Schmidt Ocean Institute Expedition Report

Designing the Future 2

Chief Scientist Dr. Brennan Phillips

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1 Overview

SOI Expedition ID	FK210812
Vessel	*R/V Falkor*
Expedition Name	Designing the Future 2
Expedition Dates	2021/08/12 - 2021/08/21
Departure Port	San Diego, CA U.S.A
Termination Port	San Diego, CA U.S.A
Ocean	Pacific Ocean

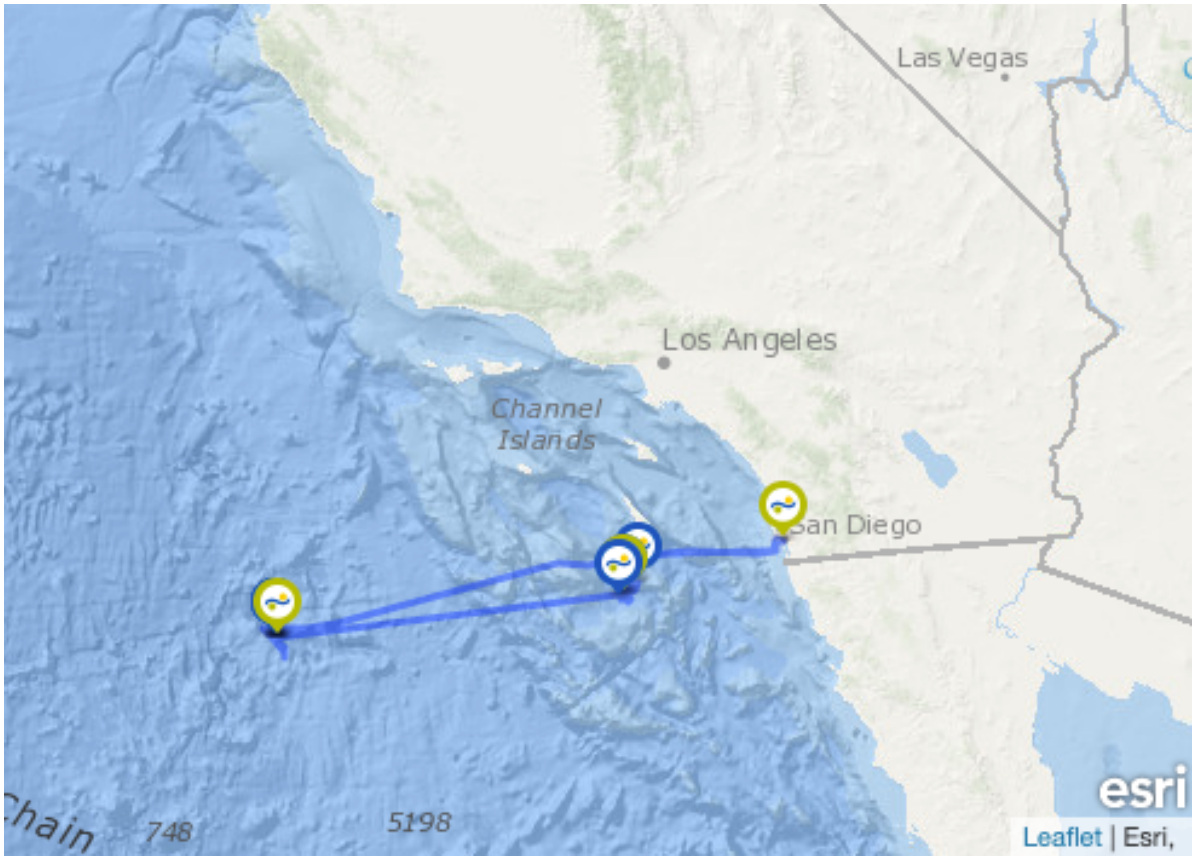

Figure 1: Map of Expedition Location

1.1 Expedition Overview

The ocean's midwater is considered to be the largest habitable space for life on earth, yet it is also one of the most minimally explored marine environments. Collecting specimens

