Interim Report

for
Passive Acoustic Monitoring off Southern California using Autonomous Underwater Vehicles: Summary of Technical Issues Encountered, Lessons Learned, and Future Recommendations

Contract No. N62470-15-D-8006
Task Order 18F0147

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Submitted to:

Naval Facilities Engineering Command, Pacific

March
2021

Suggested Citation:

Mellinger, D., S. Fregosi, and K. Ampela. 2021. Interim Report for Passive Acoustic Monitoring off Southern California using Autonomous Underwater Vehicles—Summary of Technical Issues Encountered, Lessons Learned, and Future Recommendations. Prepared for Commander, U.S. Pacific Fleet, Environmental Readiness Division, San Diego, CA. Submitted to Naval Facilities Engineering Command, Pacific (NAVFAC PAC), Pearl Harbor, HI under Contract No. N62470-15-D-8006, Task Order 18F0147, issued to HDR Inc., San Diego, CA. March 2021.

Executive Summary

In February 2020, a passive acoustic monitoring (PAM) survey using Autonomous Underwater Vehicles (AUVs, aka “gliders”) was performed off Southern California using two Seagliders™ equipped with Passive Miniature Acoustic Recorder (PMAR)-XL acoustic processing boards, manufactured by Hydroid, Inc. (formerly a subsidiary of Kongsberg Marine, now a subsidiary of Huntington Ingalls Industries). A series of delays and technological failures impacted project schedule and the ability to meet project objectives. The PMAR-XL system was not yet commercially available in 2018 at project start, and in the bench testing phase it was discovered that the gliders’ firmware no longer supported the PMAR-XL acoustic processing system and had to be updated to do so. This caused the deployments, originally planned for fall 2019, to be delayed until February 2020. The glider manufacturer company changed management twice during the course of this project, resulting in limited staff availability, and exacerbating project delays. The gliders were not ready for the mission until only several days before planned deployments and had to be express shipped directly to the deployment location instead of to Oregon State University (OSU) for additional testing (as originally planned) in order to meet the planned deployment schedule and survey during the desired winter/spring season. Four days following deployment, the shelf (inshore) glider stopped recording acoustic data. The reason was later discovered to be a failed filtering capacitor for one of the hydrophones. The abyssal (offshore) glider completed its mission without incident, recording sound files when expected and of the expected amount of recording time. Soon after glider recovery and examination of the data, it was discovered that neither glider recorded sounds above 3 kilohertz, well below the target frequency for beaked whales. This was due to a system configuration issue resulting from the lack of available documentation for the newly developed processing board. Based on these experiences and the diagnostic report from the manufacturer, the PMAR-XL system was likely not mature enough for use in the Fleet-funded Marine Species Monitoring Program despite previous research and development funded by the Office of Naval Research (ONR). In response to these challenges, HDR, Inc. and OSU have produced this interim project report outlining issues encountered, documenting lessons learned in the course of the project, corrective actions taken, and recommendations for future similar work. Acoustic data collected by the gliders were instead analyzed for the presence of baleen and sperm whales, and these results are outlined in the final project report.

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Acronyms and Abbreviations

APL-UW	Applied Physics Laboratory at the University of Washington
AUV	autonomous underwater vehicle(s)
ETA	estimated time of arrival(s)
HARP	high-frequency acoustic recording package
kHz	kilohertz
m	meter(s)
M/V	motor vessel
ONR	Office of Naval Research
OSU	Oregon State University
PAM	passive acoustic monitoring
PMAR	Passive Miniature Acoustic Recorder
SCB	Southern California Bight
SCORE	Southern California Offshore Range
SOAR	Southern California Anti-Submarine Warfare Range
SOCAL	Southern California
U.S.	United States
vdc	volts direct current

