EARTH AND ITS RESOURCES
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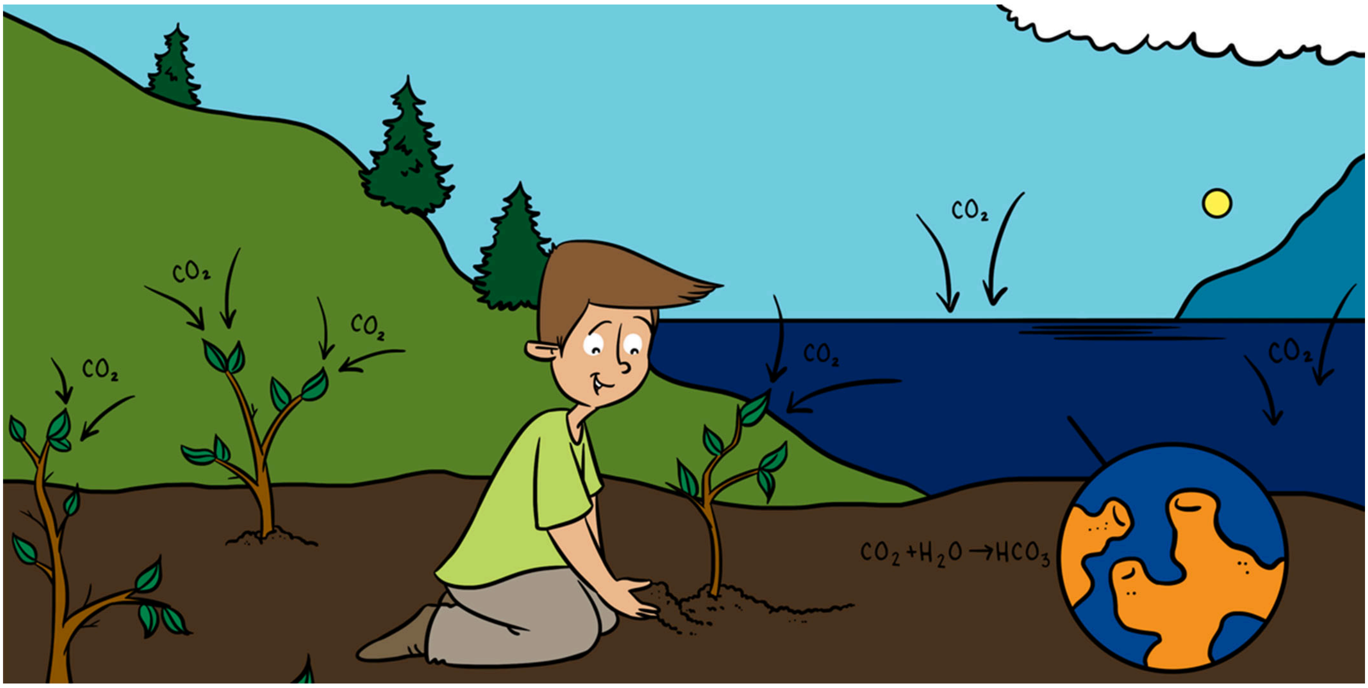

HOW DO ORGANISMS AFFECT AND RESPOND TO CLIMATE CHANGE?

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Life on Earth is diverse at many levels, meaning there is a lot of variety within species and there are many different kinds of species. This biodiversity provides many of the resources that humans need and enhances our quality of life. All of Earth's organisms are affected by Earth's climate, but they also *influence* Earth's climate. In this article, we show how research on plants, animals, and microbes helps us

better understand how living things can both impact and respond to climate change. This research also gives us insight into what the future might be like for life on Earth. Such knowledge will help us to protect our planet—and the living things on it—from the harmful effects of future climate change.

WHAT IS BIODIVERSITY?

