Schmidt Ocean Institute Post Expedition Report

Biodiverse Borderlands

Chief Scientist Dr. Lisa Levin

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1 Overview

SOI Expedition ID	FK210726
Vessel	R/V *Falkor*
Expedition Name	Biodiverse Borderlands
Expedition Dates	2021/07/26 - 2021/08/06
Departure Port	San Diego, California
Termination Port	San Diego, California
Ocean	Pacific

Map of Expedition Location

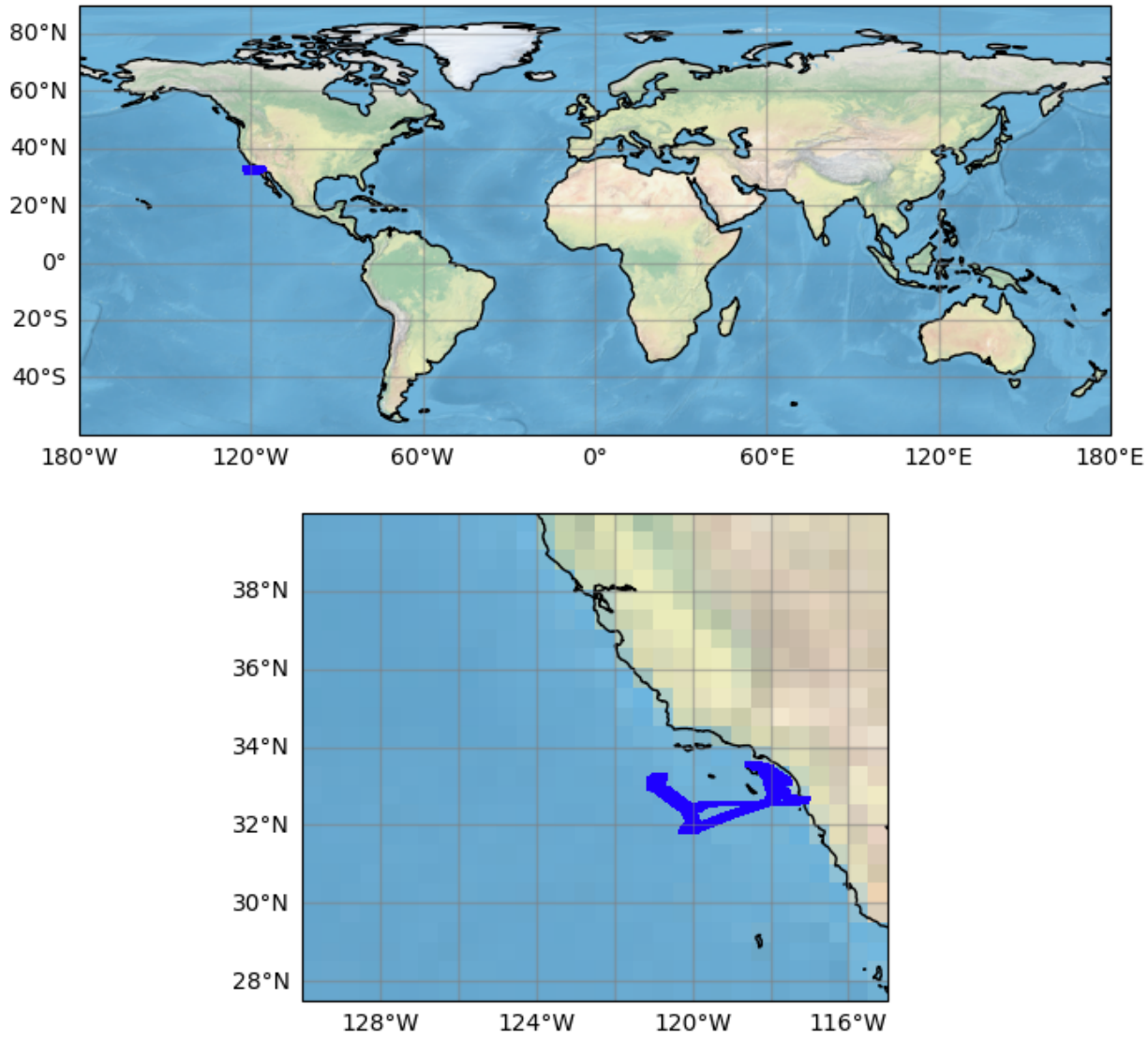

Figure 1: Map of Expedition Location.

