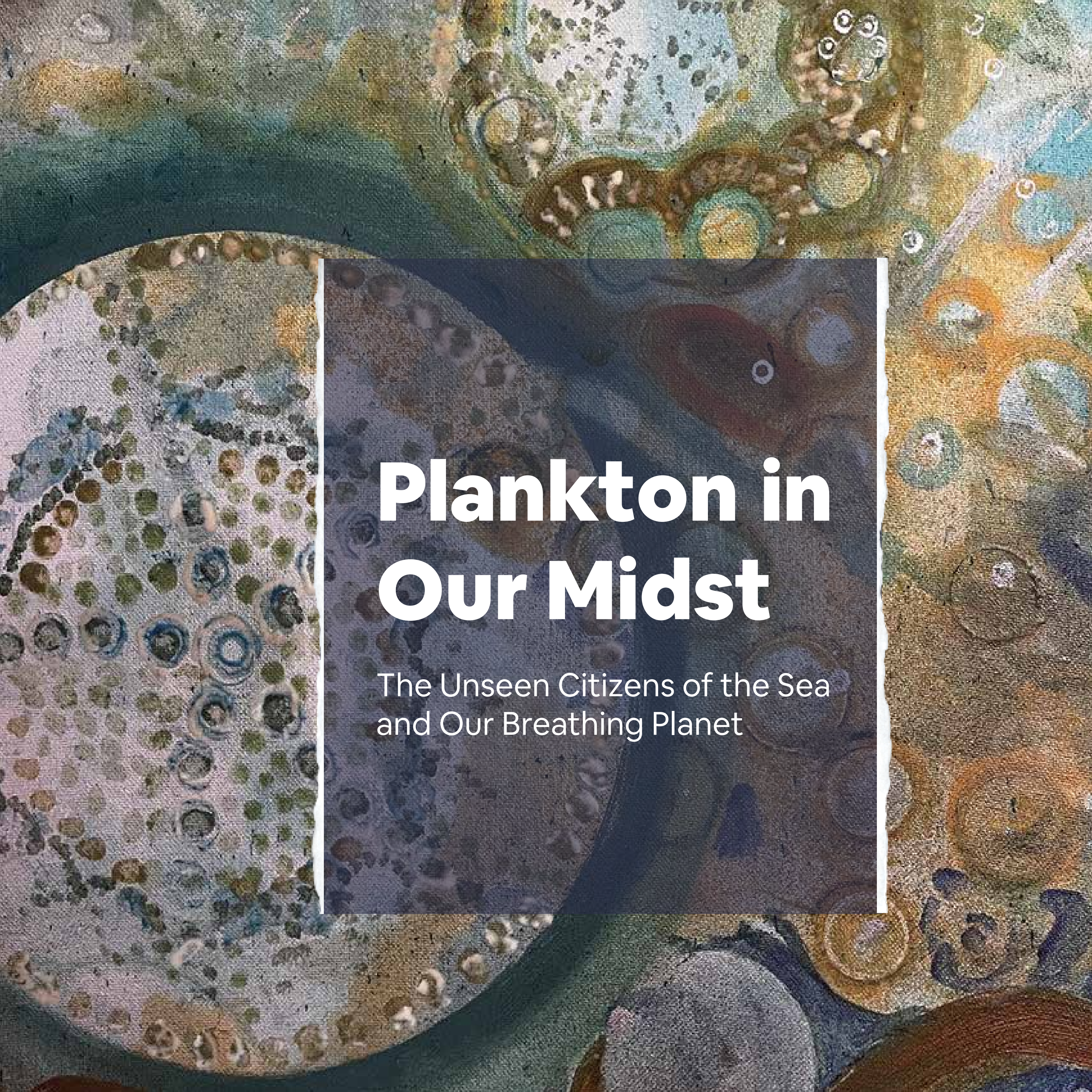


Plankton in Our Midst

The Unseen Citizens of the Sea and Our Breathing Planet

Krisanne Baker
Homage to Our Ocean Beginnings, oil, fish vertebrae, and phosphorescent pigments on wood panel, 12" x 12"

PLANKTON AND OUR BREATHING EARTH

Liz Cunningham

About a decade ago, I encountered something that changed how I see the world. Something that shines a light on paths to healing even amidst ecological catastrophes; something that is deeply entwined with the lives of plankton.

It's this: the earth is an ecosystem that breathes.

I know, you might think, "Really? The earth breathes? And how would that help us deal with catastrophes?"

But yes, the earth breathes, and understanding how it breathes can help us mend our fractured relationship with the world and be agents of change.

The first time I witnessed this was diving on a calm, clear day in some seagrass meadows. Something caught my eye. Small bubbles fizzed upward through the seagrass. The bubbles were oxygen bubbles. The seagrass was generating oxygen, and I could see it!

It was like a veil had been pulled away. I could see what was invisible on land. It was like standing in a forest and seeing oxygen coming out of all the leaves. But that experience didn't stop with the oxygen bubbles. For years, whenever I was immersed in the sea or a lake, I was struck by a halting sensation in the water. It was an aliveness at the edge of my skin, laced with the intuition that some crucial truth had fallen to the wayside. The sensation was that of a hum. *What was that?*

That day in the seagrass, the sight of the oxygen bubbles allowed me to envision streams of oxygen even finer than what I could see with the naked eye. Water is infused with microscopic plankton. Some are called phytoplankton, which generate oxygen, and others, called zooplankton, breathe that oxygen. That mysterious feeling of aliveness at the edge of my skin? *The water was alive.*

The sphere of that aquatic aliveness is so vast it's hard to wrap your head around it: 71 percent of the surface of our planet is covered by water. One has to almost repeat the numbers to allow them to register fully. Our bias toward the familiarity of land has, by and large, blinded us to over two-thirds of our biosphere.

Land: 29 percent of the planet. Sea: 71 percent.

Over 50 percent of the oxygen produced right now on our planet comes from enormous "sea meadows" of plankton in the ocean. Respiration and photosynthesis are not just the hallmarks of life on land, they are elemental to life in the ocean and other waterways—estuaries, lakes and rivers. They are elemental to life on our planet as a whole.

Scientists call breath and photosynthesis forms of gas exchange. We breathe: oxygen in, carbon dioxide out. Plants enact the mirror form: carbon dioxide in, oxygen out. "Gas exchange" is a pretty dry term. Here's a term that says so much more: *reciprocity*. Think for a moment about the oxygen in the breath you just took. Where did it come from? A tree? A meadow?

What if you could see that reciprocity, the streaming pathways of carbon and oxygen at any moment? That, at any moment, a baby is born and takes her first breath and cries. Or a man takes a deep breath, and his breath becomes song. That, at any moment, a grouper's gills pulse inside a coral cavern. A hummingbird inhales rapidly through tiny nostrils, over four times a second. Lovers fall asleep in each other's arms to the soft rise and fall of their chests. At any moment, light pours into broad and narrow leaves, into tall rainforest canopies, into the fronds of a fern, blades of grass, spore capsules of moss, and the stem of a cactus or a strand of kelp or *Sargassum* or a plume of algae. The light mingles with carbon, minerals, and water to produce the essential element of our breath: oxygen.

