Roinn Cumarsáide, Gníomhaithe ar son na hAeráide & Comhshaoil
Department of Communications, Climate Action & Environment

Geological Survey
Suirbhéireacht Gheolaíochta
Ireland | Éireann

Research Programme
- Short Call 2022 –
- Final Report -

Lead Applicant Name	Florian Le Pape
Host Organisation name	Dublin Institute for Advanced Studies
Project Title	Marine Acoustic Noise and Signals Localisation, a Test Experiment in Galway Bay Observatory (MANGO)
Contract Number	2022-sc-023

This report covers the period 1st November 2022 to project end date 31st October 2023

Research Programme
- Short Call 2022 –
Final Report

2. (a) Project information: [*est.* ***2191*** *words excluding figures and headings*]

Final project report (*max* ***2500*** *words, excluding figures and headings*):

Executive summary:

Human activities at sea are likely to increase substantially in the coming decades, as new marine renewable energy technologies are being developed to tackle the climate change threat. However, such infrastructures will bring further invasive devices into the marine world, where anthropogenic acoustic nuisance is already prevalent in the context of environmental impact on marine animals. In addition (and in contrast to most land experiments) marine surveys involve complex logistics where approximative instrumentation designs affect survey outcomes at a great cost. In this regard, the SmartBay facility located in Galway Bay provides a unique opportunity for ocean researchers to test instrumentation and validate new methodologies.

Here, this project has implemented and tested hydrophone array designs for underwater acoustic noise localisation at the SmartBay facility using iMARL's equipment. The iMARL (www.imarl.ie) national infrastructure for marine sensing, offers a broad range of acoustic sensors, with great potential for further developments in new acoustic sensing schemes in Ireland. A new design for acoustic noise and signals localisation with broad frequency coverage has been achieved with pilot testing at the SmartBay facility to locate and track "sound events" in the bay associated with ship traffic and local marine life in Galway Bay. Hydrophone array analysis has been performed to determine the limitations of the iMARL lander, as well as to validate the use of acoustic recorders as standalone equipment for broadband acoustic signals localisation.

Providing reliable geoscience assistance for environmental protection and supporting sustainable development of Ireland's natural resources are key features in the GSI research roadmap objectives. In the marine sector, those thematics rely on the development of acoustic equipment and infrastructures on the Irish seabed for monitoring marine life response to ambient acoustic pollution generated by offshore infrastructures and vessels traffic.

(i) Results, scientific/engineering targets reached beyond the state of the art and conclusions

Capacity Building (Ocean Acoustic Monitoring) & Insights into Future Deployments of iMARL acoustic Equipment

The successful design, stress testing, deployment and recovery (April-May 2023) of both lander frames that housed the iMARL equipment has provided invaluable information to revise future lander-based project designs in both shallow and deep water environments using iMARL acoustic equipment. The original lander design incorporated buoyancy floats in order to facilitate a waste-free recovery. However, the combined in-air weight of the main lander frame, iMARL equipment and 14 floats totalled more than 1,000kg. In order to mitigate for damage due to bowing or structural collapse during transit, an alternative recovery mechanism resolved the issue. Instead (and with the invaluable support of P&O Maritime), an L-shaped mooring was attached to the top of the lander, with mooring rope secured to the frame's side, coupling it to the seafloor. **This anchor and flotation-free design yielded hydrophone data with little to no negative impact on the recorded acoustic noise field (figure 1)**, **demonstrating the configuration to be a viable engineering solution for future hydroacoustic studies (in line with deliverable 1, validation of methodologies using iMARL equipment).** The resulting dataset contrasts with hydrophone data from the separate small lander, which contained higher amplitude noise, generated by a surface buoy shackled to the frame. Here, the shackling repeatedly collided with the frame and generated impulsive noise due to ocean currents (figure 2).

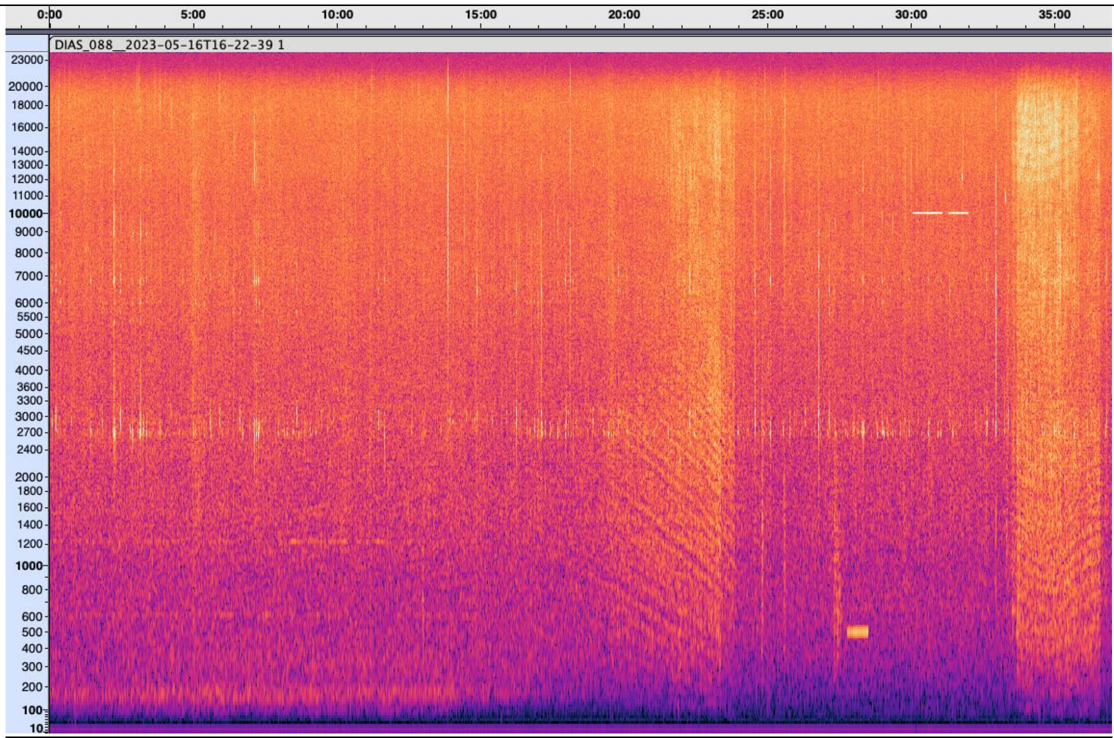

Figure 1. Example of high quality data with minimised equipment noise. Shown is a 0-24kHz spectrogram from approximately 37 minutes of data as recorded by the first hydrophone channel (high-frequency array) on the main lander on 16/05/23.