1.1 Expedition Overview

Specific locations in the deep sea host minerals that contain high quantities of elements considered to have economic value. Extractive practices for deep-sea minerals are being planned, and baseline biological data are needed to further assess the life that may dwell on or around minerals in these different benthic environments. To examine trade-offs associated with any potential mineral extraction, a science team on Schmidt Ocean Institute's R/V *Falkor* ventured to the Southern California Borderland (SCB) to investigate several sites where marine minerals are known or expected to occur and to assess the biological communities living amongst the mineral substrates.

The Southern California Borderland, the site of this 2021 expedition, is a tectonically complicated, rugged, and heavily sedimented region of the California continental shelf that lies offshore between Los Angeles and Mexico. Both FerroManganese (Fe-Mn) crusts and phosphorite marine mineral deposits occur in the SCB. Phosphorite has the potential to be a source of phosphorus for use in agricultural fertilizer, and both Fe-Mn crusts and phosphorites are enriched in rare metals that are used in electronics, green energy, and other technologies.

These deep-sea resources are being considered around the world for economic exploitation. Additionally, hard-ground habitats of the deep sea, such as those in the SCB, are often difficult to characterize, especially quantitatively. Most characterizations have been done via video for larger animals but not for smaller animals and microbes, which requires sampling, a special capability of the ship's remotely operated vehicle (ROV) *SuBastian.*

1.1.1 Expedition Timeline

The expedition commenced on July 26, 2021, departing from San Diego, California, USA, and returned to San Diego, California, USA, on August 8, 2021.

1.1.2 Authorizations and Permitting

No authorizations were required for this expedition.

1.2 Expedition Objectives

The assembled science team set out to document minerals and affiliated species distribution present in the SCB, enhancing knowledge of the ecosystems and establishing biodiversity baselines. The team also created protocols for assessing life in mineral-rich areas by examining the animals and microbes associated with varying benthic environments. By establishing these baselines, the scientific community gains a better understanding of the biodiversity tradeoffs involved in mineral extraction in deep-sea environments and habitat features, and it becomes possible to identify assemblages that may be in need of protection. In order to achieve this, the team documented the environmental conditions and the variety of fauna they encountered, based on factors such as water depth, rock type, oxygen availability, sedimentation, and proximity to shore. The science team used a variety of methods to document all shapes and sizes of life, such as small invertebrates, deep-sea corals and sponges, demersal fish, and microbes.

2 Expedition Accomplishments

2.1 At-sea Accomplishments

2.1.1 Science

Samples were taken of SCB rocks and their biota, water, sediments, and individual animals. Summaries are provided below for seafloor samples (Table 1) and video images of benthic megafauna (Table 2).

	Cnidaria		Porifera		Pushcores		Rocks Microbiology		Rocks - Macrofauna Completed	Megafaunal Transects		Sediment slurps		Water		Total Analyzed 16S Diversity (metagenomes)
	A	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**C**	**A**	**B**	**A**	**B**	**A**	**B**	
Falkor Cruise Totals	**15**	**14 (6)**	**41**	**30 (5)**	**33**	**6 (1)**	**72**	**26 (9)**	**54**	**35**	**14**	**0**	**0**	**13**	**8**	**84 (21)**
40-Mile Bank	1	1	5	3			8	1	8	0	0			3	1	**6**
Coronado Escarpment	3	2			15	3 (1)	7	5 (4)	7	5	5			1	1	**11**
Crespi Knoll	2	2 (1)	12	4			7	3	6	4	0			1	1	**10**
Hancock Ridge			6	6 (2)			5	3	8	5	0			2	1	**10**
Lasuen Knoll			5	5 (1)	18	3	7	3 (1)	3	4	0			1	1	**12**
Little Joe Seamount	3	3 (2)	3	3			8	4 (1)	8	6	4			1	1	**11**
San Juan Seamount	4	4 (3)	8	8 (2)			21	3 (1)	8	5	5			3	1	**14**
SW Patton Escarpment	2	2	2	2			9	4 (2)	6	6	0			1	1	**9**

Table 1: Summary of samples collected during FK210726 at different sites in the South California Borderland region. A) Number of samples collected and stored. B) Number of samples analyzed for microbial diversity and metagenomes (in brackets).