Each outpouring of oxygen and each breath is a pathway of energy exchange. The passage is different for each living being, be it a towering redwood tree or a cheetah sprinting across a savanna. But the outcome is the same—a certain molecular currency, a certain energy of life. These vital paths fan out like myriad, intricate tributaries through our world, sustaining all the life around us. The breath of the earth is the fabric of our existence.

Even National Aeronautics and Space Administration (NASA) scientists uses the term "breathing earth" to refer to the global rhythms of gas exchange—of photosynthesis and respiration—through the seasons. But why does this matter so much now?

It matters because the scientific name for our breathing earth is another dry term, the "carbon cycle." And we're ravaging it, stripping away forests and wetlands even while scientists tell us, "these are the lungs of the earth." We're polluting and warming seas so much that oxygen levels in the ocean are going down—the so-called deoxygenation crisis. Scientists from the International Union for the Conservation of Nature (IUCN) plead that we need to "save our suffocating seas."

It matters because the phrase "breathing earth" recognizes the earth as a living biosphere, not a machine, not a dump, and not a natural-resource stockpile. It matters because it invokes kinship, gratitude, and care.

Recognizing the breath of the earth pulls aside the dark veil of a paradigm that has driven us to the point of ecological and social collapse—the maelstrom of climate catastrophes and mass extinction, of demagogues fanning the flames of anger and discontent. Beneath these crises is a colonial mindset of extraction and oppression that is pillaging the earth's biosphere and violating the rights of the majority of the world's population. Climate change is arguably the greatest violation of human rights in history. A privileged few are protected from the worst effects, while the majority of humanity are deprived of basic human rights, among them the right to food, a healthy environment, and water.

A rising chorus of calls is being made by communities and individuals—activists, conservationists, Indigenous leaders, and scientists—to step away from the modus operandi of that dominant culture and reimagine our place in the earth's biosphere. The challenge is not only how to stop the devastation but also how to pursue pathways of revitalization.

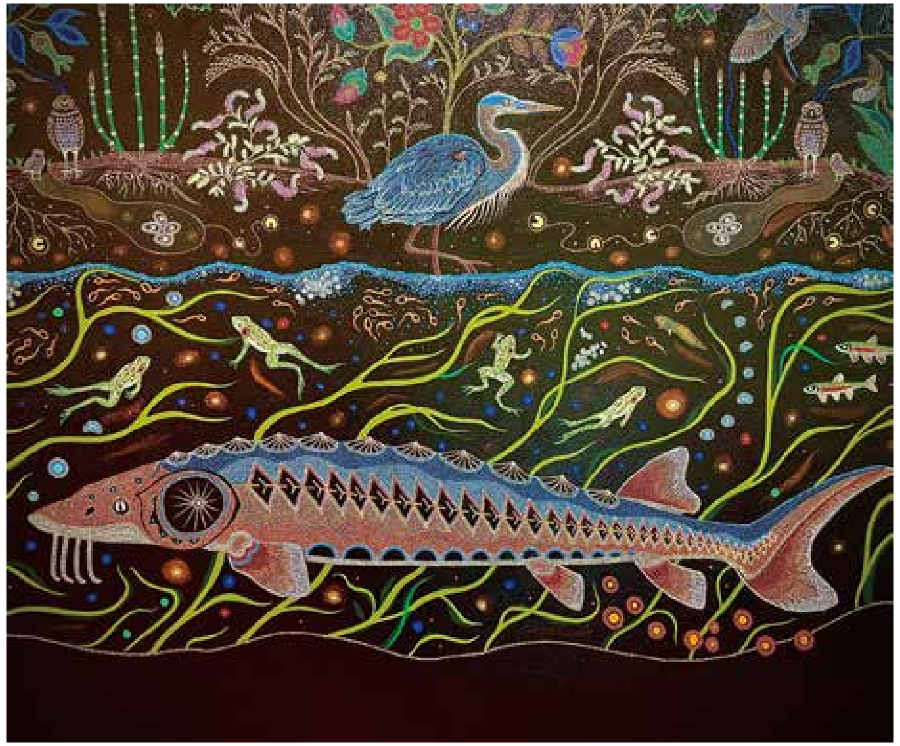
It's no coincidence that breath is popping up more and more in our zeitgeist, not just in the mindfulness movement, but also in the recognition that the breath of the earth is something we desperately need to attend to, and that social injustice is metaphorically—and sometimes literally—suffocating. But there's nothing new about the idea of a breathing earth. It is held sacred by the very cultures that have been devastated and reviled by colonial expansion.

Indigenous traditions honor the breath of the earth. The Rarámuri tribe honors the notion of *iwígara,* that all life forms share the same breath. Same too for the Cree and the Salish of the Pacific Northwest, and for the Ainu, the Veps, the Yup'ik, or the Orochen reindeer herders in inner Mongolia, who are known to speak of the "breathing of the mountains" in the evening.

But plankton? What can we learn from them? Enter the pivotal role of plankton in reimagining our place in the world. The calls to embrace our integral ties with the earth are often expressed as intimacy with the land. The lives of plankton show us that the connectivity we need to care for is not just on land but also includes the expanse of the ocean and the atmosphere.

If reimaging our place in the world were a puzzle, one of the missing pieces spans 71 percent of the globe—the ocean. Plankton are pivotal to its vitality. They give new credence to that feeling so many of us intuit: that the ocean and the air are so much more vital than we could ever fathom.

Like a long-lost friend that we suddenly pay close attention to, we can approach



Christi Belcourt
Detail *from Every Dot, A Prayer for the Saskatchewan Rivers,* (acrylic on canvas).

"History was not written about the thousands of years of song and ceremony held on the shores of this river but history was made here, many times over. This painting focuses on some of the ecosystems in the South Saskatchewan River system and features some of species at risk. The river is a life giver and she needs our help now." Christi Belcourt (apihtâwikosisâniskwêw / mânitow sâkahikanihk) is Métis visual artist and environmentalist and social justice advocate. Like generations of Indigenous artists before her, she celebrates the beauty of natural world while exploring nature's symbolic properties.

Presten Warren
Mirning Country, acrylic on unstretched canvas, 100cm x 75cm

This artwork embodies a profound narrative of discovery, resilience, and reconnection spanning generations. It serves as a tangible link to ancestral roots. Inspired by the land and waters of the far west coast of Australia, it incorporates elements of native plants and animals, symbolising a spiritual connection to Country. Presten Warren is an Indigenous artist (Wirangu, Dieri, Kokatha, Mirning, Arabana) living in Australia. He is a descendent of the desert and ocean tribes of Australia.

plankton with fresh eyes. A crucial and predominant part of our biosphere has been left out of our sense of the shape of life. To bridge the gap, we need to understand plankton. Who are these creatures with whom we share this world? Who occupy 71 percent of our planet?