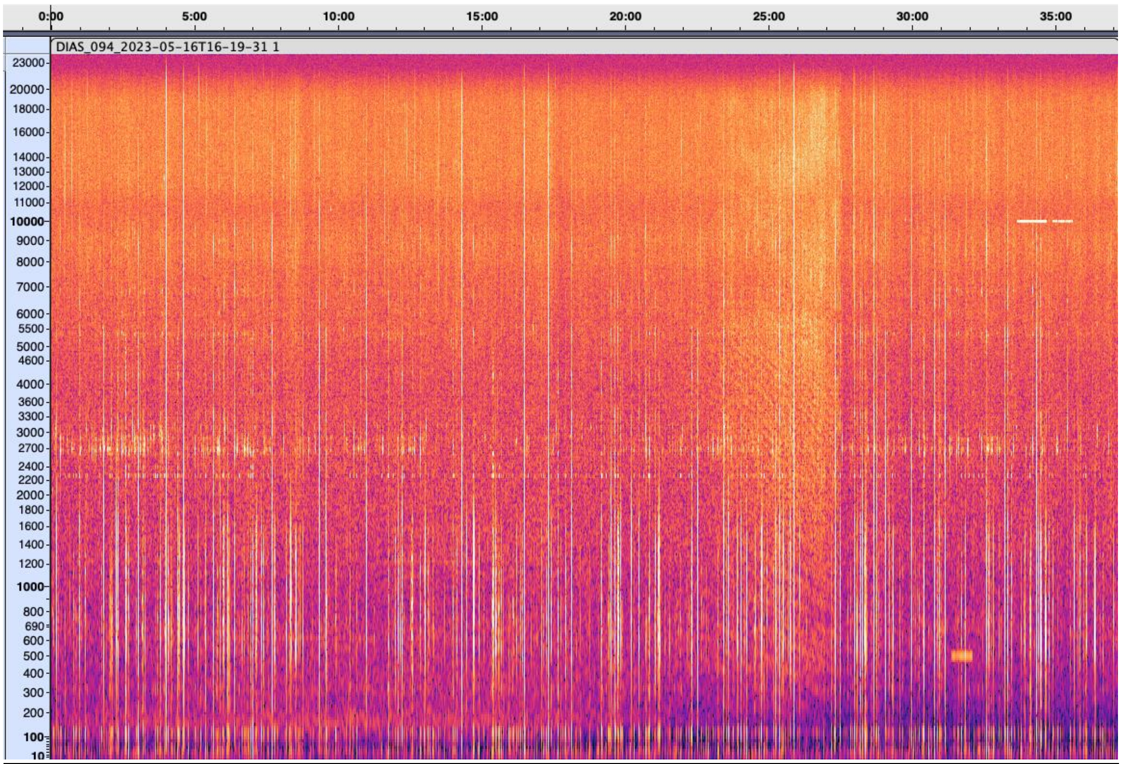

Figure 2. Same as above but for the small lander. Here the effect of repeated collision between lander and anchor-buoy shackling is clearly visible. All subsequent beamforming

using hydrophone data gathered from the small lander requires careful time window selection to avoid including this equipment noise in beamforming measurements.

In addition to successful deployment and recovery of iMARL hydrophones and recorders, the main lander facilitated the collection of ocean temperature and pressure data using an RBR pressure sensor housed on the frame (figure 3). While not a main focus of this research, the data can now be used for sound propagation models in future work.

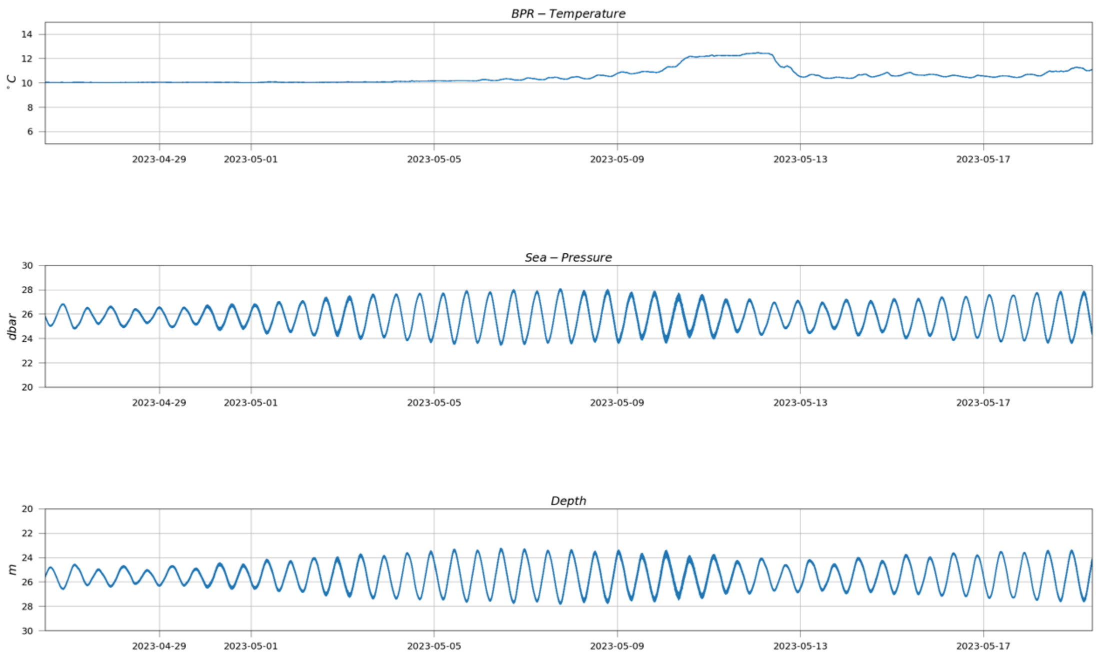

Figure 3. Time series data accumulated from the RBR pressure sensor deployed on the main MANGO lander. (top) Temperature profile. (middle) Pressure and (bottom) depth, with twelve-hour periodicity likely to be tidal effects (pers. comm via DIAS technical officer).

MANGO Reference Dataset & Characterisation of Acoustic Noise in Galway Bay

Figures 4-7 demonstrate the different types of acoustic noise detected during deployment, which we break down into four categories: A) small cetaceans (dolphins) B) possible large mammals (whales) C) shipping vessels D) equipment/mechanical noise. At the time of writing, approximately 450 candidate signals have been identified and annotated in spectrograms from high frequency hydrophones on the main lander.

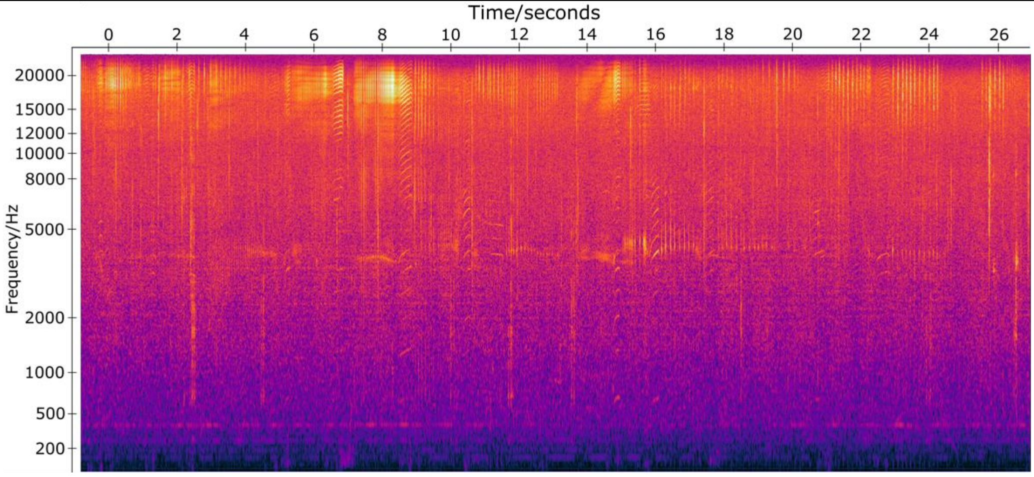

Figure 4. Spectrogram record from hydrophones as recorded at the SmartBay facility between April-May 2023, chosen to showcase the range of detectable bioacoustic and anthropogenic noise sources in Galway Bay. Shown here are dolphin whistles and clicks, 06-05-23, 6:12pm.

Signals that we consider highly likely to be dolphin signal exhibit strong variety across the useable frequency range (<24kHz). Patterns include broadband impulsive 'chirps', clicks, M-shaped signals with multiple overtones (overlapping) and sinusoids. Based on the spectral content of these signals, the calls are likely to be from bottlenose dolphins (figure 4).

