own deep-sea research programs, and the more quickly we can research and understand the deep sea's ecosystems, lifeforms and life-sustaining processes.

II. Workshop concept

The Impossible Things Workshop was designed to encourage creative thinking by creating opportunities for people from different disciplines and knowledge to contribute to the challenges of doing deep-sea research 'on a budget'. It was important that there was sufficient technical knowledge on current deep-sea technologies and constraints to guide discussions and answer questions, while also giving enough space to those from outside marine research to think freely and contribute ideas that the marine research community hasn't thought of yet (or may even be prejudiced against!).

[1] Addressing targets 9.5 (Enhance scientific research in all countries), 14.8 (Increase scientific knowledge, research and technology for ocean health) and 17.6 (Enhance international cooperation on and access to science, technology and innovation and enhance knowledge sharing).

III. Workshop format

The first Impossible Things Workshop took place on 17-19 March 2025 in a retreat format at the Dreams Madeira Resort in Caniçal, Madeira Island. Participants were divided across six areas that present challenges for developing a deep-sea research program in Madeira:

- Long-term monitoring
- Autonomous monitoring
- Imaging the deep
- Sounds of the deep
- Habitat mapping and data labelling
- Communication and navigation

Each research challenge was moderated by a marine researcher with relevant experience in the area, who could introduce the topic, joined by five additional participants who would drive the discussion with questions and ideas for how to solve the specific challenges presented.

The majority of the workshop was dedicated to small team brainstorming, but to include as many perspectives in each challenge area as possible, small teams presented their ideas to the entire group for a feedback session. There was also time to brainstorm individually (across any/all challenges), discuss ideas across teams on brainstorming hikes and to work in new groups for the final brainstorming session (Table 1).

Table 1. Impossible Things Workshop activities

Day	Duration (hours)	Activity	Format
1	1.5	Introductions to workshop, participants and deep-sea challenges	Group
	1.5	Technology showcase	Group
2	3	Brainstorming	Small teams
	2	Brainstorming hike	Small teams
	2	Ideas shared by each team, Q&A	Group
3	2	Brainstorming hike	Individuals
	1	Brainstorming (post-it notes wall)	Individuals
	2	Crazy-mode brainstorming and competition (pitch to room)	Small teams
	1	Most practical ideas – one year planning	New teams, led by idea enthusiasts
	1.5	Final presentation of ideas, closing ceremony	Group

IV. Challenge areas

The challenge areas and key questions were identified by MARE-Madeira researchers as those with the greatest relevance to developing a lower-cost deep-sea research program in Madeira, although they likely reflect the challenges faced more widely in deep-sea research at smaller institutes. They were then adjusted based on the expertise and areas of interest of the marine researchers chosen to lead each challenge.

Creating discrete challenge areas was complicated by the inherent overlap in both problems and solutions, but this overlap provided the space to brainstorm independent solutions to some of the more pervasive problems (e.g. of power, communication and data analysis).

Note that some challenges can be 'solved' today with state-of-the-art technologies, while others remain a challenge for even the most advanced deep-sea research programs. In either case, the framing for each challenge within the Impossible Things Workshop was: 'How can this be done at a lower cost, using less human resourcing and/or with simpler infrastructure?'

Challenge 1: Long-term monitoring	**Purpose**: to understand life cycles, changing ocean conditions and the ecology of deep-sea life
Key questions: ● How can we extend the life of hardware? ● How can we extend battery life (or find alternate sources of power in the deep)? ● How can we reliably deploy and retrieve equipment?	

Challenge 2: Autonomous monitoring	**Purpose**: to reduce the need for human oversight while exploring the deep
Key questions: ● How low-cost can we make an AUV? ● How reliably can we recover it? ● How does it navigate?	

Challenge 3: Imaging the deep	**Purpose**: to see the life that we can't capture in nets and observe their biology and ecology in situ
Key questions: ● How can we make low-cost housings? ● Can we reduce data/analysis and increase battery life with targeted imaging? ● How can we visualize and monitor planktonic life? ● How can we image bioluminescence?	