1 Project Overview and Objectives

1.1 Background

In late 2018 HDR, Inc. (HDR) with teaming partner Oregon State University (OSU) initiated a project to acoustically survey beaked whales off Southern California (SOCAL) using Autonomous Underwater Vehicles (AUVs). The original project scope specified the deployment of one Seaglider in August/September 2019, and deployment of a second glider during the same mission was added via a subsequent contract modification. A survey plan was prepared outlining the proposed tracks of both gliders—one over the continental shelf, and the other over deep-water areas on the shelf slope and beyond that had not been surveyed much previously. Preparation for the mission included refurbishing the gliders, which is typically done before any long-duration mission, and installing a new acoustics system, the Passive Miniature Acoustic Recorder (PMAR)-XL. This system, designed by the Applied Physics Lab at the University of Washington (APL-UW), is an upgrade of an acoustic system used on Seagliders on previous missions dating back to 2010. The refurbishing of the gliders and installation of the acoustic systems was performed by the manufacturer, Hydroid, Inc. (formerly a subsidiary of Kongsberg Underwater Technology, Inc., now a subsidiary of Huntington Ingalls Industries).

The planned objective of this project was to use AUVs to conduct passive acoustic monitoring (PAM) in the Southern California Bight (SCB) with the goal of characterizing the distribution of beaked whales in these areas.

(Initial) study questions to be addressed:

1. *What species of beaked whales are present in the SCB and off northern Baja California, Mexico[1]?*
2. *What is the spatial distribution of beaked whale species both inside and outside of the United States (U.S.) Navy's training ranges in the SCB and northern Baja California, Mexico, including on and off the continental shelf?*

During pre-deployment testing of the Seagliders, the manufacturer discovered that gliders' firmware no longer supported the PMAR-XL processing system and had to be updated to do so. This caused the deployment schedule to be delayed until winter-spring 2020.

[1] The planned glider tracklines, as approved by U.S. Navy, did not in fact cross into Mexican waters.

2 Planned Activities

2.1 Schedule

In fall 2019, HDR/OSU proposed the following, revised schedule:

February – December 2019: Prepare and configure the gliders for deployment. This step includes installing PMAR-XL high-frequency acoustic recording systems, refurbishing the gliders as needed for each deployment (batteries, pressure seal O-rings, data storage devices, etc.), testing the operation of glider components including ballasting, and configuring the gliders' operational systems for operation in the SOCAL area. This work will be done primarily by the manufacturer in Lynnwood, Washington.

Mid – January 2020: Pack gliders, associated parts, and control systems in shipping containers and ship to northern SOCAL.

Early February 2020: Deployment cruise (1-day trip) out of San Pedro, California, aboard the motor vessel (*M/V*) *Magician*. We will schedule a two-week window in which to watch the weather and will conduct the deployment when weather allows. The gliders and field team will transit overnight to the deployment location over deep (> 500 meters (m)) waters near the northern edge of the Southern California Anti-submarine Warfare Range (SOAR), perform a final test, and deploy the gliders. We chose to deploy at the northern end of the study area because currents in the offshore SCB generally flow southward, and the gliders will cover more distance when moving with the currents.

February – March 2020: Operate gliders offshore SOCAL (see **Figure 1**).

End of March 2020: Recovery cruise (1-day trip). Recover the gliders and extract the data storage devices. Recovery will be scheduled for six weeks after deployment, but the exact date will be weather dependent.

End of March 2020: Pack gliders, associated parts and control systems in shipping containers and ship to Newport, Oregon. Duplicate and hand-carry the data storage devices home.

April – August 2020: Acoustic data analysis for beaked whales.

September – November 2020: Reporting.

2.2 Planned Glider Operations

The gliders were planned to transit in a generally southern direction, with one glider traversing the abyssal plain offshore of the shelf break (referred to below as the abyssal glider, SG607), and one glider remaining at the edge of, and inshore of the shelf break (>2,500 m; referred to below as the shelf glider, SG639) (**Figure 1**). The planned deployment locations were just north of the Southern California Offshore Range (SCORE, which encompasses SOAR), in about 1,700 m of water, which would allow the gliders to transit in the vicinity (within 5 kilometers) of

two high-frequency acoustic recording packages (HARP) currently deployed within SCORE and just west of SCORE's northern edge.