In the pages that follow, we'll explore plankton at the origins of life, aggregations of plankton called the "deep scattering layer," and the role of plankton in the marine carbon cycle and food chains, which support a wide diversity of creatures, from fish to whales to birds. We'll look, as well, at the changes wrought by climate change.

The truth of what is happening to plankton because of climate change and pollution only further drives home the fact that the catastrophes we are witnessing are symptoms of a planetary emergency. But it also reveals an interdependence that can guide restoration efforts and nourish our spirits, inspire gratitude and generosity. When we see our lives as steeped in reciprocity with the world around us, possibilities for action surface, be it demanding an end to the fossil fuel era, restoring a kelp forest or a patch of land, or working to save species.

When we see our world as a living, animate biosphere in which our lives are entwined, we are among kin. In that recognition, that joy and wonder, are deep reserves of energy and wisdom. One of the most pernicious forms of injustice today is the devastated planet we will leave future generations, both human and nonhuman. It's hard to even think about—it's such a painful reality. But if we have the courage to open our hearts to kinship with future generations, to unleash the roar of our protective instincts, we will refuse to be complicit with reckless destruction and take action. Care for future generations is one of the most powerful forms of belonging.

In a world more and more filled with peril and terror, that deeper belonging still calls to us. In that call is the profound impulse to care for the life around us and each other. There's a paradox of living in our times that's a good paradox, one that holds true hope: *resurgence is possible, even amid vast devastation.*

But first, we need to begin with beginnings: When did breath and photosynthesis, those life-giving processes, begin? How did our planet become a breathing earth? The short answer is: with plankton, billions of years ago.

FIRST BREATHS

If you were to stand on top Mount Everest and take a few wheezing breaths in the thin air at twenty-nine thousand feet, some of the oxygen in those breaths might have come from plankton in the sea billions of years ago. Earth didn't always have the air it has now. Oxygen was a paltry portion of the early atmosphere—less than 1 percent was oxygen, compared with 21 percent today. The rest of that ancient atmosphere was a mix of carbon dioxide, nitrogen, and water vapor, with traces of ammonia and methane.

Then something happened in those archaic waters. Around three billion years ago, cyanobacteria, a type of plankton also known as "blue-green algae," made an evolutionary leap. They took sunlight, carbon dioxide, and water and made simple sugars: photosynthesis. The byproduct of that biological innovation was oxygen. Cyanobacteria thrived and created the atmosphere we have now. That breakthrough at the origins of life is called the "oxygen revolution" or the Great Oxidation Event. It gave us what now seems a given: the oxygen-primed atmosphere and the simple sugars that fuel all the life around us. The basis of a habitable planet.

The first person to lay eyes on photosynthetic algae was the Dutch tradesman Antony van Leeuwenhoek, who had pioneered a way to produce microscope lenses that were ten times stronger than the best microscopes of the time. Rather than grinding glass lenses, which was the normal practice of the time, he used intense heat to melt glass and reshape it—in a sense, forge it—into a more powerful lens. One day he mounted a drop of water from a local lake on one of his microscopes, and it revealed "green clouds" of life and tiny, oscillating creatures. No one had ever set eyes on them before. They later became known as "protists"—single-celled organisms, such as algae and protozoa. Leeuwenhoek's gaze had traveled a matter of inches, but it was as if he had traversed a continental divide.

Leeuwenhoek was later called the father of microbiology. For centuries, microscopes improved, but nobody thought there were any photosynthetic organisms smaller than what you could catch with a plankton net.

Then, in 1977, that threshold was crossed. John Waterbury, from the Woods Hole Oceanographic Institution, was studying bacteria in the Arabian Sea with an epifluorescence microscope that illuminated specimens using a mercury or xenon light. The bacteria emitted a distinct fluorescent color in reaction. Those pigments and the pattern by which the light scattered revealed the organism's identity. In scientific parlance, each organism has its own "signature." The bacteria Waterbury and his colleagues were studying produced a green fluorescent light. But some bacteria, to their astonishment, emitted a brilliant orange light. Anything between orange and red on the spectrum meant chlorophyll, and that meant the presence of photosynthetic organisms that not even the finest mesh of plankton nets could catch.

The "little plants" were one micrometer wide.

That's one thousandth of a millimeter. You would need millions in a glass to see them with the naked eye.

Waterbury had discovered a new type of cyanobacteria—*Synechococcus*—that was later found to be extremely abundant in the ocean. It lives everywhere in seas and lakes warmer than 41 degrees Fahrenheit. Depending on the location and time of year, you can find anywhere from a few individuals to more than half a million in one milliliter—one-fifth of a teaspoon. Cyanobacteria, blue-green algae, are objects of great fascination because they are evolutionary bridges between bacteria and plants. They are especially salient living fossils, relatives of the original cyanobacteria at the origins of life, during the Great Oxidation Event.

In the 1980s, Sallie "Penny" Chisholm and Rob Olson joined Waterbury in studying *Synechococcus*'s distribution in the Sargasso Sea. They were looking at samples with what's called a "flow cytometer," which shoots a laser beam through an extremely thin stream of water and causes organisms to fluoresce. The scientists noticed what looked like electronic noise in the display.

"We thought it was schmutz," Chisholm wryly told me when I visited her lab.