Challenge 4: Sounds of the deep	**Purpose**: to understand how animals use sound in the deep and to monitor biodiversity non-invasively
Key questions: ● How do we capture data in a low-cost way? ● How do we reduce data volume/analysis time and increase battery life of recorders?	

Challenge 5: Habitat mapping and data labelling	**Purpose:** to identify habitats and biodiversity hotspots, helping us know where to study deep-sea life and create MPAs
Key questions: ● How can we standardize data labeling across habitats, species and environmental conditions? ● Can we design plug-and-play ML/AI tools for small institutes (i.e. no AI expertise needed?)	

<table>
<tr><td>Challenge 6:
Communication and navigation</td><td>Purpose: to send data from sensors back to the surface or to know where equipment is or navigate in the dark/underwater without GPS</td></tr>
<tr><td colspan="2">Key questions:
How can we make autonomous navigation cheaper (and still reliable)?
How can we send data from deep-sea loggers back to the surface?</td></tr>
</table>

V. Workshop participants

In planning the workshop, inviting and selecting participants who represented a high diversity of thought was considered a top priority for fostering creativity and welcoming new ideas into marine research. In its execution, the workshop was close to achieving gender parity, with 44% of participants female and 55% male (Figure 1a). There were twelve nationalities and eleven countries of residence represented across four continents. This geographical diversity was aided by support from Blue Robotics, a marine technology company based in the United States, which generously covered travel grants for participants from Africa.

There was also a wide range of work or academic experience present, spanning mechanical engineering, computer science, ecology, business, design and psychology, among others (Figure 1b). Finally, a key part of this workshop's concept was to welcome individuals who have never had exposure to developing marine research methods or technologies. To this end, a quarter of participants had never been involved in marine research or technology at all – combining to a total of one third of participants not actively working in the area (Figure 1c). This feature of the workshop was felt to be essential for injecting novel ideas and for challenging experts in the field to question current practice and assumptions.