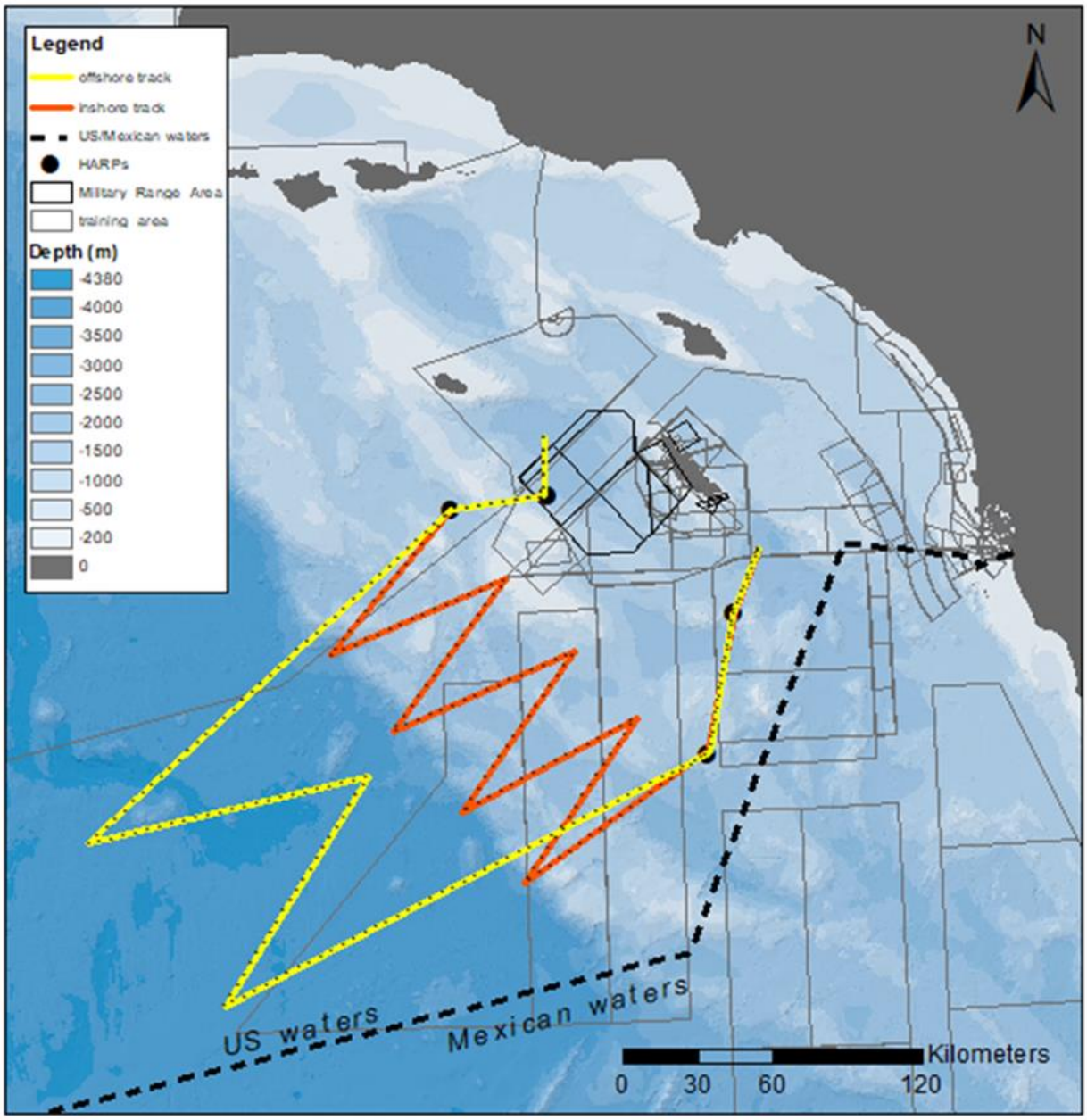

Figure 1. Planned tracklines for the 'shelf glider' (SG639, in red) and the 'abyssal glider' (SG607, in yellow).