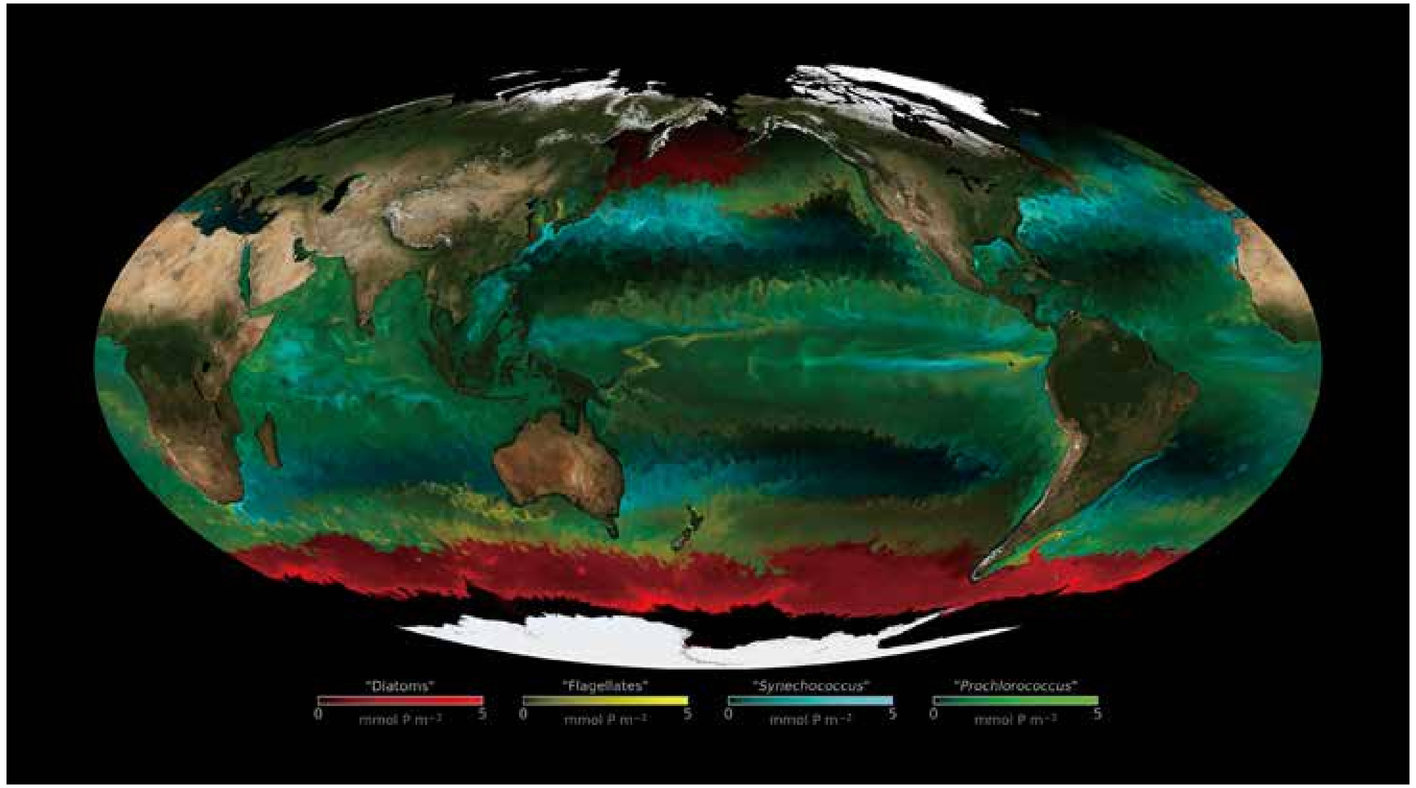
But the "schmutz" started to "behave." It wasn't static, like dirt on a lens. It changed with different samples.

Through Olson's persistent tinkering with the flow cytometer, they were able to zoom the laser beam in enough to get the "schmutz" to emit a signal—its signature.

It fluoresced red. That meant chlorophyll. Which meant photosynthesis. It was another, even smaller kind of cyanobacteria. Waterbury, an expert on Latin scientific names, called it *Prochlorococcus*, meaning "little green spheres." Chisholm's lab at the Massachusetts Institute of Technology (MIT) has studied it for decades, in conjunction with scientists all over the world.

Prochlorococcus is the most abundant photosynthetic organism on the planet. Add up all the blades of grass or all the trees in the world, and there are still more *Prochlorococcus*. An image of the globe generated by MIT's Darwin Project drives home the breadth of its abundance. The invisible sea meadows almost dwarf the continents. It's estimated there are an octillion *Prochlorococcus* in the ocean today. That's three billion billion billion, or think of it as a one followed by twenty-seven zeros. But to Chisholm, *Synechococcus* was the more significant discovery, because it changed the scientific mindset.

"We didn't know there were these photosynthetic cyanobacteria in the oceans," she told me. "It was like discovering grass. Suddenly you have this one thing, and it's everywhere!"



Above: The distribution of photosynthetic phytoplankton, which are the base of the marine food web and crucial players in the carbon cycle. Colors represent the most dominant type of phytoplankton at a given location. Red represents diatoms, yellow represents flagellates, green represents a subset of *Prochlorococcus*, and cyan represents Synechococcus. Credit: MIT Darwin Project, Stephanie Dutkiewicz, Mick Follows, Chris Hill, Oliver Jahn (MIT), Dimitris Menemenlis (JPL)

Far Right: Oxygen bubbles on neptune seagrass in the Mediterranean Sea. One square meter of seagrass can produce 10 liters of oxygen per day. Credit: Shane Gross

Right: Electron microscopy image of *Prochlorococcus*, which generates 10 percent of the oxygen that the ocean produces. Credit: Luke Thompson, Chisholm Lab (MIT) and Nikki Watson from Whitehead, (MIT)

Imagine you are a scientist from another planet studying samples of organisms from Earth's biosphere. You find deer, elephants, rabbits, swallows—creatures that breathe. Then you find photosynthetic trees, such as banyan, baobab, and hemlock, and smaller oxygen-generating organisms—cactus, elderberry, juniper. New species routinely pop up. Wood rat, buttonbush. But then you discover grass. It's all over the place! *Oh, hello*. Earth is much richer and denser with life than you had thought.

So too with the sea, down to a droplet of water.

The scope of respiration and photosynthesis is vastly larger and more intricate than we thought. The simplicity of the discovery is almost unnerving. How could we have missed something so elemental, the base of the marine food chain, close ancestors to the organisms at the origins of life? Hard not to ask: what else are we missing?

Prochlorococcus has done nothing to dull that curiosity. It retains the quality of an unfolding mystery, something akin to the poet Rilke's phrase *l'étonnement des origines*—astonishment of origins.

Prochlorococcus are exquisitely sized in tandem with the very force that they transmute into energy—they are about the same length as the wavelengths of light that they absorb. A wavelength of light runs between 400 and 700 nanometers; there are 10 million nanometers in a centimeter. The latest estimate has *Prochlorococcus* generating 10 percent of the oxygen that the ocean produces. *Prochlorococcus* and *Synechococcus* together produce about 25 percent. How do organisms with so little biomass produce so much oxygen?

The other inhabitants of the "pastures of the sea" only fuel that question. The total weight of all the plankton in the sea is less than one percent of all plants on land. Yet plankton produce as much oxygen as all those terrestrial plants, half of the global oxygen produced every year. Miniaturization par excellence: little aquatic plants that amount to *less than one percent* of the mass of land plants produce the same amount of oxygen.

There is so much we don't know about the origins of life. But what we do know is that is that photosynthesis and respiration evolved in tandem. But what about breath? When did it begin?

The first chemical traces of respiration were found by scientists in stone from northern Australia—single-celled organisms that metabolized oxygen, dating about a billion years after cyanobacteria began using solar energy to convert carbon dioxide and water into oxygen and simple sugars.

The first breaths occurred with other physiological innovations: a membrane, a nucleus, and other complex inner structures. These single-celled organisms were a part of the domain of "eukaryotes," which evolved into multicellular organisms, among them, organisms that breathe oxygen dissolved in seawater. Originally, oxygen passed through the membranes—cellular respiration, plain and simple. Then more complex ways of delivering oxygen evolved, such as gills and small breathing holes called "spiracles."