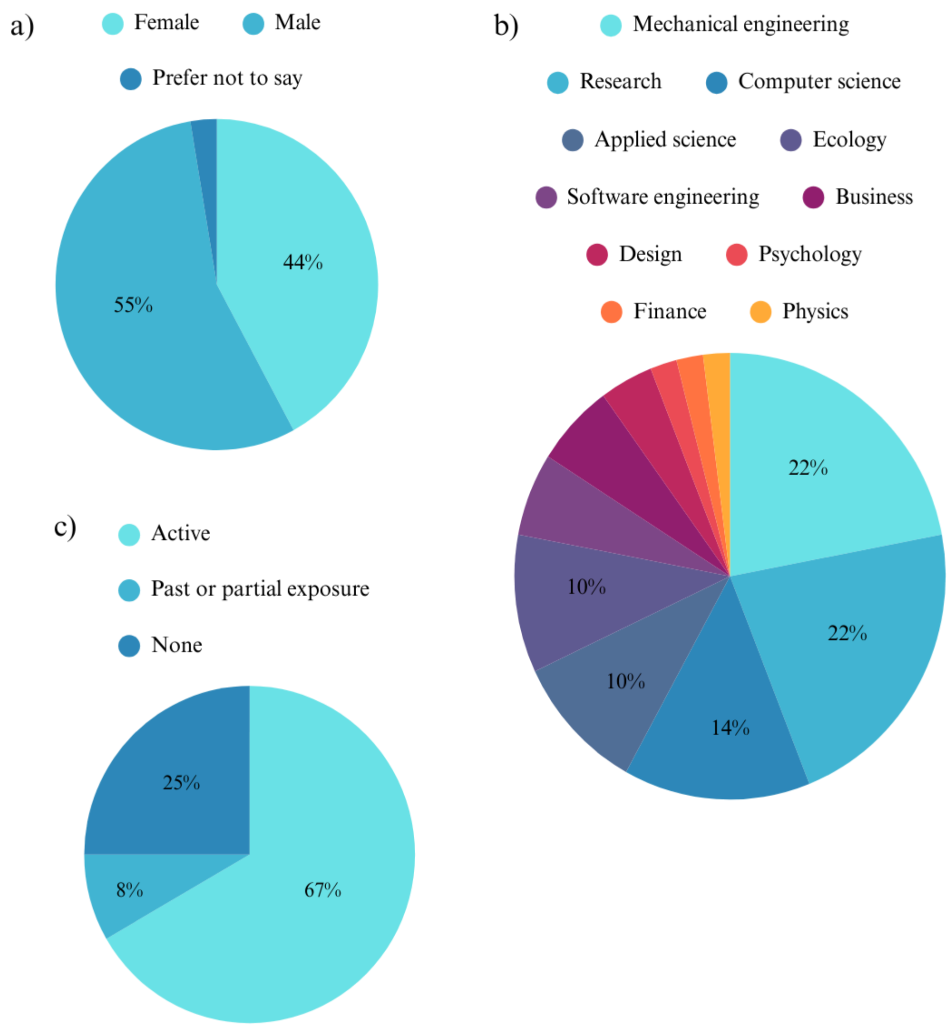

Figure 1. Participant diversity metrics. a) Gender diversity; b) Areas of work or study; c) Level of experience in marine research and/or marine technology.

VI. Ideas from brainstorming

With eight hours across two days dedicated to small team and individual brainstorming sessions, there were too many ideas from the workshop to include them all. What follows are some of the most striking ideas that emerged, ranging from easily implemented to "is that just science fiction?" We hope these can help other institutes in their deep-sea research tools and methodology development or trigger new ways of thinking.

Problem	Proposed solution(s)
General costs of deep-sea exploration	- Use resources in existing industries that are already offshore -- e.g. commercial, government. - Work with partners. E.g. there are 50-60k commercial vessels crossing the ocean, all equipped with GPS. Could they drop deep-sea pods (with sensors, for example) along their route?

	- Could we develop a renting system so that tech can be shared between entities? After a project ends, there is often a lot of unused equipment that could still be valuable to others. - Also, remember that data may already exist – it just may not be digitized. Echosounder maps from old cruises, for example. - Consider the lifetime cost of the entire system. Is it really that expensive? - Cheap for whom? The general purpose of deep-sea research is to identify areas of high biodiversity and protect them. If a cheap device means we mislabel the ecosystem, then we could face bigger costs to society down the line. This means the problem isn't necessarily an engineering one, but a social and political one. - Can involving Ecotourism help finance some of the costs?
Higher costs of 'deep-sea' parts from manufacturers	- Create a cooperative with partners and buy together. - Go directly to manufacturer with the design (don't say it's for the deep sea, just design it for the right pressure/conditions and place an order) - Open hardware. Create community, improve design by adoption. - If you are developing printed circuit boards (PCBs), these days, it is possible to get PCBs manufactured and populated within 3 days for $20 + parts cost from providers like JLC. Take advantage of this for fast turn-around electronics projects. - Explore FPV (first-person view) drone parts for low cost, lightweight sensors. In particular: cameras (+ a digital video recorder), microphones, BMS, batteries and power management, camera gimbals, high-end camera and software modules like VIO modules (for motion control near reefs), and microcontrollers (they are often tiny, cheap, powerful and possible to reprogram. e.g take FPV parts; plug them into a FPV drone microcontroller, optionally reprogram them, then encase the whole thing in acrylic.
Generating power	- Use an airbag attached to a line wound on a spool around an electric motor (thruster). Ignite the airbag and it will float up, unwinding the spool and generating electricity. The next step is to do some initial sizing and energy balance calculations for comparison against batteries. - Use shaking generator: magnet within a coil that shakes around from animal motion and creates power (used for flashlights already) - -- Piezoelectric stack on tags for deep-divers -- for stationary systems by attaching it to a flapping rubber flap or similar. - Use "magnetohydrodynamic" drive principle and apply it backwards to create power from water currents. Power without moving parts. - Tip: use batteries that are smaller than 100W (i.e. 98W). This makes it possible to ship them via air in the USA and Europe.
Saving storage space and/or power	- Use an accelerometer to trigger cameras and sensors on and off to save battery and storage on any deep-sea biologging - Reduce storage space demands with fish neural networks (neuromorphic computing), which has been shown to detect “fish vs. no fish” to date – can be used for on-site processing of sensor

