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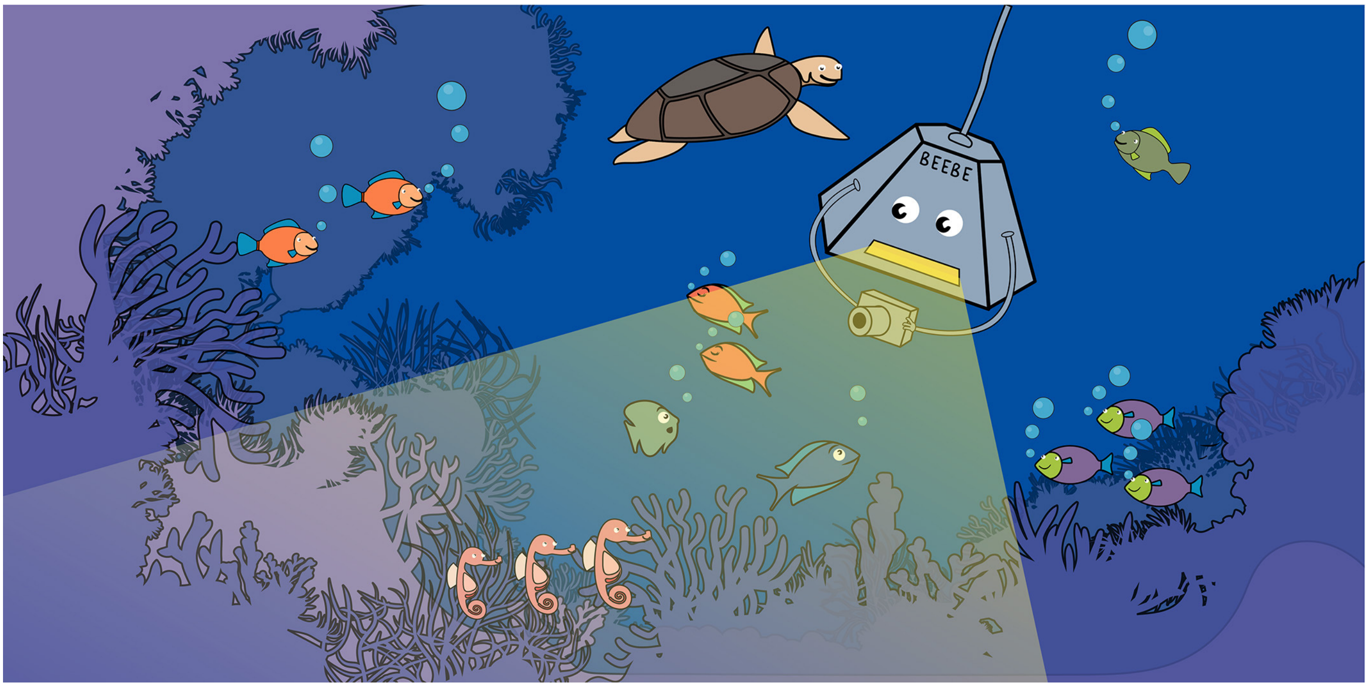

SPIES IN THE DEEP: OCEAN LANDERS EXPLORE THE DEEP SEA

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NAVID
AGE: 15

NORA
AGE: 14

Below the surface layers of the ocean, there are ecosystems full of undiscovered life. Scientists love to ask questions like, “Who is there?” and “What are they doing?” An important question scientists are beginning to ask is, “How will these living things react to warmer waters, loss of oxygen, or pollution?” To answer these questions, scientists build equipment to observe life in the deep sea. We built an ocean lander named BEEBE, with a camera, sensors, and waterproof casing. BEEBE helped us study deep-sea ecosystems near the coast of California and learn about the animals that live there. We can use what we learned to recognize vulnerable communities and the

threats some ocean animals face. An ocean lander like BEEBE can be a great tool to learn more about coastal, deep-sea ecosystems around the world!

WHY DO SCIENTISTS CARE ABOUT THE DEEP SEA?

When scientists study tide pools at the ocean's edge, they gather their equipment, drive down to the rocky shoreline, and put on their "science boots." Using only their eyes, they can observe squishy anemones, colorful starfish, and thousands of barnacles clinging to the rocks. To study what's *in* the sea, however, scientists need different tools and techniques. The invention of SCUBA diving was important because it allowed scientists to study deeper underwater ecosystems like coral reefs for the first time.[1] Beyond the coral reefs, the deep sea is as full of life as a tropical rainforest, but it is too deep for humans to visit. To uncover the mysteries of the deep sea, scientists first must build specialized equipment to go deep!