3 Major Issues Encountered

Several major issues were encountered before, during, and after the mission, and these are summarized below. A few relatively minor issues were also encountered, and these are described in **Table 1**.

3.1 Mission Delay

About a week before the planned deployment cruise in fall 2019, the glider manufacturer discovered that gliders' firmware no longer supported the PMAR-XL processing system and had to be updated to do so. The glider deployment was postponed, initially for a month, then to winter-spring 2020. The U.S. Navy was initially interested in performing two surveys, one in summer-fall and the other in winter-spring, so after discussion with U.S. Navy, the decision was made to perform the latter survey first.

Additionally, the Seaglider manufacturer changed management over the course of this project. The company had limited staff availability during this transition, which caused further delays in the glider testing schedule. The manufacturer initially targeted early January 2020 to have the gliders shipped to OSU for further testing and configuration prior to deployment. In fact, the gliders were not shipped until early February, and had to be sent directly to the deployment location in San Pedro, California, in order to stay on the revised schedule. Therefore, OSU did not have an opportunity to fully test and familiarize themselves with the gliders as planned.

3.2 Glider Recall

Both gliders were deployed west of Catalina Island on 7 February 2020. Four days following deployment, the 'shelf' glider (SG639) stopped recording acoustic data. The reason was later discovered to be a failed filtering capacitor for one of the hydrophones. The capacitors are rated to a maximum of 10 volts direct current (vdc), and the PMAR-XL was integrated into a 15vdc glider without voltage regulation in place. At the time the reason for the failure was unclear, and a water leak was suspected as one possible cause. The glider was recovered promptly to prevent potential loss of the equipment. There was no indication of this potential failure during the final at-sea test conducted by the manufacturer on 31 January 2020, prior to shipping to San Pedro; all test diagnostics were clear. Further, all dock-side self-tests run by the deployment team prior to deployment on 7 February 2020 were completed without indication of any issues.

3.3. Inadequate Recording

The 'abyssal' glider (SG607) completed its mission without incident, recording sound files when expected and of the length expected for the amount of recording time. However, soon after recovery and examination of the data, it was discovered that neither glider recorded sounds above 3 kilohertz (kHz), well below the target frequency for beaked whales, which was the priority species for the project. This occurred in spite of the fact that both gliders were configured by OSU to record at 80 kHz. It turned out that the filtering system had only a small set of allowable values for the low-pass filter frequency, and 80 kHz wasn't one of them. The nearest acceptable value was 60 kHz, but the system defaults to 2 kHz (capturing sound up to around 3 kHz) if it sees an unknown value. The manufacturer did not provide OSU with any documentation or training about what would occur if an illegal value was entered, and OSU learned about this after the fact. The manufacturer has revised documentation of the PMAR-XL to prevent future problems of this sort.

4 Actions Taken and Lessons Learned

When it became clear that the data collected were not useful for beaked whale analysis as originally planned, the HDR project manager worked with the Contracting Officer's Representative to present a range of alternative analyses that would be provide the U.S. Navy with useful data to meet its environmental compliance requirements and natural resource management goals. Based on the outcome of these discussions, the scope of work for the project was modified to focus on analyzing baleen and sperm whale vocalizations, and leftover project funds were reallocated to the development of a comprehensive Marine Species Monitoring survey database, which will provide the U.S. Navy with maximum value for task order funds. A detailed lessons-learned matrix for this project is shown in **Table 1**, which outlines the major issues described in **Section 3**, as well as other, more minor issues encountered throughout the life of the project to date. Each issue is associated with a particular project phase, a description of the impact to the project, actions taken to address the issue, and recommendations for avoiding similar issues in the future. Key recommendations are outlined in the following section.