	signals to avoid saving all data. Additional advantage of ambient temperature requirements/in theory, performance shouldn't be impacted by colder temperatures of the deep.
Active acoustics for habitat mapping or communication are expensive	- Low range / Garmin echosounders + Reefmaster software - Use synergies to lower costs (the more players benefitting, the more costs can be shared) - Use already-operating vessels around Madeira to collect data? Ecotourism, fishing fleets. (Drawback is that multibeam needs slow moving, back and forth…Porto Santo ferry?) - Create a rental market of old/written-off equipment at larger institutes or oil and gas companies.
Active acoustics for habitat mapping create sound pollution. Habitat can also be impacted by ground-truthing via deep-sea sampling.	- How much of either of these do we really need to do? If the end goal is to identify biodiversity hotspots to protect and study them, then do we really need to have a detailed map of every meter of the seafloor? Passive acoustics can help identify areas with the most activity instead.
Getting sensors to large depths	- Attach to fishing nets and lines - Have a drone with a spool of line that it can release, dropping sensors or cameras down. Like delivery drones now in use on land. Can help access areas that have rougher conditions (Madeira's north coast, for example)
Retrieving / communicating data or equipment back to the surface	- Revolver concept: use batteries/SSD's/cameras - detach as modules to be retrieved using deep-sea buoys. Main unit stays on the ocean floor. (Back in the day, satellites dropped film down to earth. Do the opposite? Beacon pops up with 5 TB of data?) - Minimize data transfer via data compression (on AUV/ROV) using latent space encodings (e.g. VGG16) - In case of bad weather, include a low-cost, simple acoustic unit for re-scheduling of retrieval date. For example, open-source AHOI acoustic modem from TUHH.
Imaging	- Fibers going down, each is a pixel, connects to camera at surface. (Very passive; no electromagnetic radiation) - 1,000m periscope with mirrors - Partner with scabbard fishery: obtain observations of scabbard fish behavior, leveraging local fishermen contacts and (low-cost) camera/ light units
Biofouling of equipment	- Diving bell "garage" for sensors/cameras to minimize fouling (e.g. timer controlled). A bathtub of air has 1L of volume at 1,000m. Use fresh water layer stratification in the bell, so to minimize corrosion with wash-through retrieval (or other liquids suitable for washing).
Reducing the costs of (reliable) hydrophones	- Open access to hardware prototypes to collect acoustic data. Provide user manuals to facilitate use. Many are already produced by many research institutes/private companies but not publicly available.

	- Use proven existing systems. NOAA autonomous underwater hydrophone (AUH) system. Rockhopper MARU (Cornell). Or redesign to reduce costs?
Labelling data (imagery or acoustic)	- Subsea "ImageNet" (collect underwater dataset to bridge data gap that limits AI applications underwater. Competition to classify subsea images to encourage creative ideas from global community) - Pre-train an acoustic generative model on all audio data: all locations, all types, above-water bioacoustics, general audio (speech, music) - If you have an existing dataset of recorded marine sounds, you could potentially host an ML model competition (i.e. on Kaggle) to get someone to build a classifier model for you. - Unsupervised clustering in learned embedding space for animal calls (esp new animals) - Work together with people from speech analysis/computer science etc to try new, outside-the-box methods for detection and classification of acoustic signals. - Start with soundscape analysis. compare soundscapes at different locations around Madeira and other locations. Species identification is not necessary for soundscape analysis. - VR tours of the deep sea: challenge users to identify habitats and species (what is a species vs what is the background) to help train ML model. How do we make it rewarding? If we figure that out, then it's a game that we can use to engage others in deep-sea exploration. (maybe if they find a new species, they get to suggest names and vote)

Find additional questions and observations from the teams in Appendix I.