[1] https://www.nationalgeographic.com/news/2010/6/100611-jacques-cousteau-100th-anniversary-birthday-legacy-google/

The deep sea includes everything in the ocean below 200 m. In some places, like California, deep-sea ecosystems can be found close to shore (less than 2 km from the beach). The deep waters are dark, cold, and mysterious. Since there is a limit to how deep the human body can go without special equipment, scientists build technologies to take people deeper [1]. Some scientists have used a one-person submarine to explore places like the Mariana Trench, which is almost 7 miles (11,265 m) below sea level [2]. Others build robots to regularly scan, collect, and record information about the seawater.

Accessing the deep sea is the key to learning about the animals living there. On the land, we have learned how worms need moist, airy soil, and tortoises prefer the dry desert heat. Ocean environments and their animals are just as unique and selective. Certain ocean animals prefer warmer, Caribbean waters, while others like colder, Arctic waters. Like us, marine animals need oxygen to breathe. Rather than coming up to the surface to breathe, most marine animals use oxygen dissolved in the seawater. We have learned that there is generally more oxygen at the surface of the ocean than in the deeper waters. Some animals can tolerate areas with less oxygen, while others need more oxygen to breathe comfortably.

Within the surface layers of the ocean, oxygen varies a lot. The constantly moving water is one reason for this: the oxygen levels change a little bit as the water moves up, down, and side-to-side. This is called **environmental variability** because these changes in oxygen happen naturally. Oxygen availability can also change with the seasons, or because of storm systems. In addition, oxygen in the ocean's surface layers is decreasing due to **climate change** caused by humans. As humans continue to burn fossil fuels and pollute the

ENVIRONMENTAL VARIABILITY

The changes and fluctuations that occur in an environment over a short period of time.

CLIMATE CHANGE

Climate change is the process of the Earth heating up due to human activity.

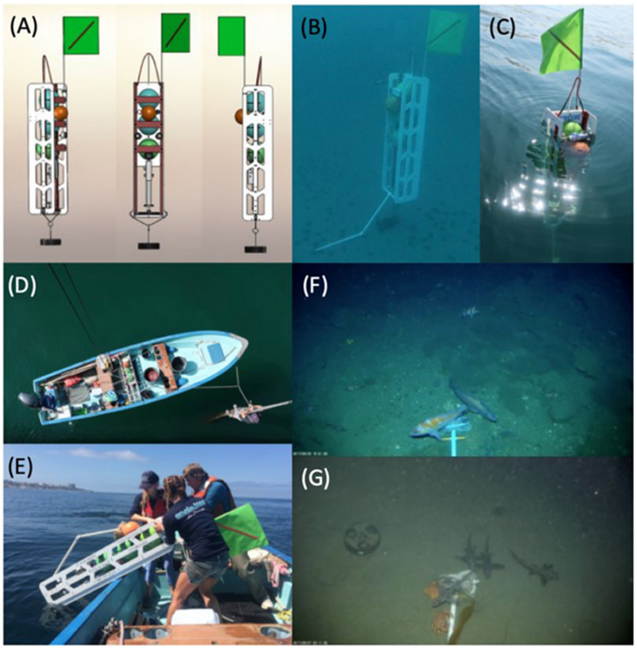

Figure 1

Figure 1

Here are the many stages of DOV *BEEBE,* our deep-sea spy: **(A)** computerized design; **(B)** underwater and in position to collect data; **(C)** floating on the ocean surface, waiting to be retrieved; **(D)** being transported in the back of a small boat; and **(E)** ready for deployment. **(F)** View from BEEBE's camera system showing the rockfish community in a shallower, high-oxygen area. **(G)** View from BEEBE's camera system showing the presence of crabs and chimaeras in a deeper, lower-oxygen area.

environment, they release chemicals into the air that lead to warmer oceans with less oxygen. This change happens slowly but can cause permanent damage.

Animals that live in constantly changing environments may have a better chance of adapting to oxygen decreases caused by climate change. However, if oxygen becomes too low, many animals, like fish, will need to find new homes with more oxygen. Our goal was to figure out how vulnerable the animals along California's coast are to changes in ocean oxygen, by watching their reactions to varying conditions. We hoped that our deep-sea observations would tell us which deep-sea animals and environments will be threatened by future decreases in oxygen, so that we can better protect them.