In addition, several dozen low frequency signals were suspected to be the grunts of large mammals: though not detected at the specific times of visual sighting, candidate noises suspected to be large mammals were often recorded within a few hours either side of the visuals. A case in point is figure 5. Two suspected humpbacks and one minke whale sighting were reported to the IWDG between 05/05/23 and 06/05/23, at Spiddal and Furbo, Co. Galway i.e. within 2-3km of the SmartBay facility. Visual reports note that the large mammals 'gave a strong blow' in between diving. Based on the MANGO dataset, there was a quiescence in spectral signals typical of minke and humpback calls at the exact time of visual sighting by hydrophone data used in this study, although audible and abundant grunts and blowing noises were recorded several hours before. **This is a result in itself because it demonstrates how acoustic detection can provide information on cetacean behaviour in addition to locating them.**

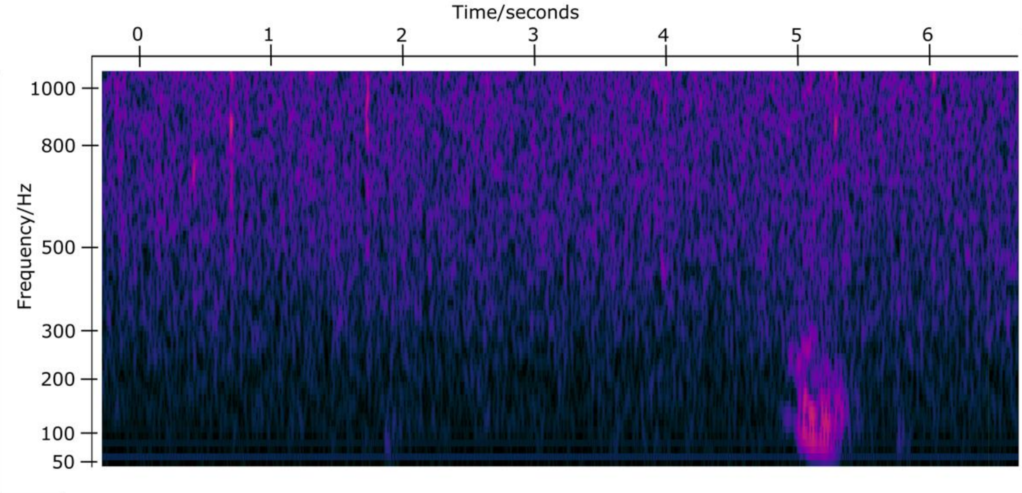

Figure 5. Spectrogram of suspected large mammal, 06-05-23, 12:40pm.

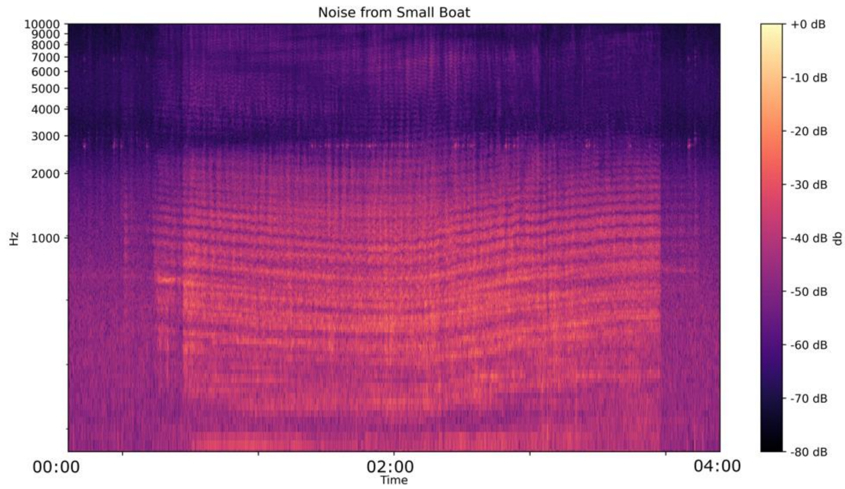

Figure 6. Noise track from a small vessel approaching and passing the SmartBay facility, 16-05-23, 5:56pm i.e. the small vessel used for the sound projector experiment implemented for this study.

Figure 7 is a prime example of mechanical noise discovered in the MANGO dataset. This signal was encountered at regular intervals across multiple portions of the database. Lab tests by DIAS technicians (figure 7) confirmed that this signal broadly conforms to the spectral signal from noise generated by the acoustic releaser of the OBS deployed north of the landers as part of this experiment**. This mechanical noise is an unexpected but useful result due to its known location. This will be used for further quality checking of lander rotations quoted in this report**.

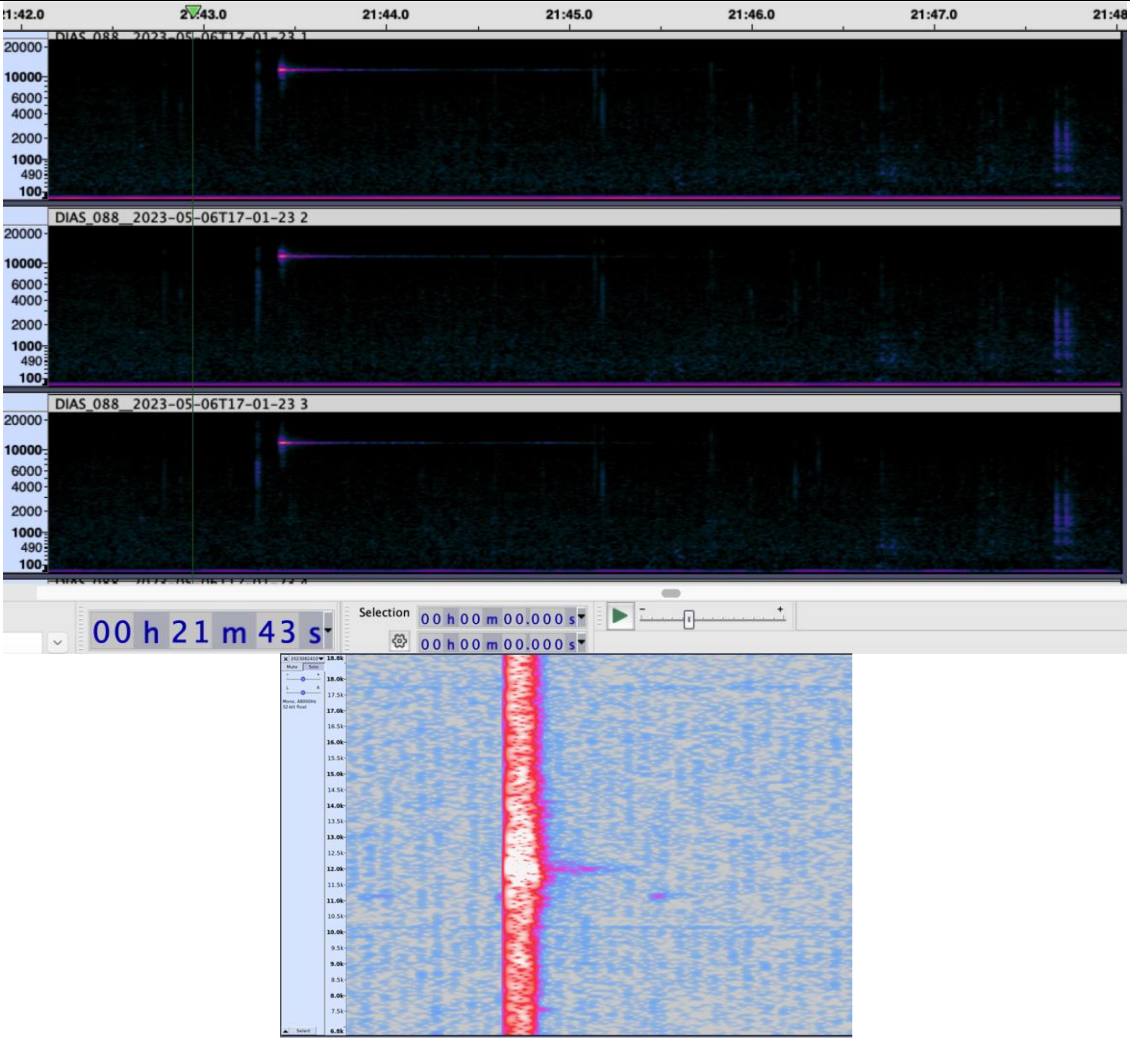

Figure 7. Mechanical noise, likely from the triggering of the acoustic release mechanism on the OBS deployed during the MANGO experiment. The OBS was located north of the two lander frames. Investigation into the reasons for the triggering of the release mechanism is ongoing. The top panel shows the mechanical noise source as recorded on three hydrophones on the main lander on 06/05/2023. The bottom panel shows a test trigger of the OBS acoustic releaser in an experimental tank in DIAS after the experiment's completion (pers. comm. By DIAS technical offiers). There is strong spectral overlap between the field-observed and lab-observed signals. Both exhibit the same wide-frequency pulse followed by ~12kHz tapering.