VII. Crazy mode

To inject extra creativity into the workshop, there was time on the third day dedicated to a 'crazy-mode' brainstorming session. This took the form of a competition in which teams were challenged to come up with an idea that a) resolved any of the workshop challenges, b) least resembled any current solution used in deep-sea research and c) could be feasible on a ten-year time horizon. Following an hour of brainstorming, each team gave a pitch to the room that was graded by all participants based on the above parameters.

Pitch	**Concept**
Braintag	Using a BCI (Brain-Computer Interface), assess the senses and language of marine species (e.g. dolphins) to answer key biological questions of cetaceans and monitor the deep-sea environment.
Deep-Sea Shazam	Adapt retired sonobuoys (acoustic recorders attached to a floating buoy) from the US Navy by adding an automatic classifier that works like Shazam for vocalizing marine species. Deploy sonobuoys around Madeira and when a Shazam 'match' is identified, the buoy sends a signal and a team goes out to collect the hydrophone data.
Educational Porpoises	Develop a network of cetacean-like robotic AUVs, each equipped with real-time video streaming, environmental sensors and hydrophones for passive acoustic monitoring. The AUVs gather data, while allowing people to engage in immersive, hands-on

	digital underwater experiences. Each AUV Porpoise docks at a floating station – the Madeira Floaty Thing – equipped with GPS and connected to Starlink for transmitting data back to land.
MAD-DNA-A	Create a low-cost deep-sea eDNA sampler for species discovery using whole genome single-cell sequencing of filtered water samples, allowing for taxonomy and population genetics and to identify areas with high diversity (indicating biodiversity hotspots).
Project APEX	The APEX (Autonomous Predator Explorer) combines a shark-brain interface (Neuralink) with an energy harvesting system (a flexible solar panel jacket), biologging tags and an eDNA sampling system. This long-term monitoring shark jacket recharges its biologgers each time the shark comes to the surface via its solar panels and communicates data with surface buoys via radio and Bluetooth.
Seasense	Seasense adapts the MARE-Madeira multipurpose auto-release system (MARS) to be triggered on-demand rather than pre-programmed. The new MARS will be equipped with underwater piezoelectricity to allow surface triggering via an acoustic emitter, leading to the ignition of the primer, release and ascent for surface recapture of the deployed deep-sea monitoring equipment (e.g. BRUV, hydrophone or drop camera)

One of the great things about this session was that some ideas had elements that were both innovative and feasible and inspired some of the one-year plans in the final session of the workshop.

VIII. One-year implementation plans

Participants were invited to self-organize into new teams, each focused on an idea they (or others) were enthusiastic about that 1) resolved any of the deep-sea research challenges presented and b) they believed could reasonably be implemented in Madeira within one year. Six ideas were developed in this way, as described below.

Idea	**Description**
Underwater cabled observatories (Challenge 1)	For long-term monitoring in Madeira, cabled observatories offer relatively low-cost (with limited environmental data) and high-cost (with high-value ecological data) options implementable within a year. Both options could deploy cables down Madeira's steep slopes to around 500-600m, with sensors (low-cost) or other monitoring devices (higher cost) attached incrementally along the cable to gather data at discrete depths. <ins>Lower cost</ins>: - Deploy thin fiber optic cables (not strongly armored) with basic environmental sensors at nodes along the cable. - Data: Environmental data (oxygen, salinity, temperature) and hydroacoustics transmitted via the fiber-optic cable. These sensors are low energy-intensive. - Cost: <€100,000 full set-up, similar to a system already in Bermuda. Cable costs around €5,000 (€5/meter and with 1,000m of cable, can reach around 500-600m in depth off Madeira's coast). <ins>Higher cost</ins>: - When new subsea cables are laid in Madeira (2026), the cable-laying ship can also bring up the old cables and allow the installation of an observatory and SMART nodes (to attach sensors and other equipment such as cameras, lights or hydrophones) on the cable.