Many different kinds of microbes, plants, and animals (including people) live on Earth. Collectively, all these different organisms make up Earth's **biodiversity**. Biodiversity includes genetic diversity among individuals and among populations within species. Biodiversity also includes diversity of species, and communities of species within ecosystems. Biodiversity provides humans with many important resources, such as a variety of nutritious foods, and recreational activities. In addition, biodiversity can be important for cultural reasons, including national identity and religious ceremonies. Biodiversity also holds the potential for undiscovered benefits, like potential new medicines and protection of agriculture and livestock from disease outbreaks. For all these reasons, we must try to understand and protect Earth's biodiversity.

BIODIVERSITY

The variety of life (plants, animals, and microorganisms) measured at within a certain species, ecosystem or on Earth.

HOW CAN LIVING THINGS CONTRIBUTE TO CLIMATE?

Living things are clearly dependent on their environment, but they also *affect* their environment—even on a global scale. Organisms can affect the global climate because of their huge numbers. For example, the majority of carbon dioxide (CO_2) in the air is eventually consumed through rock weathering into dissolved river nutrients (Figure 1). However, the enormous numbers of plants and microbes on Earth collectively control the amount of CO_2 that remains in the air because they take it up to build their bodies. This is important for climate because CO_2 traps heat in the Earth's atmosphere, which, through the greenhouse effect, contributes to global warming.

According to the International Union for Conservation of Nature (IUCN)[1], the world's forests absorb about one-third of the CO_2 that is released from burning fossil fuels (like gas, oil, and coal). In addition, the Global Carbon Project[2] reported that a quarter of the CO_2 released from burning fossil fuels is quickly absorbed by the oceans. There, ocean microorganisms take up CO_2 and use it to build their cells.

The vast majority of carbon captured by organisms is released again to the air in a few years when organisms die. However, a small fraction of their carbon is deposited in the soil or ocean sediments. This removal of carbon from the environment is largely balanced out by volcanic processes. After hundreds of millions of years, the carbon returns to

[1] The International Union for Conservation of Nature (IUCN; https://www.iucn.org) is like the Intergovernmental Panel on Climate Change (IPCC), but with a specific focus on conservation of diversity. Like IPCC, it is funded by ∼200 governments and civil society organizations, policy is built through intergovernmental studies and is government approved.

[2] Global Carbon Budget Summary Highlights.