Most of us know there's dissolved oxygen in water, but it's not a front row and center phenomenon for us. Water, for us, is unbreathable, so it's abstract to think about oxygen in the water. Breath is all about air to us—it's part of the shape of life that we know. But breath originated in the ocean, and it's the vehicle by which so much life thrives there now.

As life evolved to venture onto land, so did the means of breath. Now the oxygen had to come from the air, the advent of the trachea—the windpipe. Tracheal systems using spiracles were used by caterpillars, centipedes, and crabs. Other insects evolved with "book lungs"—thin folding membranes like the pages of a book. Amphibians evolved to breathe like agile start-up companies, using multiple modalities to insure survival. They breathe through their lungs, skin, and even a membrane in their mouth. Birds, descended from dinosaurs, evolved their own unique form of circular respiration. Our breath evolved through the evolutionary path of mammals.

The evolution of plants began with layers of cyanobacteria called stromatolites, the aquatic counterpart of grasslands. Plants evolved first in the water, then as wetlands and then finally on land. First came oxygen-producing cyanobacteria, then phytoplankton, then seaweed, then the "greenery" made landfall: liverworts, mosses, ferns, trees, grasses.

Aquatic animals made their way to land as well. Terrestrial snails evolved from sea snails like pteropods. The first documented animals were millipedes and centipedes. Dinosaurs evolved. Reptiles. Birds. While all these organisms evolved for life on land, their survival was tethered to what primed the sea meadows with life. They still needed oxygen, and they still needed water. The driving force of life is still fueled by that reciprocity between respiration and photosynthesis—the exchanges and transformations involving carbon, oxygen, water, and sunlight. All of these lives, the whole of life that we know, can be traced back to plankton, the hidden pioneers at the origins of life. But it's not just in the past that plankton have played a large role. Today these unseen citizens of the sea fuel marine food webs and play a key role in the stability of our climate.

LITTLE BREATHERS AND THE GREATEST MIGRATION ON EARTH

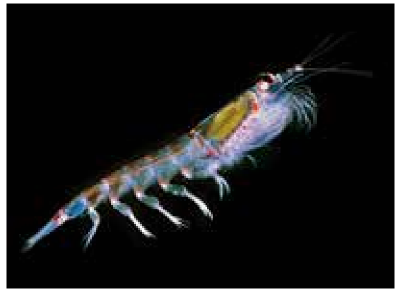
During World War II, sonar operators were flummoxed by what looked like gigantic portions of the sea floor rising from the depths. What were they? Enemy submarines of monstrous proportions? Underwater mountain ranges? In one instance, the Atlantic Task Force commander sent frantic SOS signals stating that a huge cloud in the sea was scrambling the ship's sonar.

The inexplicable masses turned out to be vast aggregations of zooplankton and fish migrating up from dark depths to closer to the surface to feed in sea meadows dense with photosynthetic plankton at night. These large aggregations are called the deep scattering layer, and they can be hundreds of meters thick and stretch thousands of meters wide and long. The migrations of the deep scattering layer take place every night in every sea of the world, from the Arctic Sea to Antarctic—up at dusk and down before sunrise.

Zooplankton include small animals—creatures such as amphipods, copepods, krill, heteropods, and pteropods—and larger organisms in the early stages of development, such as shrimp larva. The word *zooplankton* is derived from the Greek word *zoon*, "animal," and *planktos*, "wanderer" or "drifter." Diminutive as they might be—some visible only under a microscope—zooplankton are nevertheless animals. They breathe. They eat. And they try to avoid being eaten.

As is often the case, science evolves when organisms defy its categories. The discovery of *Prochlorococcus* and *Synechococcus* not only gave us a new base of the marine food chain (the "discovery of grass"), it shook up the plankton categories. Nowadays plankton are generally classified with more precision by size, from micrometer to millimeter to meter—femtoplankton being the smallest (viruses) and, one step up from that, picoplankton, the category in which *Prochlorococcus* and *Synechococcus* reside. The scale ratchets up from there, with the prefixes nano-, micro-, meso-, macro-, all the way up to megaplankton, which includes large jellyfish and Sargassum seaweed. It's a bit dizzying, so the old categories of plankton—phytoplankton and zooplankton—are still used in a vernacular way. Plankton are creatures that drift. Phytoplankton? Little plants. Zooplankton? Little animals.

The top 200 meters of the ocean is where most of the photosynthesis occurs and where almost all of the oxygen is generated, in the so-called sea meadows. The deep scattering layer migrates back and forth from those sea meadows in the top 200 meters from as deep as 1,000 meters. The record holders for the longest annual migration are



Exploring the world of plankton is an immersion into the interdependence of life. The lives of the largest animals on earth are deeply intertwined with the smallest. A full-grown humpback whale can be over 40 feet in length, a blue whale over 80 feet. Both feed on zooplankton, such pteropods and krill. Above: Juvenile humpback whale approaching the surface to breathe. From left to right: Antarctic krill, the pteropods *Clione Limacina, Heliconoides inflatus* and *Limacina helicina*.

Arctic terns, who log approximately 44,000 miles roundtrip, back and forth between the Arctic and Antarctica. But measured by mass of organisms, the nightly journey by zooplankton is the greatest migration on Earth.

The speed of that migration is also nothing to sneeze at. The pteropod *Clio pyramidata* swims up and down every night about 400 meters each way, from 450 meters deep up to 50 meters, and then back down again. It's one centimeter long. That would be like me—at five-and-a-half feet—having the muscular and respiratory acumen to swim over eighty miles every night of the year or run a marathon twice a day.

I had a chance to swim through plumes of zooplankton while scuba diving at night in the Gulf of California. Night diving is steeped in the threshold between the seen and unseen. You plunge into dark water and then, like a comic book character in a dark closet with a flashlight, the only thing you can see clearly is what's illuminated by the light's cone-shaped beam.

After I jumped in, I cast my underwater light into the dark water. The beam was filled with minute creatures, like dense snow and even finer particles. The beam was akin to the shape of a plankton net. As I moved the cone of light, it was like swishing a net through the clouds of life.

The creatures quivered and darted. They bounced off my hands like soft specks of sand. The huge sheath of life was fully enveloping. When I would move an arm or leg, that swarm of life would part and reform around the shape of my body. In their midst, the sound of my breath through the mouthpiece of my dive regulator was loud, resonant. I felt my rib cage expand and contract against the pressure of the water.

The life force of these animals was so strong. I held out both hands in front of me, palms up, and moved them gently side by side, the animate cloud of life reshaping as I moved. It felt like a moment of surrender and yet immense vitality—myself a body within bodies. I was breathing; they were breathing. My breath was nested within a greater breathing that undulated and burst into new shapes. Occasionally a sea lion would swoop through, and the entire mass of zooplankton would shapeshift like the murmuration of starlings.