	A)	B)	Annelida	Arthro-poda	Chord-ata	Cnidar-ia	Echino-dermata	Foramin- fera	Hemicho-rdata	Mollu-sca	Porife-ra	Grand Total
***Falkor* Cruise Totals**	**35**	**14**	**85**	**825**	**194**	**3595**	**3550**	**7**	**7**	**3**	**1462**	**9728**
Coronado Escarpment	5	5	0	49	118	172	1909	0	0	0	697	**2945**
Crespi Knoll	4	0										
Hancock Ridge	5	0										
Lasuen Knoll	4	0										
Little Joe Seamount	6	4	84	47	10	137	498	7	7	1	4	**795**
San Juan Seamount	5	5	1	729	66	3286	1143	0	0	2	761	**5988**
SW Patton Escarpment	6	0										

Table 2: Video Transects (100-m long) taped by *SuBastian* (A) and analyzed (B). Total numbers of individuals observed from analyzed transects, by phylum.

2.1.2 ROV

Twelve (12) ROV dives took place during the expedition, as shown in Table 3 below.

Dive	Date	Site/Location	Depth range (m)	Latitude (N)	Longitude (W)
S0441	27-Jul-21	San Juan Seamount	1113 – 1121	33.0395	121.0064
S0442	27-Jul-21	San Juan Seamount	689 – 691	33.0334	120.9999
S0443	28-Jul-21	San Juan Seamount North	689 – 1442	33.0334	120.9999
S0444	29-Jul-21	Patton Escarpment	1358 – 1797	32.4029	120.1468
S0445	30-Jul-21	Little Joe Seamount	2362 – 2772	31.8963	120.0303
S0446	31-Jul-21	40-Mile Bank	1035 – 1037	32.5994	118.0251
S0447	31-Jul-21	40-Mile Bank	662 – 692	32.597	118.0166
S0448	1-Aug-21	Crespi Knoll	430 – 550	33.1014	117.8853
S0449	2-Aug-21	Lasuen Knoll	120 – 382	33.3885	118.0069
S0452	3-Aug-21	DDT Barrel Site	886 – 888	33.5779	118.4358
S0451	4-Aug-21	DDT Barrel Site	881 – 885	33.5664	118.4252
S0452	5-Aug-21	Coronado Escarpment	376 – 477	32.6673	117.4857

Table 3: ROV *SuBastian* dives made during the expedition.

2.2 Post expedition Activities and Accomplishments

Megafaunal Distribution: Video transect analyses were carried out for fauna surveyed by ROVs on R/V *Falkor* (July 2021) and *E/V Nautilus* (Oct. 2022), covering 378-2765 m depths. The analyses extended knowledge of SCB megafaunal species distributions into greater depths than previously studied. In total, 32,426 megafaunal individuals were counted, representing 148 taxa over 41 transects across ten (10) sites. Echinodermata contributed to 48% of the total abundance; Cnidaria 24%; Porifera 13%; Annelida 6%; Arthropoda 6%; Chordata 2%; Mollusca, Foraminifera, and Hemichordata contributed <1% of the total abundance.

Four of the top five most abundant taxa belonged to Echinodermata, including the brittle stars *Ophiacantha diplasia* (12%), *Ophiuroid sp. 5* (6%), the pink urchin *Strongylocentrotus fragilis* (7%); *Brisingid asteroids* (6%). The octocoral *Acanthogorgia sp* (10%) comprised 10% of the total.

A comparison of megafauna associated with FeMn and phosphorite rocks revealed that mineral type did not have a significant effect on megafaunal density, but did appear to affect community composition, with a higher abundance of octocorals on FeMn substrates, and more pink sea urchin *Strongylocentrotus fragilis*, the carnivorous sponge *Asbestopluma* sp. and Hexactinellida sponges on phosphorites. Overall, the communities of mineral-rich hardgrounds in the SCB were highly heterogeneous, with different dominant taxa at different sites, and at different depths within a dive site.