Signal Localisation & Mapping the Galway Bay Acoustic Noise Field

Figures 8 and 9 represent examples of ongoing testing for source localisation using iMARL hydrophone arrays on each MANGO lander. Here we show the beamforming and best estimate triangulation process for suspected large mammal noise shown previously (figure 5). Figure 8a shows the estimated source direction from the high frequency array on the main lander using a 1s beamforming window. The maximum semblance broadly overlaps with the detected source direction around the known time of source, as well as a consistent slowness ~0.68s/km (slownesses in the range of 0.65-0.69 s/km are expected for plane wave propagation in water). Figure 8b repeats this process for the high frequency array on the small lander using 0.25s beamforming windows. After recording inbound signal back azimuths of 320^o and 132^o, these are corrected to 170 ± 20^o and 138 ± 24^o respectively from estimations of both landers orientations (see implementation section). Figure 9 shows the estimated source triangulation. Here the point of intersection between estimated mean back-azimuths is calculated (red pin). The standard deviation of each of these measurements is also projected from each lander (straight lines), whose overlap is used as an approximate bounding area for the possible source location.

Future work will seek to consolidate these beamforming measurements. Lander rotations will be further constrained using known noise locations (e.g. figure 7). A further line of enquiry is to repeat the process shown here using more advanced beamforming tools. Several possible software packages include:

- Geopsy-fk, which mitigates for side lobe suppression for array response functions
- MUSIC (**m**ultiple **si**gnal **c**lassification), which takes into account the ambient noise wavefield when beamforming on a specific signal (pers. comm.).

An additional challenge encountered when beamforming on real data is deviation from the expected slowness values in water (~0.66s/km). This could reflect a breakdown in the plane wave approximation. In limited cases, plane waves arriving oblique to the array in the vertical plane may exhibit lower slowness. Higher slowness values may originate from increased time delays due to multiples/reflections (i.e. for a given hydrophone array, some instruments may detect the first arrival as the largest noise source, while others detect the later-arriving multiple) (pers. comm.).

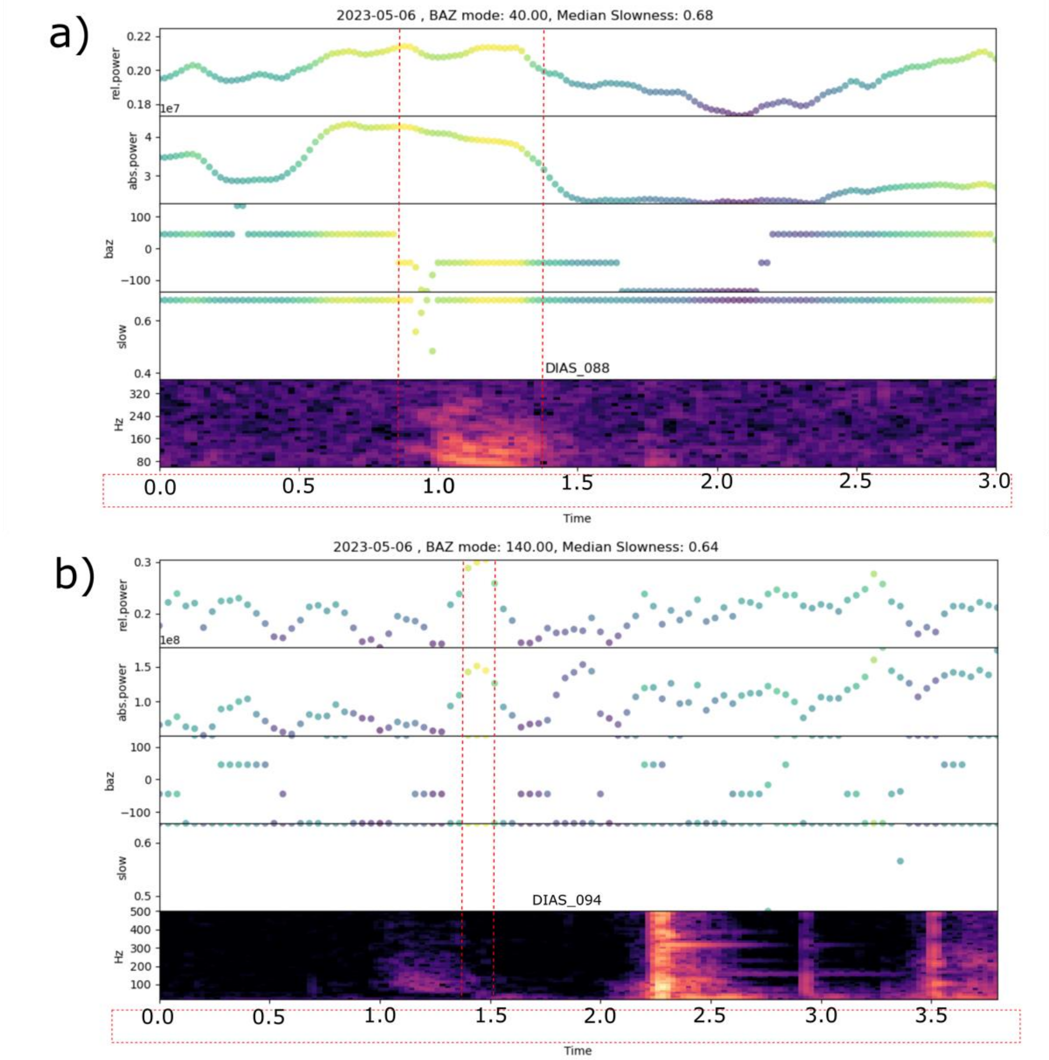

Figure 8. Example signal localisation performed on the suspected large mammal low-frequency noise shown in figure 5. a) Estimation of source localisation from the high frequency array on the main lander. Panels shown from top-bottom are semblance, absolute power, estimated back-azimuth, estimated slowness of the incoming signal and spectrogram from one channel of the hydrophone array for reference. Estimation is based on a 1 second moving beamforming window over a 50-320Hz bandwidth, with very high overlap (98%). The red lines broadly collocate with overlapping maximums in semblance and power, as well as consistent slowness and back-azimuth. Here an inbound signal with back-azimuth of 320^{o} is estimated (170 ± 20^{o} after correction). b) Same process for the small lander (panels same). Estimation is based on a 0.25s beamforming window with ~90% overlap, over a 50-320Hz bandwidth (138 ± 24^{o} after correction). Note the very high amplitude anchor shackling noise following the signal of interest, which is a clear example of the additional challenges posed when using the small lander data for beamforming. <u>Note that these measurements are subject to further ongoing testing</u>.