BUILDING A DEEP-SEA SPY TO EXPLORE

To study animals in the deep sea, we built a deep-water lander, called Deep Ocean Vehicle (DOV) BEEBE, which we call our "deep-sea spy" (Figure 1). A lander is a technology that "lands" in new environments that humans cannot easily get to, like the Mars Lander that studied Mars. Landers can be customized based on the goal of the mission. BEEBE landed on the seafloor and its mission was to observe different deep seafloor communities for up to 3 weeks. We focused on the nearshore deep-sea ecosystems off San Diego, California. This is an **upwelling** area, where cold, deep water, low in oxygen, is brought up to shallower depths in the spring and summer.

UPWELLING

The process of deep, cold, nutrient-rich water rising to the surface.

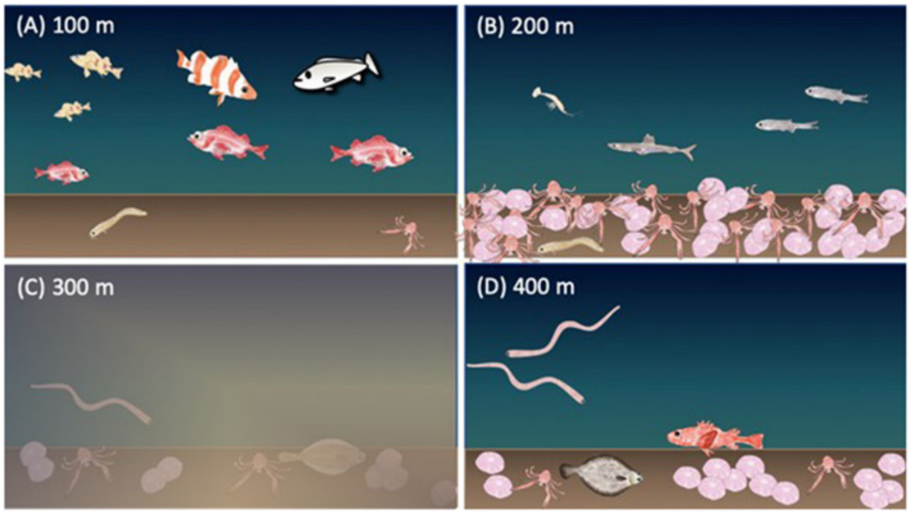

Figure 2

Figure 2

(A) The 100-m community was fish-dominant and included rockfish, pink seaperch, and spotted cusk-eel. **(B)** The 200-m community had many invertebrates like tuna crabs, pink urchins, and spot prawns, with appearances by spotted cusk-eels, lizardfish, and other small fish. **(C)** The 300-m community was invertebrate-dominant with high amounts of sediment in the water, so it was difficult to see. We occasionally saw pink urchins, tuna crabs, Pacific hagfish, and slender soles. **(D)** The 400-m community was invertebrate-dominant, including mostly tuna crabs and pink urchins, with occasional Pacific hagfish, dogface witch eels, shortspine thornyheads, and Dover soles.

Landers like BEEBE are extremely helpful when studying the deep sea because they are small enough for one person to deploy from a small boat! BEEBE stands five feet tall, about the height of an average 12-year old. At the start of each mission, BEEBE traveled to the seafloor with weights and began attracting animals with attached bait (Figures 1B, F, G). With a special camera and lights to brighten the seafloor, BEEBE recorded short videos every 20 min, to capture who was there and what they were doing. With special sensors, BEEBE also collected information on the temperature, saltiness, pressure, and oxygen in the water. After a few weeks of sampling, a signal was sent through the water to tell BEEBE to release the weights, so it could float back up (Figure 1C).

WHAT DID WE SEE THROUGH BEEBE'S CAMERAS?

BEEBE conducted seven spy missions for us, visiting seafloor communities from 100 to 400 m deep. From each spy mission, BEEBE brought back fascinating video footage and information about the ocean waters that we could upload to our computer and learn from![2]

[2] *Check out footage from BEEBE's deployments here*

During each mission, BEEBE observed seafloor communities at different depths. The videos BEEBE recorded revealed that, closer to the surface of the ocean at 100 m, there are mostly fish! We called this environment *fish-dominant* (Figure 2A). Rockfish loved this environment, and many other fish gathered when oxygen levels increased. At deeper depths, like 200, 300, and 400 m, there were fewer fish and more crustaceans and sea urchins. We called this a transition to an *invertebrate-dominant* seafloor (Figures 2B–D). **Invertebrates** are animals without backbones, like crabs or urchins. Pink urchins and tuna crabs covered the seafloor. They seemed to like the

INVERTEBRATES

An animal without a backbone. More than 90% of all living animal species are invertebrates.