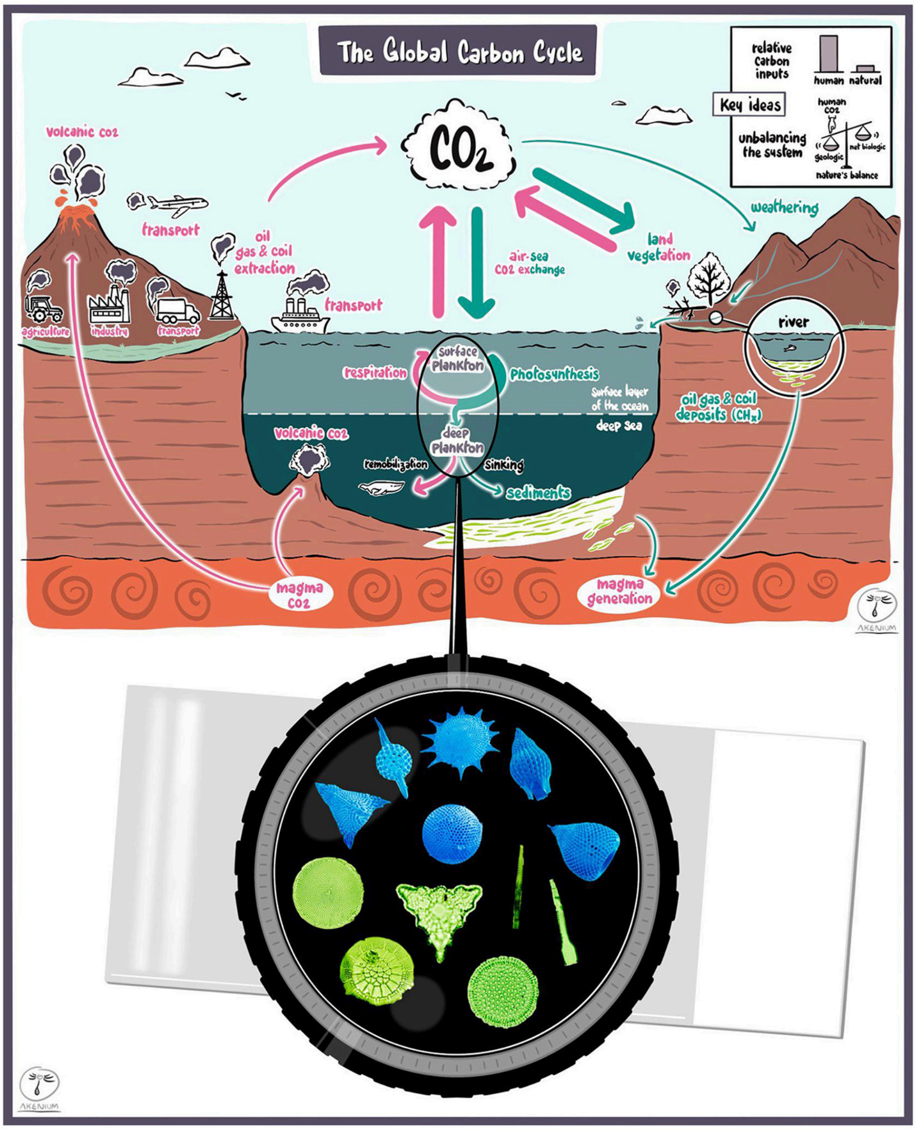

Figure 1

Figure 1

In the natural carbon cycle, the earth emits CO_2 from volcanoes. This is largely converted by the chemistry of rock weathering into dissolved river nutrients, which are taken up by plants and marine organisms along with atmospheric CO_2. The growth and death of organisms are in near perfect balance, with just enough carbon deposited into the soil and ocean sediments to balance the amount released by volcanoes. Human activities release nearly 100 times more carbon than is released by the natural cycle, causing rising atmospheric CO_2 levels and global warming [1]. Inset: Electron microsco5pe images of some of the ocean organisms that use carbon: marine zooplankton (radiolarians: blue) and phytoplankton (diatoms: green).

the air as CO_2 when volcanoes erupt, completing the natural carbon cycle (Figure 1). Atmospheric CO_2 has increased dramatically because many human activities rely on burning fossil fuels. Burning releases the carbon back into the atmosphere as CO_2 [1][3]. Currently, human activities release nearly 100 times more CO_2 into the atmosphere than volcanoes do [1].

Humans must therefore be part of the solution to climate change. We can stop burning fossil fuels and cutting down forests. Actively replanting forests and restoring or preserving other natural systems that store a lot of carbon (like peatlands) are also important to combat climate change. Scientists think that if oceans become warmer, there will be fewer carbon-removing microorganisms (Figure 1 insert). This would leave more CO_2 in the atmosphere. Preventing global warming will help protect the ocean's microorganisms, and thus help to stop climate change.

[3] In addition to the articles in this collection, for more information on climate change and global warming, check out these pages: NASA Climate Kids: Home and Climate Change and Global Warming.

EVOLUTION

The changes in traits passed down through generations of organisms. Some traits, or adaptations, help individuals survive and succeed in their unique environments.

HOW DOES CLIMATE AFFECT BIODIVERSITY?