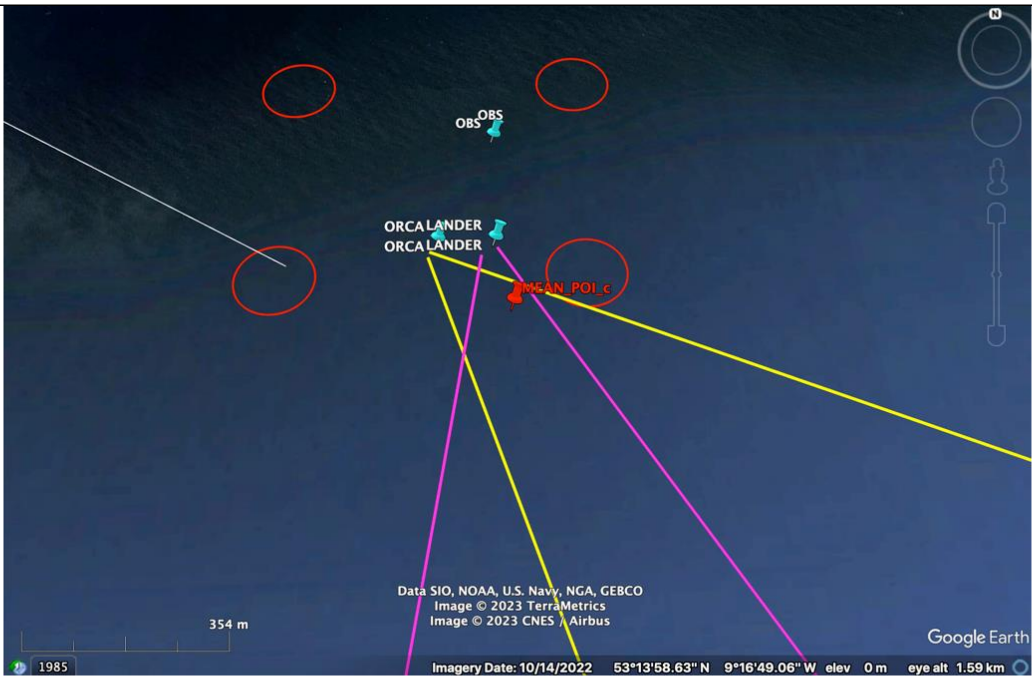

Figure 9. Source location estimation based on the beamforming in figure 8 (above). Yellow lines show the upper and lower back-azimuthal bounds (mean lander rotation bounded by one standard deviation) for the estimated source direction using the high frequency array on the small lander. Pink lines show the upper and lower back-azimuthal bounds (mean lander rotation bounded by one standard deviation) for the estimated source direction using the high frequency array on the main lander. The red marker is the point of intersection based on the two mean back-azimuth-corrected measurements. The overlapping area between the yellow and pink conic projections is a proxy for the bounding area of the estimated source location. <u>Note that these measurements are subject to further ongoing testing</u>.

(ii) Project Implementation

Milestone: Experiment

Please see section (i) for details on the successful deployment (26/04/23) and recovery (19/05/23) of all planned equipment.

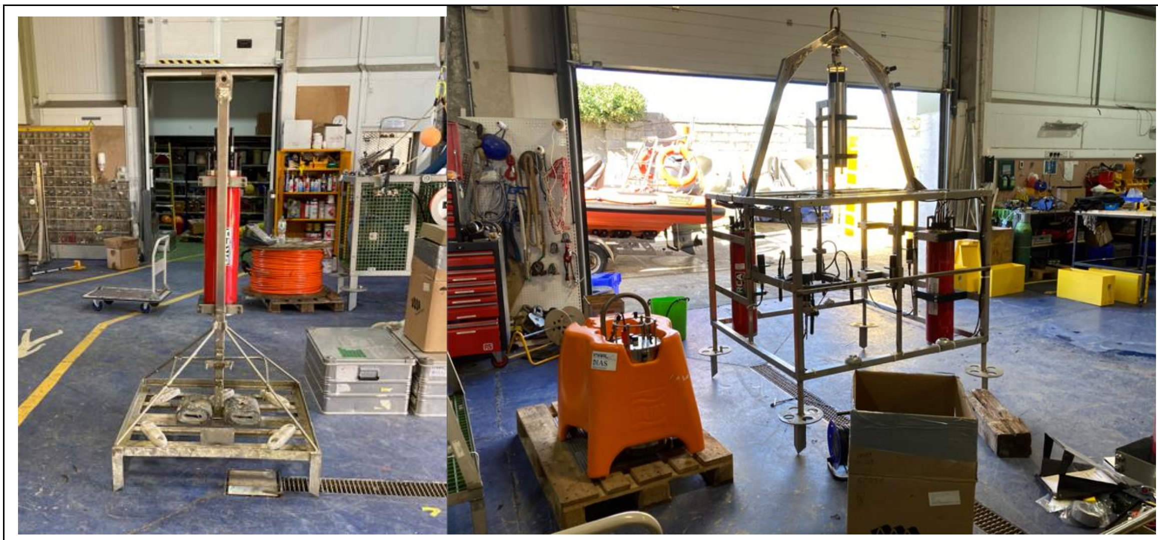

Figure 10. Landers deployed during the MANGO experiment in Galway Bay. (left) Small lander housing a single ORCA recorder and five-hydrophone high frequency array. (right) Main lander frame housing two ORCA recorders, one broadband five-hydrophone array (~1m spacing) and one high-frequency five-hydrophone array (~15-30cm spacing). Also visible is the GPS beacon at the top of the main cage, an RBR pressure sensor and the OBS deployed during the experiment (orange unit).

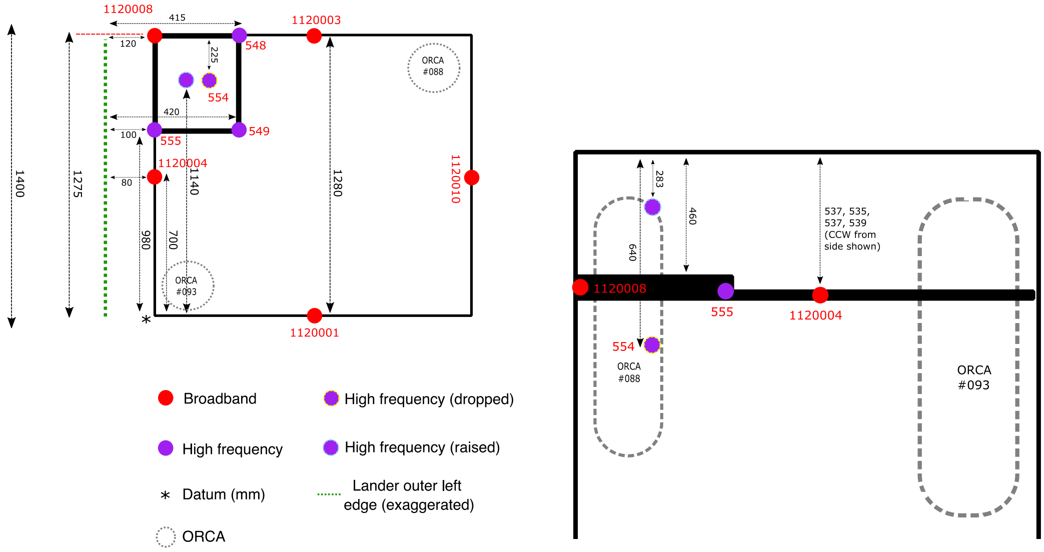

Figure 11. Schematic of the main MANGO lander with measured hydrophone apertures. (left) Plan view. (Right) Sideline view. All measurements are in mm.

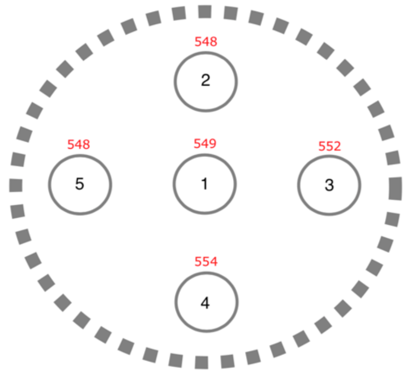

Figure 12. Plane view of high frequency array deployed on the small lander (to the west of the main lander). Aperture spacing between neighbouring hydrophones is 37.5mm. Numbers in black indicate hydrophone channel numbers and red numbers mark the hydrophone ID.