5 Future Recommendations

For similar projects in the future, we recommend, a mandatory one-week window between manufacturer refurbishment and actual glider deployment. During this time, additional bench testing can be performed in the OSU laboratory involving simulated dives to thoroughly test the acoustic recording configuration and ensure it is operating as expected. This can be accomplished while the system is plugged into a generator to avoid draining the battery and impacting mission duration. Likewise, the vacuum seal applied by the manufacturer to prevent leakage need not be disturbed during this additional testing phase. During this one-week period, the glider operators can also ensure that all user documentation is clear, complete, and accurate, and have the opportunity to have any outstanding questions answered by the manufacturer. Although these steps could likely be accomplished in a 48-hour time window, allowing a full week would also provide a reasonable time buffer if unexpected delays are again encountered during the manufacturer testing phase.

These steps would help ensure that the proper recording settings are applied, and that useable data are collected at the desired duty cycle and in the desired frequency range. In order to prevent a glider failure similar to the one experienced by shelf glider, it will be necessary to ensure that the filtering capacitors for all hydrophones have the proper voltage regulation in place, and that this is compatible with the chosen acoustic processing system. This should be confirmed by the manufacturer and proper documentation provided.

Additionally, it is recommended that two gliders be deployed simultaneously during future missions, as was done in 2020, in order to provide instrument redundancy in the event that unexpected issues are encountered, and to provide more comprehensive spatial coverage of the study area.

6 Summary

Based on these experiences and the diagnostic report from the manufacturer (**Appendix A**), the PMAR-XL system was likely not mature enough for use in the Fleet-funded Marine Species Monitoring Program despite previous research and development funded by the Office of Naval Research (ONR). At project outset the U.S. Navy indicated that the PMAR-XL processing board was the preferred tool for the project given 1) the focus on beaked whales, 2) previous glider deployments involving the non-commercially available PMAR system which was the predecessor of the PMAR-XL system, and 3) prior U.S. Navy investment in its development. The capabilities and specifications of the PMAR-XL system do make it an appropriate tool for recording beaked whale vocalizations, but prior to undertaking similar work in the future we suggest that the recommendations in **Section 5** and the lessons learned documented in **Table 1** be taken into account.

Table 1. 18F0147 SOCAL Glider Lessons Learned Matrix

Project Phase	Issue/Problem	Potential or Actual Project Impacts	Action Taken	Future Recommendations
Procurement	PMAR-XL system not commercially available at time of proposal or award	Schedule delays; inability to address scoped study question(s)	In order to be conservative, during the procurement process HDR proposed costs for a comparable system that was commercially available (AMAR) which was capable of meeting project objectives but was not the preferred data collection tool. Once the (less-expensive) PMAR-XL system became available, unused funds were allocated to the refurbishment and deployment of a second glider to be co-deployed with the first.	To the extent possible, take system availability into account during the project scoping process.
Testing	Manufacturer did not initiate testing of the gliders until summer 2019, in part because of limited staff availability due change in company management/ownership	Schedule delays; unforeseen technological issues due to compressed testing schedule	When it became apparent that the manufacturer was experiencing significant work delays, the HDR project manager initiated direct communications with the manufacturer while keeping OSU in the loop for awareness, despite the fact that HDR did not have a direct contractual relationship with the manufacturer.	Clarify communications and schedule requirements to manufacturer at the project scoping stage.
Testing	Sandisk made an architecture change to their memory cards, and the older A1 model was replaced by A2 cards. Only the A1 cards (Extreme A1 64 GB model SDSQXAF-064G) had been thoroughly tested with the PMAR-XL system, and the A2 cards proved unreliable during initial testing.	Schedule delays and impacts to data collection capabilities	HDR, APL-UW, and the manufacturer attempted to find a source of the older A1 cards without success. As a workaround, Kongsberg/Hydroid employed new (and fewer) high-density memory cards which bypassed the issue with the A2 cards (when multiple cards were inserted, A2 cards are not properly going to sleep/entering high impedance when the chip select line was disabled).	If at all possible, determine in advance of contract award whether proposed acoustic processing systems like PMAR-XL are compatible with 1) the deployment platform firmware and 2) previously-tested memory card models and configurations.
Testing	Incompatibility of glider firmware and PMAR-XL software	Schedule delays and impacts to data collection capabilities	Kongsberg/Hydroid updated the glider firmware to support the PMAR-XL system, although this was not initiated until August 2019 and resulted in schedule delays.	If at all possible, determine in advance of contract award whether proposed acoustic processing systems like PMAR-XL are compatible with 1) the deployment platform firmware and 2) previously-tested memory card models and configurations.
Testing	Testing by the manufacturer showed the programmable feature to limit recordings to certain glider depths was not reliable at the time of deployment.	Impacts to data collection capabilities and potential data loss	Recordings were programmed to be made at all possible glider depths throughout the water column. This resulted in recordings being made at shallow depths (< 25 m), and at the bottom of each dive where the glider pump operates. Both scenarios are very	Future recordings will not be affected, as the PMAR-XL system storage capacity was doubled in late 2020 and it is no longer necessary to turn off the system at