Not only does life affect the climate, but climate also affects life [2]. As Earth's climate changes, some individuals that can tolerate the new conditions might survive and reproduce, passing on their tolerant traits, while others will die. This process is called **evolution**. Some organisms migrate to follow the conditions that are right for them. Animals might move because temperatures get too high, or because food sources become scarce. But not all species can move. For example, organisms in polar regions or at the tops of mountains are already living in the coldest places on Earth. When climate changes quickly, many species cannot adjust quickly enough, and become extinct [3]. The interactions of organisms with their environments can thus affect the Earth's biodiversity in many ways.

Changes in one species affects other species within the same community. Long-term studies of the interactions between species are important for predicting the future of life on Earth. For example, scientists have studied Edith's checkerspot butterfly for over 70 years (Figure 2). At one site, the success of the butterfly was dependent on one plant species (blue-eyed Mary). Then cattle ranchers brought in a new plant (plantain). Edith's checkerspot completely switched to using plantain. When cattle were taken off the land, the plant community changed again, and this time the butterfly population died off completely. Sometimes humans change things in the environment too fast for populations to adjust[4]. This can happen if there are not enough individuals in the population that can tolerate the new conditions.

[4] See the story of Edith's checkerspot on Youtube: The tale of the Edith's checkerspot: Butterflies caught in an evolutionary trap.

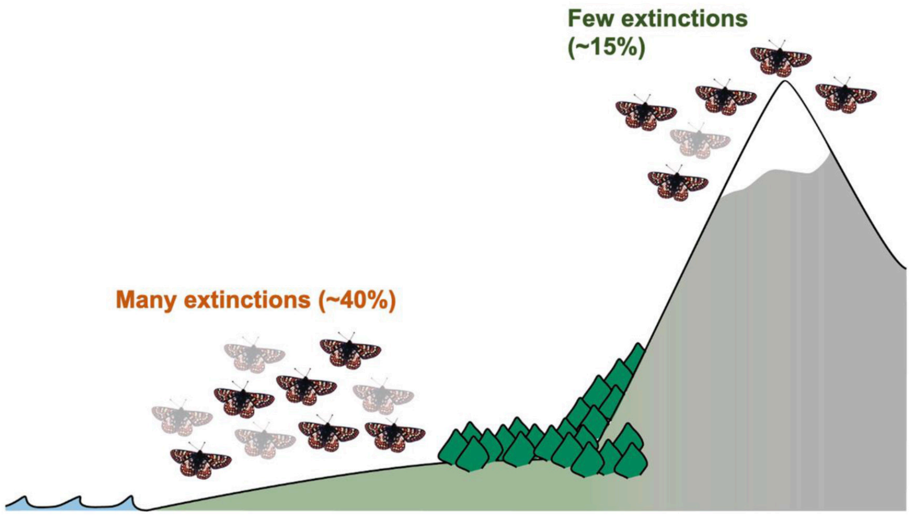

Figure 2

Figure 2

Edith's checkerspot butterfly lives in many habitats, from the seashore to the highest peaks of the Sierra Nevada mountains of California. This butterfly is sensitive to the climate. Whole populations can die off completely during extreme climate events. As western North America warmed by 0.7°C, many populations suffered at lower elevations—about 40% of the populations below 8,000 feet died off during our study. At the same time, only 15% of the populations above 8,000 feet were lost. The center of the species' range shifted 300 feet higher than it was previously [4].

Corals are another important example. These animals build their skeletons with a substance called calcium carbonate ($CaCO_3$), forming reefs like the Great Barrier Reef of Australia. Reef formation depends on the amount of CO_2 in the atmosphere because that influences how much CO_2 is taken up by the ocean. CO_2 reacts with ocean water to form carbonic acid, which makes the ocean more acidic[5]. When ocean water is acidic, it reduces the growth and survival of corals. Coral reefs are important ecosystems—they provide breeding grounds for fish and hiding spots for other marine life. Without reefs, marine communities become less stable and collapse [5].

CORAL

1: A tiny soft-bodied animal. Corals live in colonies and build a stony skeleton. 2: A piece of stony material which is the skeleton of corals.