in this region is incredibly challenging, as many open ocean species are quick, fragile, and small. Keeping a midwater animal alive for study at the surface is a difficult task due to changes in pressure or damage that may occur during collection. Despite the challenges, species sampling from the midwater is necessary for helping scientists obtain all kinds of information. Understanding the diet, life span, reproduction, and growth of an animal can only be determined with a live specimen. Obtaining this knowledge can help assess the risk of extinction and provide a baseline on the health of the ecosystem, especially in very remote regions of the ocean that are challenging for people to access. Understanding the baseline health of the midwater environment is especially important for discussions on international policy, management, and stewardship of the high seas– regions of the ocean that do not fall under any one country's jurisdiction. Sampling in the mid-water today is mostly performed the same way it was 30 years ago, but scientists and engineers have been working on new methods to improve the way we collect and understand marine species. In 2019, Co – Principal Investigators Brennan Phillips (University of Rhode Island), Kakani Katija (MBARI), Robert Wood (Harvard University), David Gruber (City University of New York/Baruch College), and their teams of interdisciplinary researchers voyaged aboard *R/V Falkor* to test new technologies that allow them to study open ocean species in situ, something that had never been done before. In August 2021, they returned to *R/V Falkor* to test improvements made to the technology since the 2019 expedition, and continue to refine the next generation of technologies for ocean exploration.

1.1.1 Expedition Timeline

The expedition commenced on August 12 2021 departing from San Deigo, California, U.S.A and returned to San Deigo, California, U.S.A on August 21 2021.

1.1.2 Authorizations and Permitting

No permits were needed for this expedition.

1.2 Proposed Objectives

It is estimated that up to a million species remain undescribed in the deep pelagic zone, owing largely to a lack of sampling effort and limited tools available for the direct collection of holotype specimens. A significant amount of pelagic deep-sea species remain undescribed/poorly understood simply because they cannot be captured and returned to the surface in good enough condition for taxonomic inspection. To address this shortcoming, this expedition involved the development and deployment of a novel robotic encapsulation device outfitted with a tissue sampling system with in situ preservation capabilities, a plenoptic light-field imaging system, and a laser-sheet PIV imaging system to enable the rapid characterization of deep-sea specimens. The physical tissue samples that were collected and preserved in situ allow

for full-genome sequencing including gene expression, which is something that has only been achievable in a handful of previous efforts. Advances in the tools available for deep-sea midwater science will create new windows into pelagic ecology. We anticipate the results of our proposed work will set a new benchmark for future midwater expeditions, in both imaging and sampling capabilities.

2 Expedition Accomplishments

2.1 At-Sea Accomplishments

2.1.1 Remote Operated Vehicle

Using *ROV SuBastian*, seven midwater dives were conducted, which utilized 3D/quantitative imaging and preserved in situ tissue samples of twenty- six (26) gelatinous/delicate organisms. Four of these organisms, are the true "poster child" examples of creating digital holotypes.

2.1.2 Innovative Technologies

DeepPIV and EyeRIS, two innovative imaging systems, created by Kakani Katija and her team at MBARI imaging systems were used. DeepPIV (particle imagery velocimetry) instrument was integrated onto ROV SuBastian and consisted of a laser and optics that illuminate a sheet of light, that can be used no only to measure fine-scale movements of the water around animals but can also create 3D scans of gelantinous animals and mucous structures. The EyeRIS (Remote Imaging System) is a real-time 3D imaging system, whose design was inspired by the multi-lens imaging in insects and uses lightfield imaging to capture volumetric data within a scene, creating sub-mm resolution 3D models of animals in the deep sea. The refined version of the Rotary Actuated Dodecahedron Sampler was also integrated onto ROV SuBastian's manipulator arms. The sphere-like device rapidly encapsulated animals, imaged them up-close, and collected samples for preservation.