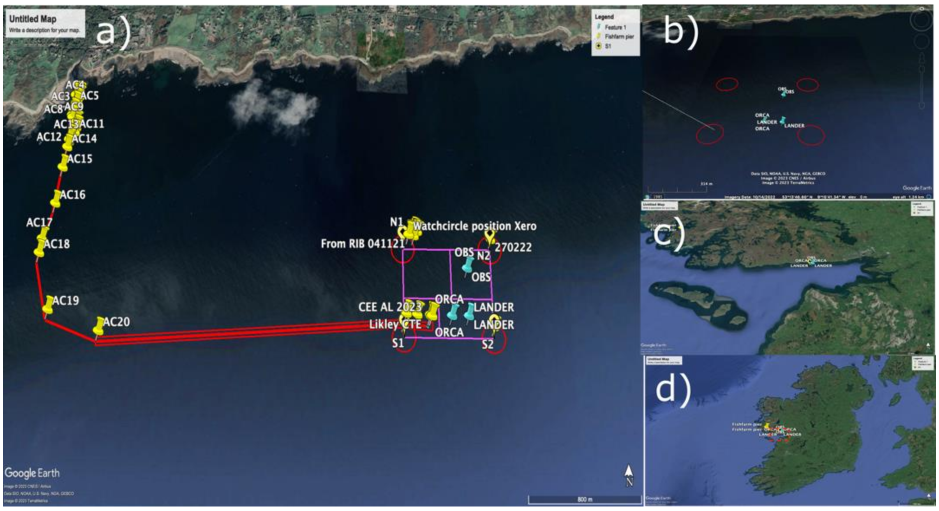

Figure 13. Overview of SmartBay facility, Galway Bay. (a) Plan view of SmartBay. Pink lines show perimeter bounds and yellow tags indicate ocean buoys. Red lines demarcate a fibre optic cable which runs inland from Spiddal and out to the facility along the seabed. Blue pins indicate the main lander ('LANDER'), small lander ('ORCA') and OBS deployed in this study. (b) Zoom of figure (a) with only the MANGO equipment shown. (c) Galway Bay-scale view and (d) National-scale view for reference.

Milestone: Localisation

Given that the original MANGO experiment deployment date was pushed back from April 1st until April 26th 2023, it was important to ensure that additional subsequent experiments were planned early. This was of particular importance for **determining the orientation of both landers with respect to true north on the seabed and in turn, facilitating accurate back-azimuthal information from localisation techniques**. This step was critical to achieve deliverables 1 and 2 (signal localisation and acoustic noise event mapping). In order to do this, we used a sound projector system (Geospectrum Technologies), which is maintained by

P&O Maritime, Galway. This system is comprised of a large battery, DC-AC inverter, a source amplifier and transducer. The latter emits high amplitude hydroacoustic energy using a source time function and frequency range of the user's choice. Figure 14 shows the testing procedure using an iMARL lander, single hydrophone, water tank and sound projector during a visit to the P&O warehouse on 11/04/2023.

Figure 14. Testing of sound projector equipment at P&O Maritime, Galway, April 2023. (top left) DC-AC inverter (top right) Experiment overview, showing DC-AC inverter, iMARL ORCA, water tank and suspended hydrophone cable. (bottom) View of tank, showing submerged hydrophone, as well as the source transducer of the sound projector.

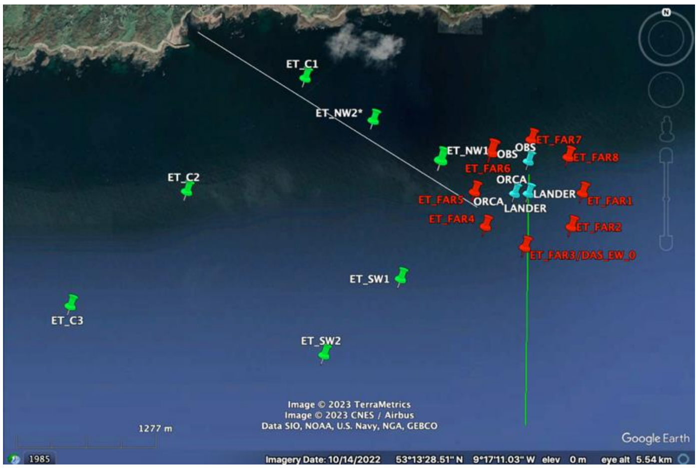

Figure 15. Sound projector planned track from 16/05/23. Green points mark locations at which the sound projector was emitted for 30-60s at 0.5 and 10 kHz respectively, along linear transects using a small fishing vessel. Red points indicate measurements completed at an approximate distance of 500m from the main lander. Note that only the red measurements at bearings of 0 °,90 °,180 ° and 270° with respect to the main lander were implemented during the deployment.

The sound projector equipment was deployed from Spiddal Pier on the evening of 16/05/23 (towards the end of the overall MANGO deployment) using a small fishing vessel. Figure 15 details the transects taken around the SmartBay facility and the approximate source emission locations. A high frequency (10kHz) and low frequency source (0.5kHz) was emitted for rough durations between 30-60s. The most important measurement subset was comprised of four measurements taken at an approximate distance of 500m from the landers and interspersed at 90° intervals. From this, the approximate rotations of each lander were determined using beamforming. Given that the true back-azimuth with respect to the landers was known for each measurement, the goal was to measure a consistent angle difference between the apparent and true source back-azimuth for each measurement. Table 1 lays out the determined lander rotations (see results - **these measurements are subject to further ongoing testing**).

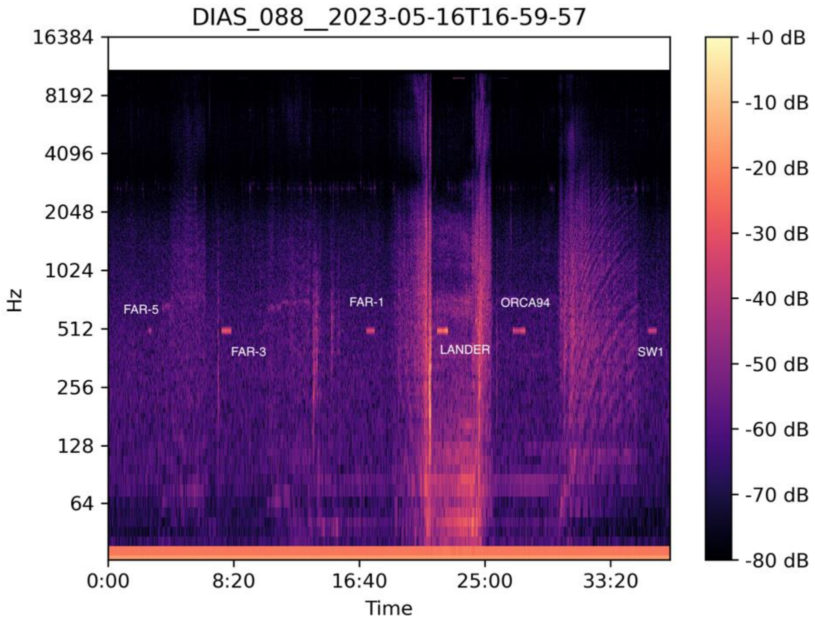

Figure 16. Spectrogram of Galway Bay soundscape with visible sample of sound projector measurements generated at 0.5kHz. White labels correspond to named waypoints from the experiment. A good example of overprinting of the ambient soundscape by vessel noise is visible from approximately 28 minutes. Spectrograms are taken from the high frequency array on the main lander.