Table 1. 18F0147 SOCAL Glider Lessons Learned Matrix

Project Phase	Issue/Problem	Potential or Actual Project Impacts	Action Taken	Future Recommendations
			noisy, and therefore not useable for cetacean analyses, and can use up valuable recording space.	certain depths to conserve storage space.
Mission Planning	Waterspace management, including permissions for flying gliders in Mexican waters	Schedule delays; operational changes on short notice	HDR submitted the proposed glider survey plan, including planned tracklines, for U.S. Navy review and approval early in the project (May 2019). The detailed survey plan included waypoints and associated ETAs to assist U.S. Navy with waterspace planning well in advance of glider deployments. Early in the project, HDR and OSU had preliminary discussions with researchers from the Universidad Autónoma de Baja California to discuss project collaboration should the gliders enter Mexican waters. In the end, the U.S. Navy approved a survey plan which did not involve the gliders entering Mexican waters.	Give the U.S. Navy as much advance notice as possible about planned operations in order to have appropriate approvals in place. Also, prepare contingency survey plans and/or routes in the event the preferred plan is not approved.
Execution	COVID travel restrictions made it impossible for OSU personnel to retrieve glider SG607 upon mission completion	Potential instrument and data loss; impacts to budget and schedule	The HDR project manager stepped in and led a successful glider recovery effort at sea. The OSU technician walked her through the procedure via satellite phone and the glider was retrieved safely with data intact.	Train multiple parties in glider recovery procedures in the event main performer cannot participate directly in recovery efforts. When budgeting for field efforts include time and travel for multiple participants as contingency.
Execution	Failure of SG639 4 days following deployment	Potential instrument and data loss; impacts to budget and schedule; inability to address scoped study question(s)	The glider was recovered promptly to prevent potential loss of the equipment, and system diagnostics initiated. The reason was later discovered to be a failed filtering capacitor for one of the hydrophones. The capacitors are rated to a maximum of 10vdc, and the PMAR-XL was integrated into a 15vdc glider without voltage regulation in place. The capacitor issue on SG639 has since been fixed and it was confirmed that SG607 did not have similar issues. The use of two gliders vs. one also mitigated the impacts from this failure.	In the early stages of project planning, build in a mandatory one-week window between manufacturer refurbishment and actual glider deployment. Use this time to 1) perform additional bench testing involving simulated dives to test acoustic recording configuration, and 2) ensure all user documentation is clear, complete, and accurate, and have any outstanding questions answered by the manufacturer.
Execution	No sounds recorded above 3 kHz	Inability to address scoped study question(s)	Hydroid is preparing a user manual for the PMAR-XL to guide future users in configuring the system properly, which among other things, clearly flags the	In addition to having proper documentation of configuration procedures, in the future it will be