The linkage by which life in the sea thrived was suddenly tactile and illuminated—the marine food chain. Zooplankton grazed on other zooplankton and on all kinds of phytoplankton, including the single-celled protists that graze on photosynthetic cyanobacteria, such as *Prochlorococcus*. That zooplankton was scooped up by baleen whales or eaten by small fish or larger fish, which were, in turn, hunted by agile and playful sea lions.

Without plankton there would be no food chain in the ocean or in other waterways. That food chain feeds innumerable creatures in the sea and the over three billion people who depend on seafood for their primary source of protein. But the importance of plankton is not limited by the water's surface. The food chains plankton are integral to sustain many amphibious and terrestrial creatures, as well as birds, winged travelers of an atmosphere containing oxygen originally generated by plankton.

NASA-generated visualizations show what scientists call the larger rhythms of our breathing planet. As the earth warms in the spring, a wave of photosynthetic activity spreads north on land and in the water, and in the summer the concentration of carbon dioxide in the atmosphere is reduced. When creatures migrate—butterflies, caribou, dragonflies, geese, penguins, salmon, seals, whales—they follow the paths of these larger rhythms. Embedded in that photosynthetic activity—forests and meadows leafing out, kelp forests expanding—are food chains that provide nourishment for them and the ones who have hibernated or overwintered in their home habitat. One of the greatest environmental writers of all time, Barry Lopez referred to migrations as the "corridors of breath." Our entire planet, land and sea, is steeped in the reciprocal energy exchange of photosynthesis and respiration, the breathing earth.

THE BIOLOGICAL PUMP

In 2018 and 2019 I had the opportunity to shadow the work of Dr. Amy Maas and Dr. Maureen Conte aboard the research vessel the RV *Atlantic Explorer* in the Sargasso Sea, a region of the North Atlantic whose boundaries consist not of land, but four oceanic currents. Maas is a biological oceanographer from the Bermuda Institute of Ocean Sciences (BIOS) and an expert on zooplankton. Conte is a chemical oceanographer and at the time was the longtime director of the Marine Biological Laboratory's Oceanic Flux Program (OFP), which is now led by Dr. Rut Pedrosa Pàmies, assisted by J. C. Weber.

The top 200 meters of the ocean is where most of the photosynthesis occurs and where almost all of the ocean's oxygen is generated. Maas studied plankton in the top 1,000 meters, gathering samples using a large plankton net called a Reeve net and a high-tech plankton sampler called the MOCNESS.

But what happens to everything beneath that? And how much does that have to do with the top layers?

Picture for a moment, dropping a line in the ocean. Attach instruments that would tell you what's happening at different depths. How much oxygen is there? What's the

pH? Temperature? Salinity? Fasten containers to the line to catch sinking particles, those bits and pieces of life—microbes, the bodies of zooplankton, fecal pellets, dust, sand, a fish scale, fragments of a bird feather. What if you could dangle that line all the way to the bottom? What would you find?

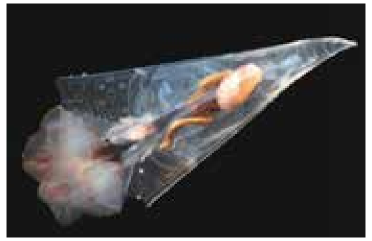
That was the OFP mooring. It was a two and half miles long. It had spent six months fastened to an anchor over 14,000 feet deep at the bottom of the Atlantic trench. Twice a year the OFP staff hauled out the mooring, processed samples from successive depths, reset and repaired the instruments and the mooring, and then redeployed it. After over 40 years of sampling, it is the longest deep-sea sequence of data in the world. It is also a precise record during a time of extremely rapid climate change.

One uncertain aspect of many climate change projections is the role plankton play in sequestering carbon and keeping our planet habitable. Oceanographers have routinely pointed out that the ocean's role in the carbon cycle has not been sufficiently factored into climate simulations and skewed the results. The ocean sequesters a *third* of all the carbon dioxide emitted by civilization and 90 percent of the heat of global warming. Like brakes on a Mack truck, the seas have slowed climate change, delaying even worse effects. Hard to believe, but true: climate change would be even worse if not for the ocean's capacity as a carbon sink and a heat sink.

Zooplankton are a big part of that equation, and their respiration—their habits of breath—figures largely in it. They exhale carbon dioxide deep in the sea, and when they die, their carbon-rich bodies sink to the seafloor, sequestering even more carbon. Sequestering carbon counters climate change; it pulls carbon out of the atmosphere into carbon sinks.

Much of Maas's research focuses on pteropods, also known as sea snails or sea butterflies, due to the oar-like wings with which they swim. They are indicator species—what we learn about them tells us legions about the ocean's ability to sequester carbon. Pteropods are such a key element of the food chain that scientists have dubbed them the "potato chips of the sea." Gigantic deposits of sedimentary rock on the sea floor are so full of pteropod shells that they are called "pteropod ooze." The out-breath of zooplankton is one of the major pathways by which the ocean sequesters carbon. The sum of those pathways is called the "marine carbon cycle" or the "biological pump."

"It's more like biological pumping systems," Conte explained to me. There are multiple pathways by which carbon is recycled or sequestered. Another pathway is the downward drift of biological matter to the seafloor. I once saw a shark feast on a school of snapper in the Caribbean. With each lightning-fast snap of the shark's jaws, a plume



Above: Amy Maas, Andrea Miccoli and Jordan Wingate deploy a Reeve net to collect samples of zooplankton. Credit: Liz Cunningham

Right: the pteropod *Clio pyramidata* which swims 400 meters up and 400 meters down every night. It's one centimeter long. Credit: Amy Maas

Far Right: Amy Mass and Jordan Wingate examining samples in the lab aboard the research vessel. Credit: Liz Cunningham.

of residual flesh was released into the water. Some of that debris would be eaten by other organisms as it drifted downward, but some would be sequestered at the sea bottom. Similarly, when zooplankton die, if they aren't gobbled up by another animal, the carbon in their bodies sinks to the bottom. The downward path of that debris—body remains, fecal pellets, microbes—is called "marine snow," a slow downward drift, like heavy flakes of snow on a windless day.

"Stuff sinks," Conte said matter-of-factly. "It's biologically driven, with the added element of gravity." She likened the shape of those interlocking processes to a slinky that narrows at the bottom end. The spiral of energy exchange gets narrower and narrower, the deeper you go. At every level, there is still some lateral exchange of energy in the food chain, eating and being eaten. But as you go deeper, there are fewer particles.

The death of larger animals is another pathway of sequestration. When a whale dies and sinks to the bottom, it become a "whale fall," an enormous carbon sink and food for communities of organisms on the sea floor. Before the whaling industry, the sum of all whale species is estimated to have accounted for the removal of over 192,000 tons of carbon each year.

The mixing of deep and shallow water is another means of sequestration. The Arctic Ocean is known for powerful areas of downwelling, where cold water sinks, and currents carry material farther downward. All the ways in which carbon is, in scientific parlance, "exported" add up to the biological pump—the marine carbon cycle. The biological pump is how the ocean puts a brake on climate change by sequestering carbon, and plankton play a huge role in it. Plankton sequester about 40 percent of the carbon sequestered globally. But that braking process is itself being degraded by climate change.