[5] To learn more about the effects of ocean acidification, see the short animation about the potential impact on sea life in the Gulf of Maine A Climate Calamity in the Gulf of Maine Part 2: Acid in the Gulf.

Marine habitats are also experiencing rapid changes in salt content. Rainfall patterns are changing around the world, and polar ice is melting rapidly. Oceans near the poles are becoming less salty, while the oceans closer to the equator are getting saltier. These rapid changes put enormous stress on marine organisms because salt levels must be maintained for proper function. Some populations can evolve in the saltier conditions, but others will die off. Species that do not live very long can evolve faster. For example, some copepods (small crustaceans) live only a few weeks and the average salt tolerance of the population can increase in just a few years. However, longer-lived plants and animals take much longer to evolve. This is true for many populations of fish which may decline in numbers or die off completely due to changes in salinity.

Changing climate conditions may also allow non-native species to thrive and become invasive. This is partly because native species may become stressed by the changing climate conditions. **Invasive species** may be more tolerant of the new conditions and may even grow more aggressively in the invaded areas than in their native areas! One example is Japanese knotweed. This plant tolerates many disturbed and stressful habitats, and has taken over in many areas around the world[6].

INVASIVE SPECIES

Organisms that are transported to a new location where they had previously not existed but then begin to change or threaten the local communities.

[6] To learn more about the invasive knotweed, see the recent article in Attempto! magazine: `https://tinyurl.com/AttemptoKnotweed`.

HOW DO WE PREDICT HOW ORGANISMS WILL RESPOND TO CLIMATE CHANGE?

Scientists study how organisms are changing in natural conditions and under experimental conditions. For over 100 years, studies of organisms in their natural conditions have shown changes in the life cycles and distributions of many plants, animals, and microbes in oceans, lakes, rivers, and on land as a result of climate change [2]. Warmer winters and springs have caused plants to flower earlier, trees to grow leaves earlier, and birds and butterflies to migrate earlier. Many plants and animals have moved closer to the poles and higher into the mountains as they try to keep pace with the changing climate (Figure 2).

It is hard to predict what will happen to living things when the Earth gets even hotter. One way is to take a closer look at corals because they provide an important window into the climate of the past (Figure 3). Corals grow slowly, and they incorporate the chemistry of the surrounding ocean into their skeletons. Scientists can "read" this information and use it to reconstruct the past living conditions of the corals. Some corals are 500 years old, giving us the chemical history of the last 500 years almost month by month!