2.2 Post expedition activities and accomplishments

The science team is working on:

- Image processing of DeepPIV/EyeRIS datasets
- Tissue sample genetic sequencing (staged process)
- Preparing publications outlining the expedition's outcomes the technology used.

3 Societal and Scientific Impact

3.1 Overview

The results of this expedition will include peer-reviewed publications, conference presentations, and compelling imagery and data visualizations, which have started to be share with the scientific community and general public. The broadest, most impactful result will be the demonstration of what is possible using these new technologies for biological exploration in the deep-sea - in a very short amount of dive time per organism (15-20 minutes), the research team was able to quantitatively image midwater targets of interest in 3D and collect/preserve tissue vouchers in situ. Select samples have been sequenced for full genome and gene expression, with the actual sequence data to soon be posted in publicly accessible repositories. These results offer examples of the rich amount of data that can be collected on a single ROV dive, leading to more efficient and productive operations and advancing our overall ability to explore the deep ocean biosphere.

3.2 New Discoveries & New Species

New discoveries: Genetic data and 3D imagery was collected for four specimens with state-of-the-art innovative technology, resulting in high-quality reference transcriptomes for the species: two (2) siphonophores, one (1) salp, and one (1) tomopterid. The high-quality genome assembly of the salp was only the second salp genome published and the most complete salp genome to date. The quantitative transcriptome data for the salp (Pegea socia), identified structural components of its soft tissues. The quantitative transcriptome of the tomopterid identified specialization of tentacle structures as neurosensory organs that detect chemicals (e.g. sugars and ammonia) and dim light (e.g. bioluminescence). Future work includes generating high-quality reference transcriptomes for an additional twelve (12) species using long read RNA-sequencing and also completing metabarcode analysis of eDNA filters collected during the cruise.

3.3 Technological Update

Since the 2019 research expedition with SOI, two imaging systems: DeepPIV and EyeRIS were further operationalized. DeepPIV 3D reconstructions have been published in Nature, and methods for analyzing data have been refined. Two contractors are currently processing DeepPIV visual data from the 2021 cruise. The team's first descriptive paper for EyeRIS as well as a companion manuscript that combines EyeRIS with the other technologies used on *R/V Falkor* is in preparation.

4 Appendix 1

All information below is up to date as of January 2023

4.1 Publications

The design elements of the RAD2, including the tissue sampling system are available via the University of Rhode Island RAD2- Rotary Actuated Dodecahedron Project

4.2 Data

Data Type	Curator	Completed
Environmental sensor data collected by *R/V Falkor*	Rolling Deck to Repository	Y
Google Earth visualization, imagery, navigation, CTD data, and event documentation from *ROV SuBastian* and navigation from *R/V Falkor*	Marine Geoscience Data System	Y
3D Imagery, Visualization and Description data	MBARI's Deep-sea Guide, SketchFab	Y
Genomic sequencing data	NCBI	N

4.3 Cruise Blogs

- A series of Cruise Log Videos are available

4.4 Conferences/Presentations/Posters

- Daniels, J., Erickson, J., Klimov, D., Roberts, P., Sherman, A., Katija, K. (2022). Studying Flow Inside and Around Deep-sea Animals in 2D and 3D Using Novel Imaging Techniques. Oral Presentation, ASLO Ocean Science Meeting, virtual.
- Katija, K. (2022). Fantastic Beasts and Where to Find Them: Giant Larvaceans in the Ocean's Midwaters. Oral Presentation, International Congress on Invertebrate Morphology, Vienna, Austra.