The shelled pteropods Maas studies have become the object of much attention because of the mirror they hold up to climate change impacts on the ocean. Their shells are starting to thin and fray, an indicator of a vastly bigger problem. Pteropods are less able to form their shells because of ocean acidification. The carbon dioxide we've pumped into the atmosphere since the onset of the Industrial Revolution has not only warmed the seas, but it has also made them 30 percent more acidic in the last 200 years. From the point of view of geologic time, it's a cliff-edge drop. The drop in pH is more dramatic than any change in ocean chemistry in the last 50 million years.

The more acidic water is, the lower the pH. But what's the big deal about a drop in pH? Well, in your body or mine, a blood pH drop of 0.2 or 0.3 can cause seizures and comas, even death. An aquarium keeper knows the wrong pH bodes illness or death for aquatic creatures.

Above: Aboard the R/V *Atlantic Explorer*. From left to right, J.C. Weber, Rut Pedrosa-Pàmies, Maureen Conte, Amy Maas and Liz Cunningham. The mooring gear belongs to the Oceanic Flux Program (OFP), which has measured particle flux—the transfer of energy and materials in the water column—in the Sargasso Sea for over 40 years. The OFP has revealed how the deepest reaches of the ocean are intimately connected to phytoplankton sea meadows near the surface and even weather events. It is a bellwether of ocean health during a time of extremely-rapid climate change. The mooring is deployed all the way to the bottom of the Atlantic Ocean. Credit: Liz Cunningham

One of the most prominent effects of ocean acidification is die-offs in oyster hatcheries because oyster larvae are not able to form shells in corrosive water. Ocean acidification affects sea creatures with shells and skeletons—clams, coral, mussels, oysters, starfish. It also affects behavior. Pollock and clownfish have trouble detecting predators in more acidic waters. If carbon emissions continue to climb, the seas will get even more acidic.

The diminishing ability to form shells and skeletons has been dubbed the "osteoporosis of the seas." But with ocean acidification, it's not creatures in old age who are affected, it's the young—an inability to properly form shells and skeletons in infancy. It's like a toddler with osteoporosis, trying to grow strong bones without vitamin D or calcium.

There are more problems compounding the situation, such as deoxygenation—the amount of dissolved oxygen in the water is decreasing. Oxygen-poor regions of the ocean and other waterways are becoming more prevalent due to warming and pollution. Warming waters are more stratified, meaning that the warmer some layers are in juxtaposition with other layers, the harder it is for them to mix, and consequentially for carbon, nutrients and oxygen to be exchanged.

All of this adds to the unfolding climate emergency: the biochemical backbone of life as we know it is collapsing. The evidence is all around us. Melting ice sheets. Thawing permafrost. Burning rainforests. Coral reef die-offs.

How does one even begin to absorb such facts? The reality is almost unbearable to think about. But what is truly unbearable is not to speak of what hope there is, what courage we can summon, our love for the world and each other. That's what breaks the deadlock of shock and inaction and allows us to ask *and answer* the question, "What can we do?" That's where another connection to the breathing earth comes in. To make those connections we need to go past the boundaries of ocean science.

KINSHIP

The Zen master and peace activist, Thich Nhat Hanh recounted how, during the Vietnam War, he, along with other Buddhist peace movement members in Singapore, helped rescue hundreds of Vietnamese refugees stranded in rough seas without food and water. In the middle of the night, the police came, confiscated their travel documents and issued deportation orders. But there were still hundreds of people out there in boats.

Now the crisis was amplified, and they were suspended in a state of inaction. In that long night, they struggled to figure out what to do.

"I saw that, if I couldn't have peace in that moment, I would *never* be able to have peace," Thich Nhat Hanh recounted of his experience that night. "Peace can be found in the midst of danger." Just before dawn he realized they could make an appeal to the French ambassador to intervene on their behalf. They were able to stay long enough to assist those refugees.

It takes a deep and unflinching peace to look at the facts of climate change with open eyes. To think of entire communities incinerated by a fire tornado. To think of the seas becoming so acidic an oyster larvae can't form a shell.

What peace can we embrace that will allow us to face these realities, take action, and save lives?

We can rewind and ask what supported Thich Nhat Hanh in finding such peace and resilience amidst chaos and immense suffering. It was meditation—mindfulness of breath. But not just one's own breath. Something more.

The breath of the earth.

There is a synchrony between what is experienced in mindfulness of one's breath and the passageways of breath by which life thrives on our planet. That awareness might unfold in meditation or in painting or sewing or playing music or listening deeply to a friend, writing in a journal or walking in a forest at sunrise—a feeling of breathing with life.

Breath takes us deeper into ourselves, into the chords of the soul, and it takes us outward into the interconnectivity of all life. Thich Nhat Hanh often called it "interbeing." Attending to our own breath—nurturing it—is healing. It opens us to profound gifts. These might include gratitude at the start of your day, aid in recovering from an illness, or resilience in a time of trauma or grief.

But there is something more. Resident in our breath is a kinship with other living beings that is, quite simply, a form of love. It gives us energy. It gives us grace. It gives us wisdom.

We breathe. The earth breathes.

Seeing our world as a breathing earth unleashes the best in us: a strength and perseverance rooted in kinship, in gratitude and reciprocity, in compassion. Embracing the knowledge that we live in community with other species comes with a duty that is not a burden, but an honor. We recognize that other living beings have rights too, and they deserve our consideration and care.

Seeing our world as a breathing earth leads to solutions. They may not halt glaciers from melting, sea levels from rising, but they make a difference in our lives and lives of creatures that we share this planet with. They support the resurgence of life even in a

time of cascading crises; they are primed with the knowledge of how the exchanges of carbon and oxygen are at the core of what makes life possible.

Project Drawdown, the world's leading resource for climate solutions, documents the top one hundred climate solutions that can not only limit carbon emissions, but drawdown carbon from the atmosphere. The solutions are wide-ranging and available to implement now, things like alternative refrigerants, geothermal energy, land tenure to protect Indigenous people's rights, and solar and wind power.

Seagrass restoration is one of those regenerative solutions. By sequestering carbon, seagrass can locally bring the acidity of the water back to preindustrial levels. That's a huge deal for the creatures that will live in those waters, from shellfish—such as clams, mussels, and oysters—to microscopic zooplankton. Seagrass restoration or protection can be paired with shellfish farming, helping working waterfront communities stabilize coastlines and adapt to extreme weather and sea level rise. Seagrass beds are a type of Blue Carbon coastal ecosystem. These ecosystems sequester 50 percent of the carbon absorbed by the ocean, even though they cover just 2 percent of the ocean floor. Restoring and protecting Blue Carbon ecosystems is a powerful counter to climate change.