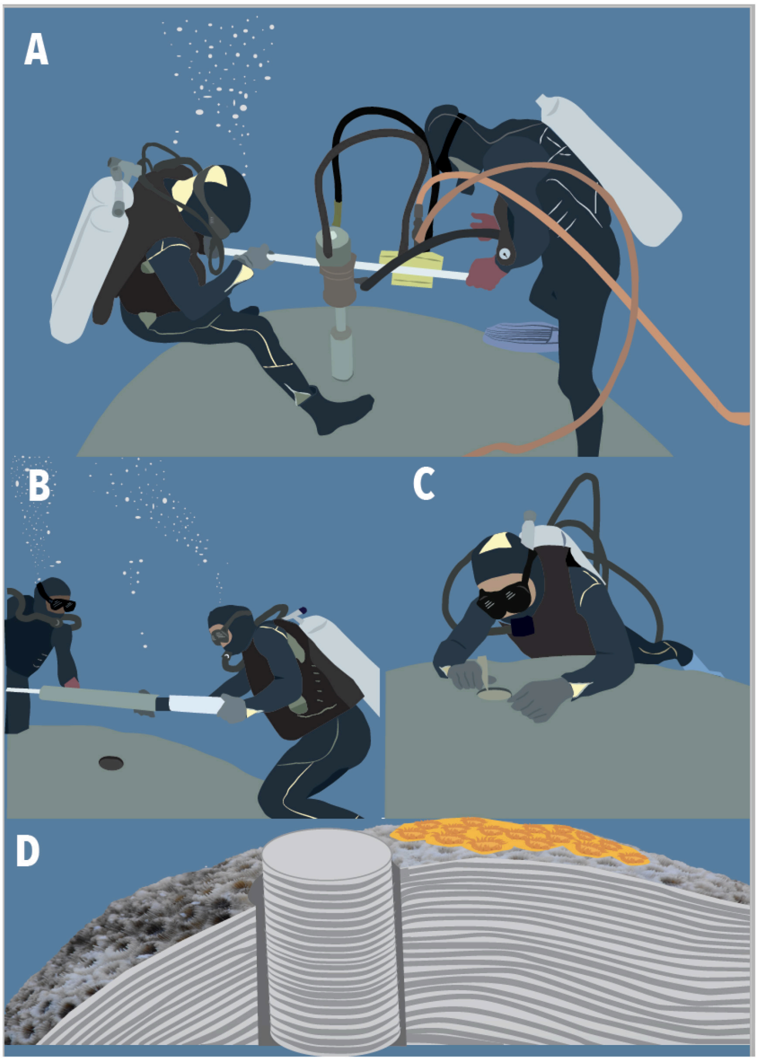

Figure 3

Figure 3

(A) Scientists dive down to an old massive coral, to take a sample. **(B)** The sample is removed and analyzed to reconstruct Earth's past climate. **(C)** The hole is filled with a cement that has similar properties to the coral skeleton, so no burrowing animals can enter and harm the coral. **(D)** The coral is not harmed by this process. From the sample, we can see the coral's density banding like tree-rings. One dark and one light band represent 1 year.

Scientists also study fossils from the distant past. Over great spans of time, plants, animals, and microorganisms have been forced to respond to very large climate changes. Sometimes, the changes were similar in size to changes we will see in future climates. In the fossil record, we can see what happened to life when the climate changed dramatically [3]. During major changes in Earth's past climate, many species migrated to more comfortable locations, some species became extinct, and a very few managed to stay in place and adapt to the new climate.

HOW CAN BIODIVERSITY HELP US UNDERSTAND THE FUTURE?

As far as we know, the diversity of life seen on Earth is unique in the universe. This diversity has provided humans with many of the things we need to survive. Plants and microbes on land and in the oceans, produce the oxygen that all animals (including humans) need to breathe. Ocean fisheries provide food and jobs for many people. Reefs, marshes, and mangroves protect our coasts. Forests provide us with wood to build things, and our croplands give us food. In addition, living things remove CO_2 from the atmosphere and the oceans. Without them, temperatures would be much hotter. Living things are also affected by the changing environment. Climate affects the availability of resources and the chemistry of the oceans. By studying many different types of life and many different environments, we hope to understand how life will respond to—and affect—future climate change.

AUTHOR'S NOTE

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CONFLICT OF INTEREST: The 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.

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DEREK, AGE: 14
My name is Derek. I enjoy playing soccer and I also enjoy reading.

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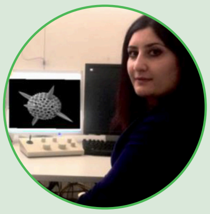

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Gayane is a leading researcher at the Museum für Naturkunde Berlin, a laureate of the "Make our Planet Great Again German Research Initiative" program. She has a Ph.D. in geosciences and natural resources from the University of Pierre and Marie Curie-Paris VI. She then worked at the University of Lausanne and at the University of Queensland. As a micropaleontologist, Gayane is fascinated by microfossils. She studies fossils of the tiny marine plankton called radiolaria. With her group, she aims to understand how plankton and oceans interacted with atmospheric CO_2 and climate change during the Paleogene.