Hardground Macrofauna: Macrofaunal (> 300 μm) density, diversity, and community composition on mineral-rich substrates in the SCB were assessed, focusing on the effects of FeMn crust and phosphorite substrate types, sites in the SCB, and various environmental variables, including oxygen, depth, temperature, proximity to shore and megafauna presence. Analyses combined rocks collected in 2020 on *Nautilus* and in 2021 on *Falkor*. A total of 3,555 macrofauna individuals were counted, and 417 different taxa were identified from 82 rocks from depths between 231 m and 2,688 m. The average density for SCB macrofauna was 11.08 ± 0.87 individuals/200 cm2 and the mean diversity per rock was H′ (loge) = 2.22 ± 0.07. A relationship was observed between site, substrate type, and macrofaunal communities. Phosphorite rocks had the highest diversity on a per-rock basis and, when pooled, FeMn crusts had the highest number of species. The phosphorite rocks were characterized by holes, crevices, and depressions, which could account for the observed high macrofaunal diversity on a per-rock basis when compared to the other smoother substrates in this study.

Of all the environmental variables, depth explained the largest variance in macrofauna community composition. Macrofauna density and diversity had similar values at sites within and outside the oxygen minimum zone (OMZ). This study is the first to analyze the macrofaunal communities of mineral-rich hard substrates in the SCB. Results suggest extensive spatial heterogeneity, thus contributing crucial baseline information for effective conservation and management of the SCB.

Rock Analyses: All rock samples were cut and carefully described to identify rock type, textures, and stratigraphic features. Ferromanganese crust and phosphorite samples were subsampled for geochemical analyses to determine mineralogy and element composition. Geochemical data for each sample were published in a data release in the USGS data repository, ScienceBase. Habitat and substrate type identifications were made for selected video transects. Primary habitat distinctions were made based on visual estimation of the amount of seafloor that was sediment-covered. Substrate rock type (e.g., FeMn, phosphorite, basalt, other) along the transects was identified during video footage review using rock shape (plate-like, lobed, angular, rounded, etc.), surface texture (botryoidal, smooth, undulating, etc.), sediment cover, and outcrop morphology. Results from these transect reviews are published by Vlach (2022) in the thesis listed below.

Colonization Experiments: A series of 24 experimental substrates were deployed at two sites and depths for ten (10) months (8 wood blocks, 8 carbonate rocks, 2 ferromanganese crust, 2 phosphorites, and 2 sedimentary rocks) and recovered during this expedition. These yielded 25,278 macrofaunal individuals from over 117 taxa. Xylophagaid bivalves played an outsized role in the colonization of wood substrates but also settled as juveniles on surrounding rocks. Colonization experiment substrates exhibited significantly higher densities than background rocks, possibly reflecting early successional stage dynamics. These findings suggest that

substrate type may be a dominant driver of macrofaunal assemblages in this region, which may have future management implications for industries impacting hard substrate systems.

DDT Dumpsite Analyses: DDT-production waste barrels dumped in the San Pedro basin (SPB) at ~890 m from 1947 to 1961 were studied for effects (0, 1, 3, 5, and > 10 m from barrels) on sediment concentrations of DDX, PCBs, PAHs, and sediment properties, as well as on benthic macrofaunal assemblages, including meiofaunal taxa > 0.3 mm. DDX concentration was highest in the 2-6 cm fraction of the 10 cm deep cores studied but exhibited no correlation with macrofaunal density (with or without meiofaunal taxa), composition, or diversity. Macrofaunal diversity was lowest and distinct in sediments within the bacterial halos surrounding the barrels. Low SPB macrobenthos density and diversity, high dominance by Entoprocta, and numerical prevalence of large nematodes reflect the very low oxygen concentrations in bottom waters (< 0.1 ml L-1).

Benthic Invertebrate Diversity: Representative vouchers of benthic invertebrates from various habitats (including hard- and soft-ground substrates, colonization experiments, the surfaces of the DDT barrels, and barrel-adjacent sediments) have been deposited in the Scripps Institution of Oceanography Benthic Invertebrate Collection (SIO-BIC) and are available to the global research community. They have contributed to publications in taxonomy, biogeography, and phylogenetics, including the description of two new species. Additional specimens from this cruise have been determined to represent yet more new species and will be formally described. Several taxonomic specialists have visited SIO-BIC and/or borrowed specimens for further identification. Specimens from the DDT dumpsite are being prioritized for identification to the highest possible degree of accuracy, using a combination of DNA data and morphological examination by taxonomic specialists.