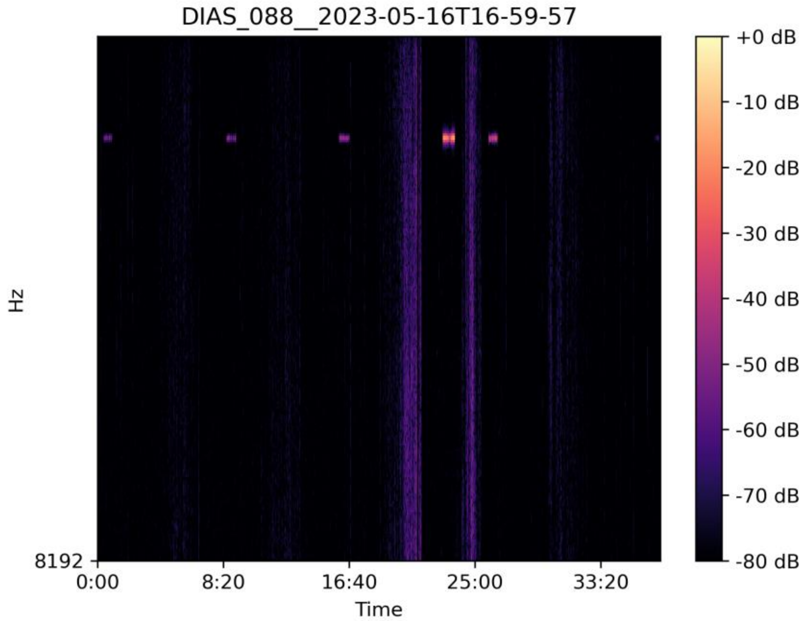

Figure 17. Same as per figure 16 but tapered in frequency between ~8.2-11kHz, with a sample of sound projector measurements emitted at 10kHz. Spectrograms are taken from the high frequency array on the main lander.

Figures 18-19 and table 1 show the estimated rotations for both landers. The rotations are 220 ± 20° and 6 ± 24° respectively (based on the mean and standard deviation of estimated rotations with respect to known source locations). **We note that these rotations are by no means final and are subject to further ongoing testing.**

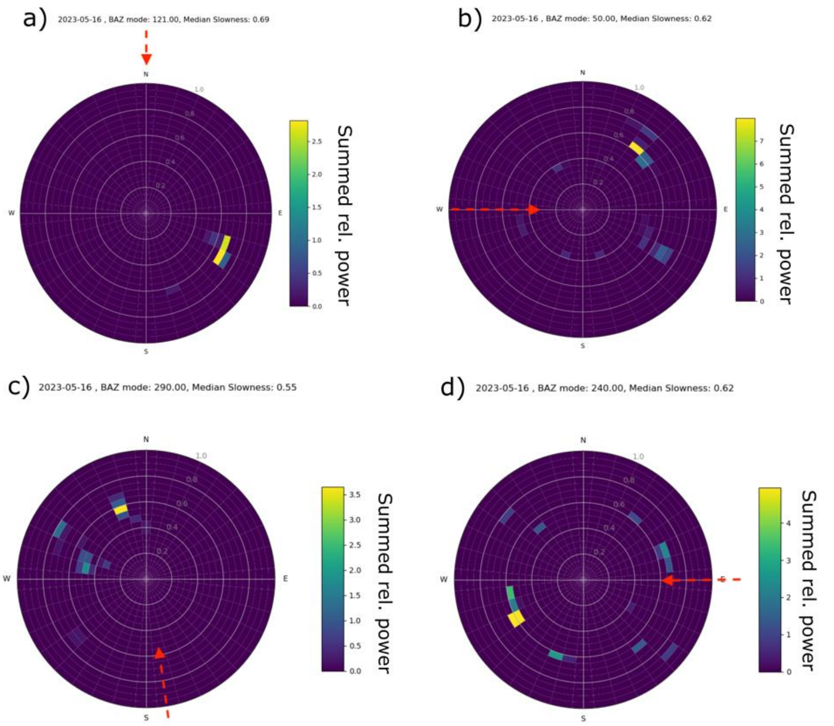

Figure 18. Estimated main lander rotation on the seabed with respect to true north. Red arrows on each polar plot indicate the true source direction from the sound projector experiment on 16/05/23, when four sources of 30-60s duration were emitted at 90° intervals with respect to the main lander: a) north b) west c) south d) east. Each polar plot shows the summed beam semblance as a function of slowness and back-azimuth across the whole time window used for each beam-forming measurement. The rotations were determined using the high frequency array on the main lander.

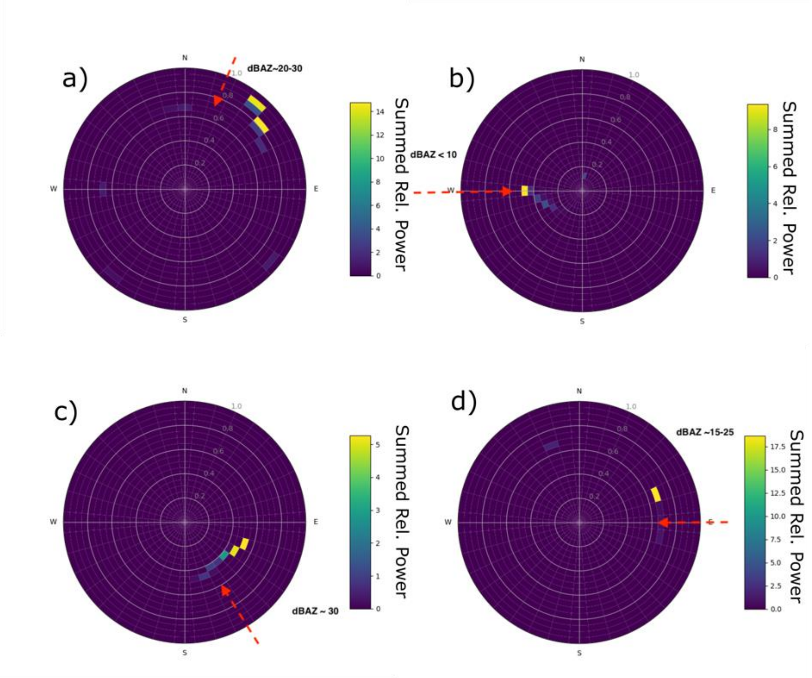

Figure 19. Same procedure as above but for the small lander, which was located several hundred metres west of the main lander.

Lander	Mean Rotation/°	Standard Deviation on Rotation/°	Correction to Measurements/°
Main lander	220	20	220 ± 20
Small lander	6	24	6 ± 24

Table 1. Mean and standard deviation rotations estimated from the four known source locations used in the 16/05/23 experiment. <u>Note that these rotations are subject to further testing</u>, especially the small lander, which suffered from significant noise effects due to repeated anchor and lander collision.

Having got an indication of lander rotations on the seabed, beamforming was applied to noise sources in the dataset in an attempt to localise them in line with deliverable 1 (see figures 8-9 in results section) and to pave the way to a future full mapping of acoustic noise events (deliverable 2). Please see results section for discussion and future steps.

<u>Milestone: Characterisation of Acoustic Noise Signals in Galway Bay</u>

This research benefitted from five sightings of whales and dolphins reported to the Irish Whale and Dolphin Group (IDWG) during the deployment duration (figure 20). As discussed in the outputs (see below), hundreds of dolphin signals were identified in MANGO spectrograms (e.g. figure 4) as well as dozens of grunts and blowhole-type noises, suspected to be large mammals (e.g. figure 5). Vessel noise was also abundant throughout the MANGO dataset (figure 6). As noted in the results section, the large mammals were not detected at the specific times of visual sighting: however, candidate noises suspected to be large mammals were often annotated within a few hours of the visuals. **This demonstrates how passive monitoring using array-based hydrophone techniques can provide invaluable additional spatio-temporal information and support extant cetacean tracking methodologies, in line with deliverables 1 and 2**.