Look for these solutions, and you will find come-back stories that defy the gravity of the degradation gripping our world, that show us that resurgence is still possible. These solutions employ a moral imagination that brings out the best in us—creative verve, an undaunted courage that verges on joy. Wetlands laid waste by draining and pollution have been restored and teem with birds and fish; farmland degraded by soil erosion now thrive because of regenerative agriculture, which sequesters carbon and promotes local food security; urban agriculture has spawned innovative solutions such vertical farming and mobile "market buses," which bring affordable produce to schools, community centers, and health clinics.

But what did Project Drawdown determine as the two most impactful solutions? High-quality education for women and access to family planning and health care. Drawdown calculated that fostering equality through voluntary family planning and high-quality education for women could reduce carbon dioxide equivalent emissions by nearly 70 gigatons in a thirty-year time span.

It's a clear example of how working to counter the degradation of our planet goes hand in hand with advocating for social justice. We need systemic change, *and* we need community-level change. Yes, we have to do our part as individuals to counter climate change, but systemic oppression needs to be countered with systemic change. You don't have to look far for an example: fossil fuel companies raked in a record seven trillion dollars in subsidies in 2023. But community-based conservation efforts are also pivotal. They honor the rights of local populations, many of whom have endured cultural oppression and historical trauma. They support local conservation leaders and decision-making.

One of humanity's ways of searching out who we are and how we fit into the shape of life is through stories. Stories recount history and anticipate the future; they can be catalysts for transformation. The story of plankton and our breathing earth expands our vision of the interconnectivity to which we belong. We exist not just in relation to land, but to all our waterways, the largest of which is the ocean, and the broader life-rhythms and cycles that envelope land, sea, and sky. The topography of our world that we hold in our mind's eye and in our souls is vastly enriched. It's intimately related to every breath we take.

A good life is lived at the fulcrum between gratitude and generosity. Gratitude for all that supports our life by its very nature pivots to generosity. It is here that the depth of what we owe future generations makes itself clear. We need to act on behalf of those who will inhabit this planet beyond the bounds of our individual lives.

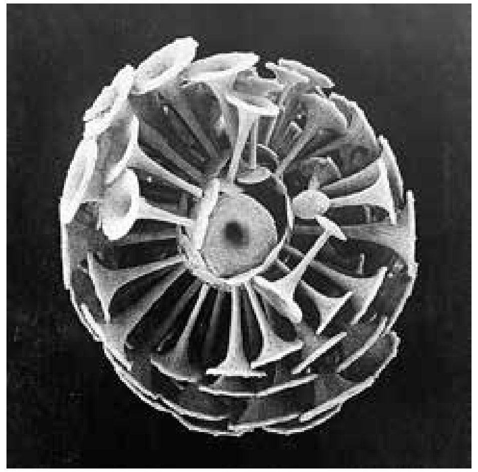
But then there are the perennial questions: Where do you find the energy for this? The inspiration? The possibilities to pursue?

It begins with the gift of life. Chief Seattle (Chief Si'ahl), the venerable leader of the Duwamish and Suquamish peoples, said, "We don't inherit the earth, we borrow it from our children." It was he who also said, "All things share the same breath."

When I saw the oxygen bubbles in the seagrass and sensed the plankton in the water, I was steeped in that reality of shared breath. I want to leave you with this: Seeing our world as a breathing earth can unleash breakthrough wisdom and energy. It can inspire a courage we didn't even know we had. To speak the truth. To refuse silence. To take action rooted in our kinship with the earth and each other: that's how we thrive, that's how we can heal. That's what gives us strength and joy. Because inside that reciprocity is an energy that just won't quit. Because we care for what we love. The truth of the breathing earth that plankton and so many other living beings show us is that our life-breath and the life-breath of our planet are inseparable.

Opposite Page:

Kim Corona
Our Breathing Earth, Digital art utilizing AI-generated content from Midjourney prompts.



As this book closes, we are reminded that the heart of what we want to convey about plankton and our breathing earth is the vital interconnectivity between creatures large and small, visible and invisible. Poets, philosophers, and even scientists sometimes, speak of the "song of the earth." The metaphor is apt: the truth of song comes through connection. Multiple modalities form a whole vastly greater than the sum of its parts, a beauty that is a consequence of the connections by which life thrives. We exist within each other's midst. Honoring these webs of life with respect and gratitude is key to caring for future generations, to the regeneration of life and a more just and equitable future.

Above Left:

Electron microscope photograph of *Discosphaera tubifera*. Credit: Bigelow Laboratory for Ocean Sciences.

Left:

Julie Crane
Tubifera Sketch, colored pencil on gelatin print.

Opposite Page:

Julie Crane
Clam song, multi-block woodcut. Otter with DNA, snail trails and dispersed trumpet-shaped plates of calcium carbonate from the *Discosphaera tubifera*, a type of coccolithophore. Sea otters feed on sea urchins and shellfish, such as clams, which feed on plankton, including coccolithophores.

The most immediate sensory evidence of our belonging is the breath.
It represents our transient vitality and responsiveness to change, and also
demonstrates our participation in the larger body of the Earth,
whose breathing we share.

— Joanna Macy

Krisanne Baker is an ocean advocacy artist. She creates art, often through science collaborations, about of the contents of the living, breathing ocean to spark curiosity in others, educate them about the rights of ocean inhabitants, and inspire stewardship of the Great Blue. Krisanne has had many solo exhibitions and received a multitude of awards and fellowships such as the Bow Seat Educator of the Year and Japan Fulbright Memorial Scholar. She is represented by Caldbeck Gallery. As an educator she developed the *Gulf of Maine: Dare to Care* curriculum.

Julie Crane refers to her work as "the songs of spies" the search for truth through what is living, a glimpse into how each creature contributes to the whole of life. Her work often times juxtaposes microscopic organisms suspended mid-air around a central subject. By switching the scale of objects, the viewer is invited to consider the impact of the invisible and the attributes we share. Her work has appeared in numerous exhibitions in the United States and overseas.

Liz Cunningham is the author of numerous articles and the award-winning *Ocean Country*, with a foreword by Carl Safina. Her mission is to inspire and empower others to protect the life of this planet and achieve social justice. She speaks to a diverse range of audiences, from inner-city high schools to universities and large public venues such as the Commonwealth Club and the New England Aquarium. She is the co-founder of KurtHahn.org, the online archive for the founder of Outward Bound, Kurt Hahn.

Michael Lomas is a Senior Research Scientist at Bigelow Laboratory for Ocean Science and Director of the National Center for Marine Algae and Microbiota. He is a marine biogeochemist with a broad interest in the role that phytoplankton play in mediating the key processes of the biological carbon pump, as well as the flow of carbon and energy to higher trophic levels, and how these respond to global change. Lomas and his research group actively conduct leading-edge scientific research in the Sargasso Sea and the subarctic Bering and Chukchi Seas.