Microbial Diversity and Biosynthetic Potential: A large amount of data was acquired detailing the microbial communities associated with the animals, sediments, and mineral surfaces collected during the expedition. What appear to be symbiotic associations have been identified, with some of the sponges and linked microbial populations to the production of unusual, halogenated natural products. Biosynthetic potential using both amplicon sequencing and metagenomics is also being analyzed. In regards to the sediments collected from the DDT site, similar data describing the sediment communities has been acquired and there is strong evidence that the white halos around the barrels are not microbial mats as previously suggested, but are instead calcium carbonate precipitates formed due to the high pH of the barrel contents. The science team believes this also explains the formation of the brucite rock around the barrels. Two manuscripts are currently in preparation, some describing the sediments around the barrels and a second describing the microbial communities and biosynthetic potential of the mineral-rich habitats sampled.

Samples have been shared with collaborators who are in the very early stages of researching natural product biosynthesis in corals and the bioaccumulation of DDT compounds in animals.

3 Impact to date

3.1 Overview

The deep ocean off southern California has historically been a dumping ground for the pesticide DDT and other industrial waste. Invertebrate samples collected from discarded barrels will help understand the impacts and spread of DDT contamination throughout the food web.

Findings of high biodiversity, including many rare species and distinct faunas associated with ferromanganese crusts and phosphorites, will inform decisions about seabed mining, bottom fishing, and the establishment of marine protected areas. ROV sampling at the chemical barrels has helped to launch extensive follow-up research on the potential roles of benthic invertebrates in spreading DDT and other contaminants.

This research provides a first look at the small biota (microbes, macrofaunal invertebrates) of the southern California Borderland and mineral-rich hardground habitats, and it extends the study of megafaunal invertebrates to deeper depths. This expedition also provided the first high-resolution sampling of benthic macrofauna associated with sediments surrounding DDT production waste barrels in San Pedro Basin. Such knowledge is critical for management and conservation decisions.

3.2 New Discoveries & New Species

To date, two new species have been identified: *Yoda demiankoopi* - a new species of acorn worm (Figure 2), and *Munidopsis girguisi* - a new species of squat lobster (Figure 3). Additionally, this expedition has established a new northernmost record of the deep-sea squat lobster, *Uroptychus occidentalis.*

Figure 2: image of *Yoda demiankoopi*, photographed by ROV *SuBastian*. Photo Credit: Schmidt Ocean Institute.

Figure 3: Photos of *Munidopsis girguisi* against a black backdrop. Photo credit: Dr. Greg Rouse, Scripps Institution of Oceanography.

4 Data

Data Type	Curator	Completed
Raw environmental sensor data	Rolling Deck to Repository	Y
CTD, Event Logger, Navigation, and Imagery from ROV *SuBastian*	MGDS	Y
Rock samples	USGS and Scripps Geological Collections. Samples can be requested using this form. Also, a list of all rock samples collected can be viewed here, with photos of the rocks available here.	Y
Benthic macrofaunal data from colonization experiments.	Ocean Biodiversity Information System (OBIS)	Y
All specimen data, including animal DNA	Scripps Institution of Oceanography - Benthic Invertebrate Collection (SIO-BIC). *Integrated Digitized Biocollections (iDigBio) and Global Biodiversity Information Facility (GBIF) in progress*	Y
Voucher specimens	Scripps Institution of Oceanography - Benthic Invertebrate Collection (SIO-BIC)	Y
3-D Model of Chemical Barrel, ROV *SuBastian* Dive S0451	Scripps Institution of Oceanography - YouTube	Y
Metabolomics data		N
Sequence data		N
Invertebrate survey data		N

Table 4: Datasets acquired during this expedition and derived from the analysis of collected data and samples (*Shared at time of Report Publication*).

5 Publications

Current publications as of the date of this report's publication.

Holland, Nicholas D., Avery S. Hiley, and Greg W. Rouse. 2022. "A New Species of Deep-Sea Torquaratorid Enteropneust (Hemichordata): A Sequential Hermaphrodite with Exceptionally Wide Lips." Invertebrate Biology 141 (3): e12379. https://doi.org/10.1111/ivb.12379.

Mongiardino Koch, Nicolás, Ekin Tilic, Allison K. Miller, Josefin Stiller, and Greg W. Rouse. 2023. "Confusion Will Be My Epitaph: Genome-Scale Discordance Stifles Phylogenetic Resolution of Holothuroidea." Proceedings of the Royal Society B: Biological Sciences 290 (2002): 20230988. https://doi.org/10.1098/rspb.2023.0988.