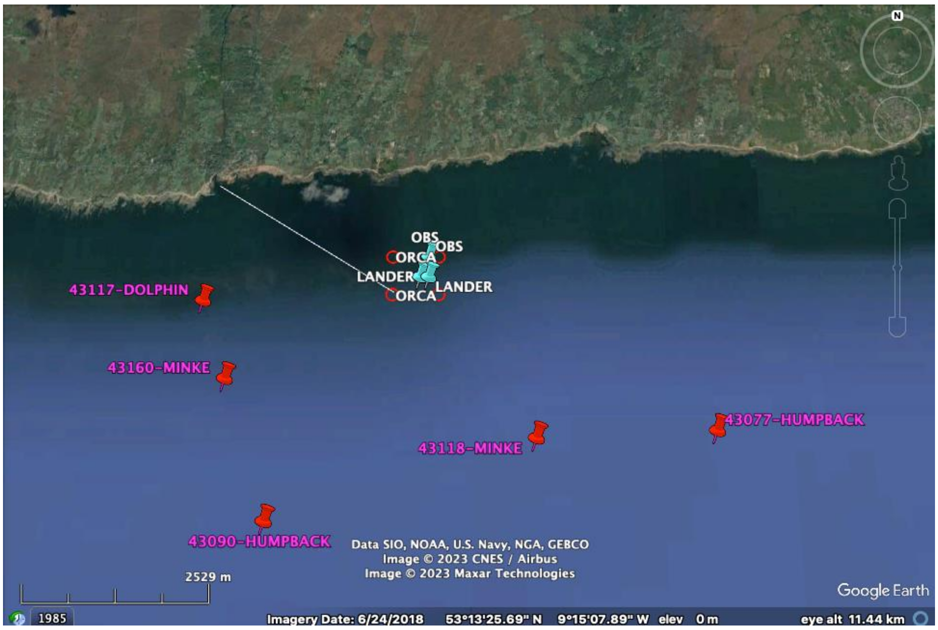

Figure 20. Main cetacean sightings reported to the IDWG during the deployment of the iMARL equipment used to collect the MANGO dataset between 26/04/23 and 19/05/23. Pins are labelled for sightings within the general vicinity of the SmartBay facility.

Milestone: Results Communicated at GSI Outreach Events

The output of this research to date was presented as a poster at GSI's 2023 annual conference (see impact) highlighting the main results but also the broad team that worked together on this project.

MANGO: Marine Acoustic Noise and Signals Localisation, a Test Experiment in Galway Bay Observatory E. Totten1, F. Le Pape[1,2], C. Gómez García[1], C. O'Malley[5],, C. Bean[1], D.Craig[1], L. Collins[1], C. Horan[1], A. Vijayan[1], S. Fennell[3,4], M. White[3], S.Burke[4], D. Murray[4]

[1]Geophysics Section, Dublin Institute for Advanced Studies, [2]Now at French Institute for Ocean Science, Brest, France, [3]University of Galway, [4]P&O Maritime Services, Galway, [5]Marine Institute, Ireland

The management of the project was performed through formal monthly meetings between the PI and the project's team.

Eoghan Totten (etotten@cp.dias.ie), hired on the project, has been looking after the data analysis and processing, results interpretation and the writing of the scientific report.

(iii) Outputs to date

Capacity Building (Ocean Acoustic Monitoring) ,Collection of Reference Dataset and Insights into Future Deployments of iMARL acoustic Equipment

The frontline output from this research is the successful deployment and recovery of both lander frames housing the iMARL equipment, from which approximately 2.5TB of large bandwidth (~0.1-24kHz) hydrophone data was collected across 15 hydrophones in total between 26/04/23-19/05/23. The use of iMARL hydrophones and ORCA recorders has been verified as a first-in-class means to facilitate the generation of large datasets for acoustic signal localisation (**deliverable 1**). In addition to confirming that ORCA data recorders can reliably record data for a period of three weeks, we have learned how future deployments can be improved, including: A) improved methods for coupling landers to the seabed to suppress acoustic noise from anchors and cabling, to improve overall signal quality; B) Revised hydrophone array spacings and geometries for improved array response functions and signals localisation. See project implementation for more information.

The MANGO reference dataset is currently stored within well-structured DIAS data repositories, in addition to the original SD dataset copies extracted from three ORCA recorders used in this study (these are retained securely by DIAS geophysics section technical officers).

Methods and Algorithms beyond state of the art (event detection) in most waters: towards event localisation

Where previous monitoring of the bioacoustic and industrial soundscape in Irish territorial waters has focused on detection of discrete signals, this research has shown that array seismology can calculate the origin direction of these sources, as well as demonstrating that triangulation for direct localisation of sources is possible, **in line with deliverables 1 and 2**.

Mapping the Galway Bay Acoustic Noise Field

While this is described in detail in section (i) (results), hundreds of acoustic signals with a very strong likelihood of a cetacean origin have been annotated in the reference MANGO dataset. This includes hundreds of dolphin calls, clicks and whistles visible in spectrograms generated from the dataset, as well as several dozen candidate signals for larger cetaceans (e.g. Minke and humpback whales). In addition, spectrograms from boats with a large likely size range (and by extension, broad and varying frequency range) have been annotated. This is in line with our **target milestone** to **characterise the acoustic noise and signals in Galway Bay**. While full annotation of the entire 2.5TB MANGO dataset was not realisable within the scope of this short project (annotations were constrained around several time windows based on IWDG visual sightings), it is hoped that this annotation can be completed in future research. This will contribute to achieving the long-term goal of **deliverable 2**, a complete mapping of acoustic noise 'events' in Galway Bay.

(iv) Impact

- Relevance/application to GSI programmes, where applicable

With the aim to further develop Ireland's underwater acoustic monitoring capabilities, the project has a strong potential crossover with the INFOMAR program on sea bed mapping (sea floor characteristics affect sound wave propagation), funded by the Department of Communications, Climate Action & Environment (DCCAE) and operated by the GSI and Marine Institute.

Presentation at National Meetings

The results in progress from the MANGO dataset funded by this project were presented as a poster ('Marine Acoustic Noise and Signals Localisation: a test experiment in Galway Bay Observatory') at GSI's Geoscience 2023 conference at Dublin Castle, 07/11/23.

- Other impacts

Societal impact, policy and governance

Marine renewable energy is a great opportunity to **lower greenhouse gas emissions**. However, its development is likely to generate significant **acoustic pollution at sea**, from the deployment of submarine cables to the operating and maintenance of offshore infrastructures. Monitoring marine life and its response to anthropogenic activities is therefore key to mitigating for humanity's impact on the ocean and for a healthy and sustainable use of ocean resources. For **long-term sustainable development of Ireland's offshore area**, assessment of the environmental impact from marine activities is essential, as planned by the **Irish government's** National Marine Planning Framework 2021.

Development of marine capacities

The validation of the lander's "acoustic design" proposed here as **standalone equipment for broadband acoustic signals localisation** opens up medium-long term research developments between iMARL and research groups working on marine acoustics in Ireland, from marine biologists to oceanographers.

Reference Dataset Access

In line with **FAIR** data principles (**F**indable, **A**ccessible, **I**nteroperable and **R**eusable), the MANGO reference dataset will be made available one year from this project's end. This has the potential to benefit other Irish research centres working on marine-based challenges into the future, to enable sustainable climate action, ocean management, as well as mitigate for inadvertent harm to the biosphere in Irish oceans from marine sector development. This is in line with EU Horizon Europe recognised priorities and GSI's core roadmap objectives to geoscientifically assist sustainable development of Ireland's natural resources and to protect its environment.

Publication in International Peer-reviewed Journal

In line with target **deliverable 3** for this project, we aim to submit a summative article on the iMARL array design, presentation of the Galway Bay soundscape and test event localisation and triangulation (from cetaceans and ships) by the end of Q1 2024.

Publications: TBC

3. Supplemental information/datasets *(please clearly mark any sensitive or confidential information that should not be published and include a justification for the request)*

At the time of the experiment associated with the project, due to the lease situation at the SmartBay facility, the Marine Institute has asked us to restrict communications regarding the project and in particular, communications on the experiment itself remain restricted at this time. We are still waiting on the final ok from the Marine Institute on the project's communication situation. Therefore, we would like to request the delay in any publication of this report until we get an update from the Marine Institute.