<table>
<tr><td></td><td>A similar set-up already exists in Hawaii (Station Aloha) and Norway
Cost: millions for installation and maintenance, but these systems can last for up to 20 years. Furthermore, each node can receive 10 kW of power, for example – compare to other deep-sea monitoring systems where supplying 1W for a year of monitoring is a major challenge.</td></tr>
<tr><td>eDNA monitoring

(Challenges 1 & 5)</td><td>For biodiversity sampling and monitoring or detection of microplastic contamination or other chemical contaminants in deep-sea environments, a water filtering system can be developed, contained in high-pressure-resistant housing, deployed via fishing line (used for scabbard fishing in Madeira) and attached to a buoy until recollection.
<u>Basic components</u>: filter, pump, battery, microcontroller, housing, deployment system. Make low-cost by using commercially available parts.
<u>Specifications</u>:
Filter: cheap, replaceable, interchangeable based on what you’re measuring
Valve: to make sure the system only draws in water when turn on pump
Pump: with ability to measure current drawn through so know if it’s clogged (and can estimate how much water passed through for quantification)
Battery: probably need 2Wh to pump 100L across filter (~1/5 of a mobile phone battery)
Microcontroller: to measure current drawn through pump and to ensure the system only pulls through water at desired depths (most basic: could have a timed start for the pump, estimated as the time to unspool fishing line to desired length – timer programmable on phone via Bluetooth). Basic option ESP32.
Housing: 3D printed. Could have several filter channels to reduce mechanical pressure.</td></tr>
<tr><td>Acoustic recording platform

(Challenge 4)</td><td>For passive acoustic monitoring of marine life and human disturbances, a low-cost recording platform can be developed for depths to 1,000m at an estimated cost of €3,500 including an acoustic release system.
<u>Basic components</u>: hydrophone (€1,500), pre-amplifier (€35), audio card (€60), Raspberry Pi (€70), DC-DC converter (€50), deep-sea buoy (€1,000), penetrator (€15), 14.8V lithium-ion battery, Dyneema (fiber cable for tether, €50), pressure vessel (PV, €300), hardware (€50), MARS release system (€100).
<u>Specifications</u>:
Tether: allows system to float 10m above seafloor (where it is expected to have a downward-refracting sound velocity profile)
Penetrator: located on the pressure vessel, to help ensure clean acoustic recordings
Hydrophone: similar to what is being trialed by M. Schinault at Northeastern University
If a modem is added, it permits this system to communicate with an acoustic release system (adds ~€100 of cost). This modem signals that it’s running out of battery or memory or that the hydrophone isn’t operating (it’s not sending raw data). Could send SOS signal to topside source with low-frequency underwater speakers, like Lupen (used for synchronized swimming).
Housing: off-the-shelf from Blue Robotics or could 3D print
Raspberry Pi: used successfully for a surface hydrophone in the WAVY-NOS project. Can model this deep-sea system on that success.
This platform is an opportunity to get clean data affordably for acoustic processing. By deploying multiple systems, you could also estimate the origin of the sound with a rough time difference of arrival.</td></tr>
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Madeira Floaty Thing (Challenge 1)	For long-term monitoring and education, a mobile platform could be developed and made inexpensive through shared use. A similar concept has been used for health education and support (e.g. Rotary International's AIDS Clinic – The Africa Project). - The Madeira Floaty Thing (MFT) is a floating platform made for open ocean weather. It uses renewable energy for propulsion and electrical on board power. It can be equipped with sampling systems, cameras, hydrophones, multibeam sonar and an ROV. Connected to a satellite network, or mobile network, data from this system can be live-streamed to aid education and remote operation. - All equipment and the MFT can fit inside a shipping container, making this system mobile and deployable around the world. This high-cost system can then be shared globally, used for both science and education.
Multi-modal species identification (Challenge 5)	For identifying species from a variety of deep-sea monitoring sources, a consistent protocol for aggregating and sorting data can aid the development of ML/AI programs that speed up the process. Step 1) Aggregate the sort data from acoustic, visual and/or sampling sources. Sync wherever possible. Use collaboration to access more data. Step 2) Label unknown species in a standard annotation format. Can we outsource to AI platforms? Can we make ML processing more accessible by training domain specialists in marine biology to use these tools more effectively? - In one year in Madeira, this could be trialed by mapping locations with known species and pairing this with audio and visual data. This could be done in healthy and degraded locations for comparison. - By standardizing annotations, a pipeline can be established for data annotation, making it easier for ML/AI processing in future.
Deep-sea education and ocean literacy	To aid education and to inspire the community with the deep sea in Madeira, a program could be co-developed with multiple stakeholders --including schools, the government and businesses. One-year plans were divided by stakeholder and included the following actions: - Schools: Drawing contest of Madeira's marine species, from which a mural by a professional artist could be commissioned; 'Messages in a bottle' (older generations share stories about the ocean, which are in bottles and share with schools); Create a deep-sea observatory live feed, with chat bot for students to ask questions to scientists. - Government: Deep-sea educational boards along coastal walkways/marinas ("What's under the water?"); 'Festa do Mar Profundo' (day with storytelling, music, food, booths). - Businesses: Design a 5-course menu featuring sustainably-caught species in Madeira with a local chef and provide diners with information about how these species interact with the ecosystem and deep sea; work with natural history museum to create interactive activities that bring species on display to life, with an AI chatbot to learn more.