Rodríguez-Flores, Paula C., Charlotte A. Seid, Greg W. Rouse, and Gonzalo Giribet. 2023. "Cosmopolitan Abyssal Lineages? A Systematic Study of East Pacific Deep-Sea Squat Lobsters (Decapoda: Galatheoidea: Munidopsidae)." Invertebrate Systematics 37 (1): 14–60. https://doi.org/10.1071/IS22030.

Vlach, Devin S. 2023. An Illustrated Guide to the Southern California Borderland. https://escholarship.org/uc/item/1hg7v0q0.

Wicksten, Mary K., and Kevin W. Conway. 2023. "The Chirostyloidea of the Northeastern Pacific: Host Associations, Range Extensions and a New Species (Decapoda: Anomura)." Zootaxa 5284 (1): 167–76. https://doi.org/10.11646/zootaxa.5284.1.7.

6 Appendix

6.1 Cruise Records

- Cruise Logs.
- ROV *SuBastian* Dive List.

6.2 Science party information

Name	Institution
Lisa Levin	Scripps Institution of Oceanography, University of California, San Diego
Greg Rouse	Scripps Institution of Oceanography, University of California, San Diego
Kira Mizell	U.S. Geological Survey
Paul Jensen	Scripps Institution of Oceanography, University of California, San Diego
Nicolás Mongiardino Koch	Scripps Institution of Oceanography, University of California, San Diego
Michelle Guraieb	Scripps Institution of Oceanography, University of California, San Diego
Johanna Gutleben	Scripps Institution of Oceanography, University of California, San Diego
Devin Vlach	Scripps Institution of Oceanography, University of California, San Diego
Tanya Young (Artist-at-Sea)	Del Mar, California
Brady Lawrence (Multimedia Correspondent)	

Scientists and Artist-at-Sea aboard R/V *Falkor*:

6.3 Media

- Possible cure for cancer could be under the sea, This Green Earth
- Racing to catalog, study deep-sea biodiversity, Harvard Gazette
- Biodiverse Borderlands - Expedition Update 2022, Schmidt Ocean Institute
- Who Drinks the Water of Life? ,Schmidt Ocean Institute
- Back Ashore: Finding and Describing New Species, Schmidt Ocean Institute
- History of DDT ocean dumping off L.A. coast even worse than expected, EPA finds, LA Times
- Identifying Benthic Invertebrates at Southern California DDT Dumpsites 1 and 2, Scripps Institution of Oceanography -Benthic Invertebrate Collection

6.4 Community Outreach

- California Stakeholder DDT Research Needs Workshop, July 2022

- DDT+ Community Meeting, Assessing the extent and scope of contaminant impacts and mitigation strategies for deep ocean dumping sites in Southern California, March 2024
- Scripps Institution of Oceanography's DDT dumpsite research project.

6.5 Presentations and Posters

Current presentations/posters as of the date of this report's publication.