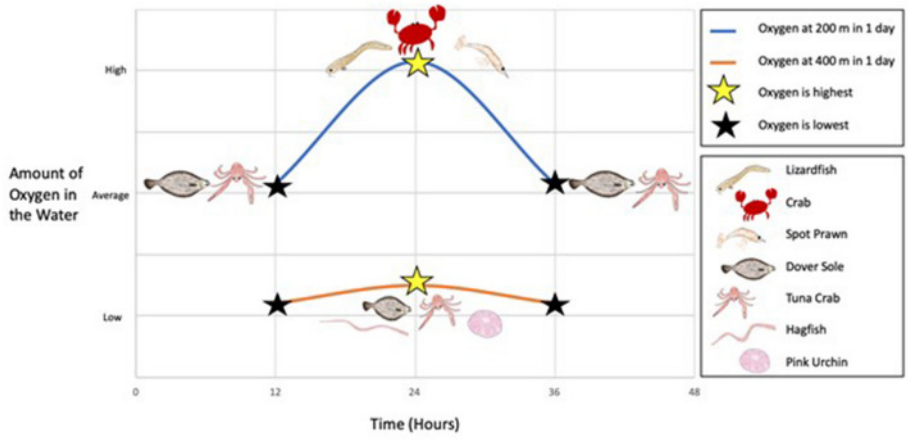

Figure 3

Figure 3

Oxygen variability and animals present at 200 and 400 m. At 200 m (blue line) the water experienced large daily changes in oxygen. The animals observed during oxygen highs were lizardfish, crabs, and spot prawns. During oxygen lows, we saw Dover soles and tuna crabs. Water at 400 m (orange line) experienced smaller daily changes in oxygen. Animals at 400 m, like hagfish, Dover soles, tuna crabs, and pink urchins, like their stable, low-oxygen environment. This shows that certain animals prefer water with high oxygen, while others prefer low oxygen.

colder, lower-oxygen environments. The few fish we observed in the invertebrate-dominant area were much less active, sitting still along the seafloor, compared to those seen at 100 m, which swam around frequently. Being less active could be a behavioral adaptation to preserve energy while living in a cold, low-oxygen environment.

WHAT DID BEEBE'S SENSORS TEACH US?

Our sampling equipment measured the temperature and oxygen level of the seawater every 5 min! This helped us compare ocean environments at various depths. It also helped us see how one environment changes from day to day. The 100 m environment had the most oxygen and highest variability of temperature, meaning the temperature at 100 m changed the most from day to day. At 200 m, the oxygen and temperature were lower than at 100 m. We were surprised to find high oxygen variability here, meaning the oxygen levels changed the most from day to day at 200 m (Figure 3). Conditions at 300 and 400 m had extremely low oxygen levels that did not change much throughout the entire mission. We called these regions **hypoxic** because they are extremely low in oxygen and can be stressful for fish and other organisms.

HYPOXIC

Having an extremely low oxygen concentration, making it difficult for many animals to survive.

HOW DO CHANGES IN OXYGEN AFFECT OCEAN ANIMALS?

Our sensors taught us that water at 200 m experiences the most oxygen variability. By comparing which animals were present in the video footage to the oxygen conditions at the time, we noticed a pattern! We found that some animals prefer high-oxygen waters, while others like low-oxygen waters. For example, during high-oxygen periods, spot prawns, crabs, and lizardfish were more common. During low-oxygen periods, tuna crabs and Dover soles were more common

(Figure 3). This shows that certain animals living at 200 m are sensitive to changes in oxygen. Overall, most animals did not seem bothered by these natural and temporary oxygen changes. However, as oxygen loss worsens due to climate change, we still do not know how each animal will respond to permanent decreases in available oxygen.

SPIES LIKE BEEBE CAN HELP SCIENTISTS UNDERSTAND CLIMATE CHANGE IMPACTS

OCEAN DEOXYGENATION

The loss of oxygen in the ocean due to human-caused climate change.

As climate change causes the ocean to warm, the water loses oxygen. This is a crisis called **ocean deoxygenation**. Exploring with our seafloor lander BEEBE gave us day-to-day insight into which animals and depths may be more sensitive to permanent climate change impacts [3]. What will happen to the animals that prefer high-oxygen conditions, like rockfish, spot prawns, crabs, and lizardfish? These animals may be forced to find new homes in shallower, better oxygenated waters. When animals shift habitats, they may experience more stress or become more vulnerable to predators. It is also possible that, as some animals move away from low-oxygen areas, other animals that are not stressed by low oxygen conditions, such as tuna crabs and Dover soles, may expand into these areas.