IX. Feedback, future and final thoughts

On the morning of the third day, we gathered feedback from participants to take the temperature of the event and solicit ideas for how to best spend the rest of the day. This gave time to redress expectations that hadn't yet been met, to increase the utility of the outputs for the MARE-Madeira team and to generally improve the success of the workshop. Specifically, the 'crazy-mode' brainstorming and one-year implementation plans were ideas sourced from participants and both ideas helped keep the energy of the workshop high and led to a mix of thought-provoking and practical ideas.

For any institutes inspired to replicate this workshop, below is a summary of the participant feedback from which to learn from our successes and from our areas for improvement! For the elements of the workshop that worked well, we summarized the feedback with ChatGPT (being an impartial reviewer):

"Participants overwhelmingly praised the workshop for its inclusive, interdisciplinary atmosphere and dynamic format. The mix of technical and creative sessions, including outdoor brainstorming hikes and the technology showcase, energized participants and promoted open discussion. The diverse backgrounds of attendees and encouragement for everyone to contribute were frequently cited as major strengths."

Areas to improve for future workshops, based on participant feedback and MARE-Madeira reflections include:

- Offer an introduction to each of the challenge areas as a whole group (not just in individual teams) so all participants feel primed with all the research challenges and are oriented to the 'end goal' / deep-sea research objectives before diving in.
- Before splitting into small groups, lay out some brainstorming 'rules' to help ensure all voices are heard and all ideas (especially the wild ones!) are encouraged.
- It's important to find a balance between a) placing people outside of their area of expertise to inspire new ways of thinking and b) giving people the chance to contribute within their area of expertise. The self-selecting teams on the third day provided a way for people to follow their own interests, which was important.
- Streamlining and standardizing note taking (perhaps integrating more audio recordings and automated transcripts?) will help post-event reviewing and reporting.
- Mechanisms that allow for future collaboration are really important, as is real-life (future) feedback on how the ideas from the workshop are being used.
- Six groups with six individuals each led to a lot of ideas, and perhaps a few too many for one workshop. We'll likely limit this to four or five groups of five to six individuals each for the next workshop.

Overall, we highly recommend using multi-disciplinary, cross-sector and highly diverse groups with a range of expertise to think up new solutions to difficult problems. Of course, the people who participated were far more than a collection of diversity metrics, and we could see the immense value of recruiting personable people with a positive energy and open mindset -- together, such people can create a cooperative environment where the diversity of thought and experience can be better captured. The ideas brought by participants to the Impossible Things Workshop were valuable in many ways to the MARE-Madeira team and will help the institute conduct more creative and cost-effective deep-sea research going forward.