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Marie is currently working on her Ph.D. at the Leibniz Center for Tropical Marine Research (ZMT) in Bremen. Although situated in the north of Germany, she is investigating corals as climate archives and is trying to reconstruct environmental changes in the Caribbean Sea and Gulf of Mexico with a special focus on ocean acidification as part of the MOPGA team "OASIS."

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JED O. KAPLAN

Jed grew up in Silicon Valley, California where he hiked in the nearby mountains and played computer games. He combined his passion for nature and computers into university degrees in earth sciences and geography and later a Ph.D. in plant ecology. As a climate change researcher, Jed has lived in Sweden, Germany, Canada, Italy, Switzerland, and China. He is now a MOPGA research fellow at Augsburg University, Germany and professor of earth sciences at The University of Hong Kong. Jed is passionate about nature and the outdoors, and loves working with students and young people.

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Dave grew up in various locations across the USA, then attended university in Minnesota. After his Ph.D., at the Lamont Earth Observatory, Columbia University, he held positions at Woods Hole Oceanographic Institute, Massachusetts, and the Swiss Federal Institute of Technology in Zurich. From 1996 until his retirement last year, he was curator and head of the micropaleontology research group at the Museum für Naturkunde Berlin, Germany. His research interests include evolution and paleobiology, paleoceanography and climate change, taxonomy, biodiversity informatics and data analysis. He is lead author of the most recent standard reference work on radiolaria.

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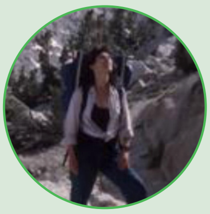
Carol is a professor in the Department of Integrative Biology at the University of Wisconsin, Madison. She is an evolutionary geneticist, focusing on evolutionary responses to anthropogenic change, including biological invasions, climate change, and pollution. Her MOPGA project at the Université de Montpellier in France investigates evolutionary genomic and physiological responses of zooplankton populations to rapid alterations in salinity and temperature induced by global climate change. Ocean salinity is declining rapidly at higher latitudes, and we do not fully understand how populations will respond to these changes.



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Camille is a professor at the Experimental and Theoretical Ecology Station in France and a MOPGA laureate. She studies the impacts of climate change on wild plants and animals with field-based work on butterflies in North America and in Europe, and global analyses across a range of terrestrial and marine species. She has worked with the Intergovernmental Panel on Climate Change for more than 20 years, and is an official contributor to IPCC's Nobel Peace Prize in 2007. She is also affiliated with the University of Plymouth (UK) and the University of Texas at Austin (USA). She lives on a farm in the foothills of the Pyrenees, where she can watch butterflies all year.

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Johan studied geology and biology in Toulouse and Paris in France. He now works at the Museum für Naturkunde Berlin, Germany, where he studies the glass skeletons of fossil planktonic microorganisms. His current work aims at quantifying how the evolution of microscopic algae affected the global carbon cycle in the last 66 million years.

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Helmuth is a MOPGA laureate at the Helmholtz Zentrum Hereon in Germany, in cooperation with the Universities of Oldenburg, Hamburg, (Germany), Alfred Wegener Institute for Polar and Marine Research (Germany) and Exeter (UK). His research focuses on The Ocean's Alkalinity: connecting geological and metabolic processes and time-scales. He is chair of the newly founded Institute of Carbon Cycles at the Helmholtz Zentrum Hereon. Before his MOPGA project started in January 2019, Helmuth was professor of oceanography at Dalhousie University, Halifax, Canada.

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Henry grew up in California and studied marine biology at the University of Southern California where his enthusiasm for the ocean got him involved with corals. He finished his postgraduate studies in earth and atmospheric sciences at the University of Pennsylvania and the University at Albany—State University of New York before settling in Europe investigating the changes to our Earth's climate. Henry is currently a MOPGA laureate at the Leibniz Center for Tropical Marine Research (Bremen, Germany) investigating the impact on tropical coral reefs because of the CO_2 that is pumped into our atmosphere by humans.

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