Table 1. 18F0147 SOCAL Glider Lessons Learned Matrix

Project Phase	Issue/Problem	Potential or Actual Project Impacts	Action Taken	Future Recommendations
			allowable values for the low-pass filter frequency settings. The HDR project manager proposed a range of alternative analyses to the U.S. Navy when it became clear it would not be possible to address beaked whale occurrence/distribution as originally planned. The project scope was eventually modified to focus on baleen and sperm whale vocalizations, since both gliders recorded these data.	critical to allow enough time for the performer (OSU) to test and familiarize themselves with any new acoustic processing system prior to deployments.
Execution	On 3 March 2020, recording stopped for approximately 4 hours when the first of two secure digital (SD) cards filled up halfway through Dive 116. Recording resumed on the second SD card at the start of Dive 117. This was because the PMAR-XL system requires the card switch to be made when the first card is 95% full (vs. 100% full) which was not clarified by the manufacturer prior to the mission.	Data loss	Fortunately, if the system senses the first card is too full, it will switch automatically but will not record for the rest of that dive, which it did, just one dive earlier than the pilot had programmed, so the recording gap was only half of one dive.	We now know to make the switch at 95% if the PMAR-XL system is used in the future.

Note: AMAR = Autonomous Multichannel Acoustic Recorder; APL-UW = Applied Physics Laboratory at the University of Washington; ETAs = Estimated Time of Arrival(s); COVID = Coronavirus Disease; OSU = Oregon State University; kHz = kilohertz; PMAR = Passive Miniature Acoustic Recorder; SOCAL = Southern California Range Complex; U.S. = United States.

A

Appendix A – Manufacturer's Post-Recovery Diagnostic Report for Glider SG639

Huntington Ingalls Industries

SEAGLIDER "SG639" SERVICE REPORT

CUSTOMER	OSU	RMA	CASE 3341
AUTHOR	R.Healy	DATE	10/2/20

RETURNED EQUIPMENT

SG639

CUSTOMER REPORT

Failure in Field

In short, the PMAR developed problems recording early in the mission.

Customer correspondence:

> SG639 stopped recording more than 1 pam file starting on dive 25. I have attached the log files for both Dive 24 and Dive 25. No commands regarding PMAR were changed between these dives - they were identical dives. According to the log PMAR was on for 324 minutes on Dive 25, but only a single file each is reported for the dive and climb (and no actualy 10 sec windows with clip readings are reported). The MAMPS output for Dive 25 is very low compared to 24 even though the PMAR system SECS is reported as near the same. ppm63900##_base_ch00.eng are not reported after dive 24, only the more generically labeled pm_ch00.eng files.
>
> The following few dives (Dives 26 through 30) were relatively shallow 300 m dives, but a single file each on the dive and climb is reported. PMAR time on matches what would be expected for the dive duration, but the MAMPS are low and space used is low.
>
> Update:
>
> Tried turning loggers off ($LOGGERS,0) then back on for the next dive did not change anything.
> Also tried changing sampling scheme from 1100, 900, 600 to 1100, 300, 120. No change.
> Tried changing hydrophone and analog warmup from 2 and 4.5 seconds to 5 and 7.5 seconds. No change.
>
> For all dives prior to Dive 24, the pm_ch00.eng and ppm64900##a_base_ch00.eng files contain a line "%osc: 8400117" On Dive 24, both dive and climb files, this is "%osc: 8400158". Dive 25 the value returns to the same values before Dive 24 ("%osc: 8400117"), but now the pm_ch00.eng files are essentially empty of 10 sec duration data lines, and no ppm64900##a_base_ch00.eng file is created. What does the OSC line mean? Although it reports 1 file recorded, space used is only 512 kb and it doesn't look like any recordings are being made.

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Huntington Ingalls Industries

INCOMING EVALUATION

While troubleshooting the problem remotely, it was noticed that the PMAR unit installed on SG639 was drawing about three times the current as the similarly configured SG607 (75mA:25mA average draw) during the initial dives while sampling. It was also noticed that when the unit failed to record the draw dropped to about 29mA, a high value while the system was not recording acoustic data. Fearing that there was a potential seawater short between the hydrophone and the glider, it was suggested that the mission be aborted.

SG639 was recovered and sent back to Hydroid for failure analysis and repair.

Initial visual inspection did not reveal any signs of a seawater leak on the system.

WORK & RESULTS

Bench inspection of the PMAR board from SG639 revealed that C43 developed a short connecting power and ground. The short prohibited the PMAR unit from operating properly.