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X. Appendix

Appendix I. Additional observations and questions from some challenge areas

Challenge	**Observations and questions**
Sounds of the deep	For acoustic identification and monitoring of deep-sea species, the three main challenges relate to: 1. Hardware – reliable and high-quality data acquisition 2. Labelling – use of automated methods (how reliable?) 3. Data processing – AI tools *("Asking one PhD student to be an expert in all three seems to be asking a lot...")* Hardware (status quo): - Fixed cabled buoys – issues to align and synchronize - Towed arrays – good for species confirmation through visual observers onboard - Autonomous recorders – probably most cost-effective ways we have so far to collect acoustic data - Biologgers – fine-scale high-resolution tags, affordable and reliable and commercially available Incorporating AI - Labelling data is the biggest limiting factor at any institute, and especially small ones. - How much data can we get versus what's the minimum data needed? We didn't come to an answer. - It's easier to build a particular classifier rather than a generalist one, even though biologists want to detect and classify ALL sounds! Generalist classifiers means training the model is more tricky and the outcomes are more uncertain. - Training a classifier in one region in the ocean and using in another region works badly in most cases. Can use benchmark datasets (e.g. NOAA's passive acoustic data and HARPS from Scripps), but shouldn't generalize across locations without doing rigorous testing. So existing datasets in other regions may be of limited use.
Communication /Navigation	Two main challenges: 1. How can we make autonomous navigation less expensive? (and still reliable) 2. How can we send data from deep-sea loggers back to the surface? Review of the physics of acoustic and optical propagation (and the limitations and proven performances measured so far): 11 bps data rate successfully measured and used at a distance of 9,000 km for both communication and positioning (velocity via Doppler shift, compared with ship GPS; Heard Island Experiment 1991), 2 km error for range measurements over 1,900 km using narrow band 250 Hz source (RAFOS), about 100 m accuracy over 700 km in Phil Sea using broadband source (200 Hz, 50 Hz bandwidth). Prediction: to get better than 50 m accuracy over 1,000 km need to have estimate of sound speed field. Main ideas discussed: - Smart cables with integrated acoustic gateway and transponders for providing underwater wireless access points and the underwater positioning system. The SMART cable initiative presents an opportunity to provide cabled power and data infrastructure for the scientific community by adding wireless access points and positioning system-supporting nodes throughout the infrastructure. *(long-term, reliable)* - Accelerated life testing to improve the reliability of sensors underwater. *(long-term, reliable)*

	- MicroElectroMechanical Systems (MEMS). See Yang Yang, et al 2024 *(low-power, low-cost, from scratch approach)* - Battery-less backscattering transducers. *(low-power, low-cost, from scratch approach)* - Neural Acoustic Fields (NAFs) to model underwater sound propagation by encoding physical water properties, such as salinity and temperature, enabling innovative, potentially low-power, and low-cost underwater physical simulation and soundscape analysis. *(innovative underwater, potentially low-power and low-cost)* - Involve fishery boats in underwater communication tests by providing visual information during their operations, helping reduce bycatch. *(low-cost, from scratch approach)*
Habitat mapping/ data labelling	Questions discussed: General limitations and costs: - What are the current barriers to scaling up deep-sea habitat mapping using cost-effective technology, and how can they be overcome? - What emerging materials and technologies could play a role in improving the efficiency and cost of deep-sea sensors or equipment? - How can smaller institutes access habitat mapping/echosounder technologies? Acoustics: - How can we identify and reduce the impact of noise and interference in acoustic data collected from deep-sea echosounders? - How could we overcome the challenges of interpreting acoustic backscatter data in deep-sea environments? - How can we improve the ability of acoustic systems to detect and classify biological features in addition to physical seafloor characteristics? Ground truthing: - Is there any way to ground-truth deep-sea habitat maps beyond observational methods and sampling? (Below 200m, no hyperspectral or remote sensing technologies, such as satellites or airborne drones, will work) - How can we minimize the ecological impact of deep-sea sampling for ground-truthing? - Which of these methods offers better scalability at a lower cost? Scalability & Standardization: - What steps can be taken to improve the accuracy of habitat maps, including classification approaches, spatial resolution, and replication of samples? - How can we standardize methods and data interpretation for deep-sea habitat mapping to improve comparability across studies and regions? - Could plug-and-play ML/AI tools reduce the human resourcing (and expertise) demands of data labelling at small institutes? How can we make them relevant across habitats, species and environments? - Could citizen science or crowdsourced data (e.g., from fishing vessels) aid deep-sea mapping efforts?