Maintaining biodiverse ecosystems with many types of animals is key to supporting a healthy ocean. Oceans around the world are facing similar concerns stemming from warming and oxygen loss. Ocean landers can capture unique footage of seafloor communities in deep-sea ecosystems that are close to shore and could help scientists in other parts of the world explore their understudied seafloor habitats, too. Someday this type of information may help marine managers or young scientists like you to understand which deep-sea ecosystems and species are most vulnerable to warming and oxygen loss. This knowledge will help us to make better decisions about how to manage deep-sea ecosystems and preserve biodiversity in a changing world.

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ORIGINAL SOURCE ARTICLE

Gallo ND, Hardy K, Wegner NC, Nicoll A, Yang H, and Levin LA. 2020. Characterizing deepwater oxygen variability and seafloor community responses using a novel autonomous lander. *Biogeosciences* 17: 3943–3960. doi: 10.5194/bg-17-3943-2020

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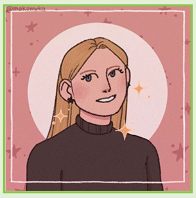
CONFLICT OF INTEREST: KH was employed by Global Ocean Design LLC.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS

NAVID, AGE: 15

Navid likes to ask questions or learn new things—especially about science. He is interested in a lot of things and tries to understand them as well as he can. Many of his classmates ask him for help as he is a good teacher as well. In his freetime, Navid likes to do sports like CrossFit or play online with his friends.



NORA, AGE: 14

Hi! My name is Nora and I am 14 years old. I love playing volleyball as well as surfing in the ocean. My favorite subjects are design and science, and I am currently a freshman in High School. In the future I would like to be an architect.

AUTHORS

HALEIGH T. YANG

Haleigh T. Yang completed her undergraduate degree at University of California, San Diego. Spending time in the outdoors helped spark Haleigh's interest in the natural world. Through research, she learned how diverse the ocean is and how important it is for people's livelihoods. She is currently working as a marine naturalist teaching people about the Salish Sea and the animals that call it home—killer whales, humpback whales, salmon and more! She hopes to continue learning about the world in order to teach more people about marine life. *htyang@ucsd.edu

KEVIN HARDY

Kevin Hardy founded Global Ocean Design to design and build unmanned deep ocean landers for oceanographers. He participated in James Cameron's DEEPSEA CHALLENGE Expedition to the Challenger Deep of the Mariana Trench (2012), and the University of Concepcion's ATACAMEX dive to the deepest place in the Peru-Chile Trench (2018). He previously was an ocean engineer at the Scripps Institution of Oceanography for 40 years. He is currently on multiple academic advisory boards. He received a Doctor of Science (honoris causa) from Shanghai Ocean University in 2018.

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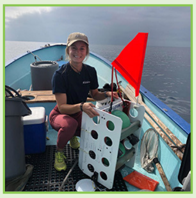
Dr. Nicholas C. Wegner is a Research Fisheries Biologist for the National Marine Fisheries Service in La Jolla, CA. His research focuses on the physiology and behavior of marine fishes and invertebrates. He is particularly interested in the way animals adapt to their surroundings and how environmental factors such as temperature and dissolved oxygen affect their physiology and behavior. Dr. Wegner's claim to fame is his discovery that a strange-looking fish known as the Opah is able to keep its body warmer than its cold and deep ocean habitat.



ASHLEY NICOLL

Ashley Nicoll received her master's degree from Scripps Institution of Oceanography. She used ocean landers to see the animal communities that live on the seafloor in the submarine canyons and study how they may change between day and night as well as when the water gets deeper. Now, Ashley is pursuing a Ph.D. at Stony Brook University studying changes in how fish move over time.

LISA A. LEVIN

Dr. Lisa A. Levin is a Biological Oceanographer who researches benthic communities in deep-sea and shallow-water environments. She is a Professor at Scripps Institution of Oceanography at the University of California. Together with her students Dr. Levin has participated in over 45 oceanographic expeditions around the world and served as Chief Scientist on about half of these. She has perceived over the years a growing threat to deep margin settings and has turned her attention to conservation issues. She has helped establish scientific networks that bring deep-sea science to policy makers.

NATALYA D. GALLO

Dr. Natalya D. Gallo is a scientist at the University of Bergen studying marine fjord ecology. Her curiosity about the ocean and its animals began at a young age and has taken her on scientific adventures to study deep sea ecosystems around the world. She is interested in what environmental factors determine where animals live and how they interact, how climate change affects marine ecosystems, and how we can use science to inform ocean management and protection. Before moving to Norway, she worked at the Scripps Institution of Oceanography.