- Discovery of pigments in a deep-sea glass sponge possibly made by a symbiotic bacterium. Center for Marine Biotechnology and Biomedicine Symposium, UCSD, La Jolla, 11/2023. Castro et al.
- Pigmentation in Glass Sponges from Deep-sea Habitats of Southern California Department of Marine Sciences. University of Puerto Rico, Mayagüez, 05/2023. Castro et al.
- Pigmentation in Glass Sponges from Deep-sea Habitats of Southern California Natural Products Affinity Group (NPAG) Seminar Series, UCSD, La Jolla, 10/2022. Castro et al.
- Exploring microbial biodiversity and biosynthetic potential in the Southern California Borderland. Wageningen University and Research, Wageningen, The Netherlands, 10/2023. Gutleben et al.
- Biodiversity in the Southern California Borderland. 262 Seminar Series, Scripps Institution of Oceanography, UCSD, La Jolla, 06/2023. Gutleben et al.
- Biodiversity in the Southern California Borderland. SIO 90 "Perspectives in Ocean Sciences" undergraduate seminar course, UCSD, La Jolla, 11/2023. Gutleben et al.
- Mizell, Kira and Lisa Levin. Dec. 2021. Key components of marine mineral-related characterization studies learned from collaborative research on mineral systems in the Southern California Borderland (Invited). AGU Fall meeting.
- Levin, L., Gr. Rouse, K. Mizell, E. Cortez, B. Grupe, A. Thurber. 2022. Does substrate matter to hardground macrofauna? Ocean Sciences. Feb. 2022.
- Frontiers in Biodiversity, Dynamics and Management of Methane Seeps (Oral Presentation L. Levin. Hong Kong University of Science and Technology Deep Sea Symposium April 5, 2022.
- Oxygen dynamics and deoxygenation effects on benthos. Invited Keynote: L. Levin at Eastern Boundary Upwelling Symposium Sept. 2022.. Lima, Peru.
- Deep Sea sustainability challenges in the 21st century (Oral Presentation - L. Levin). University of Bergen, May 29, 2022.
- Frontiers in Biodiversity, Dynamics and Management of Pacific Methane Seeps (L. Levin) Bjerkness Center University of Bergen, June 2, 2022.
- Pereira, O.S., Mendoza, G., Vlach, D., Mizell, K., Rouse, G.R., Cortés, J., Cordes, E.E., & Levin, L.A. (2022). Low oxygen effects on hardground macrofaunal communities at bathyal depths. Ocean Sciences Meeting (online). Oral presentation.
- June 8, 2022. World Ocean Day Pontifical Academy, Vatican. Deep-Sea Biodiversity: Frontiers and Challenges in the 21st Century (L. Levin).
- UN Ocean Conference Lisbon 2022 (L. Levin presentations)
    - June 27: Grand Challenges for Ocean Science (Woods Hole Side event).
    - June 28: Biodiversity for a Resilient Planet: A deeper look (L. Levin Panelist).

    - June 29. Seabed 2030: Mapping for People and Planet.
    - July 1: Deep Ocean Observing for Ocean Sustainability.
- COP 27 Sharm El Sheik – Nov. 9 2022. 4:30 PM Session title: The Deep-Sea, the Climate and the Next Generation Climate Education Hub (Levin, Pereira, Guraieb)
- COP 27. Nov. 15, 2022 11:30 AM – 1 PM. Observing and Understanding Climate Change and Biodiversity from the coast to the deep ocean.
- Jan 9, 2023. Xiamen XMAS Ocean Sustainability Conference keynote by L. Levin: Challenges to Deep-Ocean Biodiversity in the 21st Century.
- Aug. 16, 2023. NOAA Central Library Seminar. Diversity and biopharmaceutical assessments of deep-sea mineral rich biomes off southern California. P. Jensen and L. Levin.
- Huc, Sonja (oral presentation; M.S. student, Rouse lab). "Triopha project", Southern California Unified Malacologists (SCUM) Meeting XXVI, Feb 5, 2022.
- Greg Rouse (oral presentation), "So, you found a new species. Now what?", Scripps Institution of Oceanography Institutional Seminar, Oct 31, 2023, La Jolla, CA.
- Guraieb, M, G. Mendoza, K. Mizell, G. Rouse, O. Pereira, L. Levin. 2024. Relationship of substrate type, low oxygen and megafauna presence with deep-sea macrofauna assemblages on mineral-rich hardgrounds of the Southern California Borderland. Ocean Sciences. Feb. 2024.

6.6 Student Projects, Thesis, and Dissertations

Current presentations/posters as of the date of this report's publication.

- McBean, Rita. Isolation of Deep Sea Actinomycetes and their biosynthetic potential. Mesa Community College Impactship in the Jensen Lab.
- Ullman, Ailish. 2022. Effect of substrate type and environment on macrofaunal colonization in the southern California Borderlands. Masters of Advanced Studies Capstone Project. Scripps Institution of Oceanography. University of California, San Diego.
- Vlach, Devin. 2022. Characterizing megafaunal communities on ferromanganese and phosphorite-rich hardgrounds in the Southern California Borderland. Masters Thesis in Oceanography. Scripps Institution of Oceanography. University of California, San Diego.
- Bradley, Angelica. 2023. Benthic macrofaunal invertebrates of the San Pedro Basin and the relationship to DDT waste barrels. Masters Thesis in Marine Biology. Scripps Institution of Oceanography. University of California, San Diego.
- Guraieb, Michelle. 2024. Deep-ocean macrofauna assemblages on ferromanganese and phosphorite-rich substrates in the Southern California Borderland. Masters Thesis in Oceanography. Scripps Institution of Oceanography. University of California, San Diego.