- Katija, K., Roberts, P., Daniels, J., Erickson, J., Henthorn, R., Klimov, D., et al. (2022). EyeRIS (Remote Imaging System): Enabling Time-resolved Three-dimensional visualizations of particles and animals in the deep sea. Oral Presentation, Microscale Ocean Biophysics 6.0 Meeting, Mallorca, Spain.
- Katija, K. (2022). Developing Image Technologies to Search for, Discover, and Understand Life in the Deep Sea. Oral Presentation, Breaking the Surface - 14th International Interdisciplinary Field Workshop of Maritime Robotics and Applications, Biograd na Moru, Croatia.
- Katija, K. (2022). Developing Image Technologies to Search for, Discover, and Understand Life in the Deep Sea. Invited Lecture, MIT-WHOI Steinbach Scholar Seminar, Woods Hole, MA USA.
- Katija, K. (2022). Developing Image Technologies to Search for, Discover, and Understand Life in the Deep Sea. Invited Lecture, Swarthmore College, virtual.
- Roberts, P., Daniels, J., Orenstein, E., Erickson, J., Klimov, J., Henthorn, R., et al. (2022). Plenoptic and Multi-camera Imaging on ROVs and AUVs. Oral Presentation, 4th Marine Imaging Workshop, Brest, France.
- Multiple lectures/seminars at URI (Phillips), Seminar at RISD March '22 (Phillips/Kitchen),

4.5 Community Outreach

- Non-academic presentations: UCONN Adult Learning Program Presentation (June '22)

4.6 Student Projects/Thesis/Dissertations

Contributions to this project/paper will be part of a PhD dissertation for Alexander Yin (URI).

4.7 Science party information

4.7.1 Scientists aboard *R/V Falkor*:

Scientist	Institution
Brennan Phillips (Co-Principal Investigator)	University of Rhode Island
Kakani Katija (Co–Principal Investigator)	Monterey Bay Aquarium Research Institute
Robert Wood (Co–Principal Investigator)	Harvard University
David Gruber (Co–Principal Investigator)	City University of New York/Baruch College
Kaitlyn Becker	Harvard University
John Burns	Bigelow Laboratory for Ocean Sciences
David Casagrande	University of Rhode Island

Scientist	Institution
Joost Daniels	Monterey Bay Aquarium Research Institute
Eric Orenstein	Monterey Bay Aquarium Research Institute
Paul Roberts	Monterey Bay Aquarium Research Institute
Alana Sherman	Monterey Bay Aquarium Research Institute
Shona Kitchen	Artist-at-Sea
Alyson Ogasian	Artist-at-Sea

4.8 Media

- A Gentle Grip on Gelatinous Creatures – Wyss Institute
- A Gentle Grip on Gelatinous Creatures – The Harvard Gazette
- Soft Robot gives Jellyfish a Hug – Science Friday (audio interview)

There was a range of media engagements during research cruise FK191120 and these impressions and impacts are summarised in Table 4 (below) that was prepared by the SOI media team shortly following the cruise:

Table 4: Summary of media engagements, impressions and impacts during research cruise FK210812, from the SOI FK210812 Social Media and Press Report.

Section	Highlight
Website	• Four blogs posted on the site • 13,078 users from 153 Countries • 15,551 sessions and 27,741 page views during the cruise • 70 hours of video resulted in 10.4k views on YouTube and 12.9k video views on Facebook
Programs	• Artist-at-Sea Shona Kitchen joined this expedition. Her work included creating 3D printed
Press	• No press release was issued for this expedition, but 2 stories were published without a release
Community	• Two Ship-to-Shore connections took place during the expedition, engaging 329 people. Refer to the second page for more details.
Facebook	• 38,254 people reached • 10 posts had 190 shares, 1.2k likes and reactions, and 100 comments • Total of 12.9K Video View on Expedition-Specific Videos; 1.8k viewers engaged with content via likes, shares, and comments; 23.7k Minutes of Video from the Expedition watched overall
Twitter	• 48 Tweets received 401.2k impressions over 18 days • 1.4k Likes, 683 link clicks, 505 retweets • 2 Videos with 2.8k views

Section	Highlight
Instagram	• 12 posts - 8 photo-based posts (some with multiple photos in post), 4 videos • 78k people reached, 7.8k likes, 83 comments • 13k video views
YouTube	• 10.4k views on videos generated by this expedition • 1 Expedition Update, 1 4K Highlight Reel • F70 hours of video related to this expedition posted - 69:53:00 of which came from ROV Dives