C43 & C44 are filtering capacitors for hydrophones 1 and 2 respectively. These capacitors are rated to a maximum of 10vdc. The PMAR was integrated into a 15vdc glider without voltage regulation in place. The capacitors were removed from the board as they are not currently used in the setup configuration for SG639.

The firmware was updated to return free space reports on all SD cards during mission. The firmware upgrade also fixed a bug so that snippets can be uploaded from all cards during mission.

After analyzing the first mission and finding that the SD cards filled up prior to battery depletion, the PMAR has been upgraded to include (4) 512GB SD cards rather than (2), doubling storage capacity.

To test the system, a signal generator hooked up to an antenna was used. Recordings were generated during simulated dives with both the hydrophone and signal generator antenna submersed in a garbage can of water to isolate the signal picked up. Sweeps from 1kHz-200kHz over 30 second intervals were used for the testing to analyze the upper frequency limit of the PMAR. Below, the spectrogram shows that the PMAR was able to pick up signal to ~90kHz.

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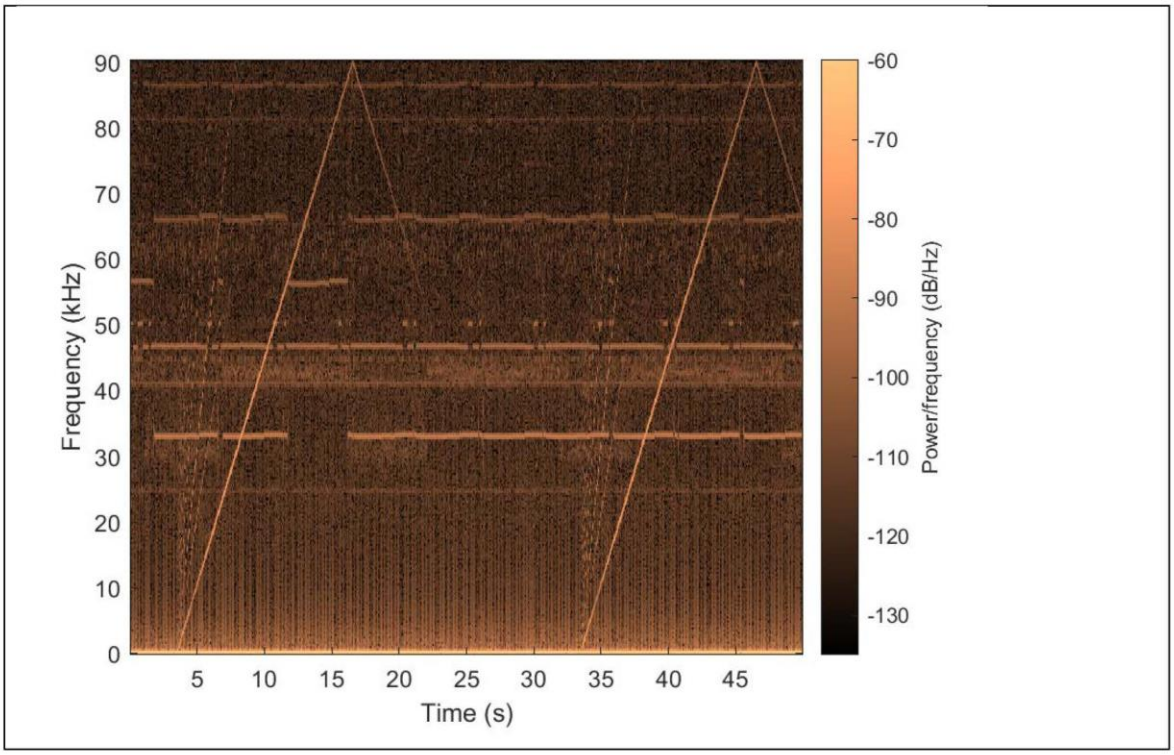

INSTRUCTIONS TO THE CUSTOMER
The information on the included thumb drive includes the most recent calibration certificates and trimsheet for SG639. If you have any questions, please email seagliderssupport@hydroid.com

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