Plumes of diesel fuel exhaust reflect in the waters of Magdalena Bay, Mexico.

THOMAS BACKER / AURORA PHOTOS

Carbon Dioxide: The Curse of the Deep

Ocean warming, acidification, and corrosion wreak havoc on marine populations.

BY MARAH J. HARDT

I was 8 years old, diving down in the waters off Cape Cod, when I first saw a strange shimmering within the sea. About 7 feet beneath the surface, I cautiously extended my hand to where the water appeared blurry, as if I were gazing down through a thick, melting pane of glass. My fingertips struck very cold water. I had encountered a thermocline, literally a line of temperature, and discovered that the ocean is far from a uniform pool of blue.

Different layers of warm and cold water, some with more minerals, some with fewer, alternately rise and sink, creating currents, distributing nutrients, and forming distinctive habitats. Temperature and chemistry govern ocean life in a way not seen on land. When water warms, it absorbs less oxygen and increases stratification, reducing its ability to mix with waters below. As a result, deeper waters do not receive as much oxygen from the surface, and surface waters do not receive as many nutrients from below. Marine animals have a hard time living in such depleted waters. If we change the temperature or alter the chemistry of the ocean, we change the rules for survival.

Industrialization has done exactly that. Burning fossil fuels releases carbon dioxide into the atmosphere, which reflects more heat back to the earth. The oceans absorb much of this excess heat, warming an average .56 degree Fahrenheit to a depth of 1,000 feet over the past 50 years across the globe. Oceans also absorb the carbon dioxide—30 million metric tons every day. But as oceans sponge up our carbon waste, they reduce climate change on land at the expense of the climate and life in the sea.

Life responds to the changing climate by seeking out preferred temperature ranges in which to best grow and reproduce. We see this in butterflies living farther north and in insects hatching earlier than ever before. Beneath the waves it is no different, except that changes are happening exceptionally fast. Tiny shrimp-like animals called copepods are shifting geographic distribution poleward at rates up to 30 times faster than many land species. Marine animals from baby cod to humpback whales dine on copepods, which are the most abundant multicellular animals on earth. When they move, the whole food web tilts. Predators must keep up or go hungry.

As species move into new areas, increased competition for food or introduction of new threats may result. Warmer winter temperatures favor development of a deadly oyster disease that has now spread along the entire eastern seaboard of the United States. Species that do not like warm water move poleward or deeper or both, but many have nowhere else to go. For corals, movement is not an option. How does one relocate the towering walls of Australia's Great Barrier Reef, which took millennia to build?

Increasing oceanic concentrations of carbon dioxide affect wildlife by changing the chemistry of the seawater *around* and the fluids *within* the bodies of marine plants and animals—an effect without parallel on land.

When water mixes with carbon dioxide it becomes more acidic. This alters the rate at which many minerals can form or dissolve. Since industrialization, the surface layer of the ocean has become 30 percent more acidic, a phenomenon known as "ocean acidification." One consequence is a decrease in free carbonate ions—small molecules (untold billions of them could fit in one teaspoon) that are major building blocks for calcium-carbonate shells and skeletons of organisms such as clams, corals, and microscopic snails called pteropods. These animals provide important food and habitats for thousands of species, from reef fish to salmon.

The more carbon dioxide, the more difficult it is to construct new shells and skeletons. Too much carbon dioxide and seawater becomes corrosive. Calcified hard parts start to dissolve.

Deeper waters become corrosive faster than surface waters because they naturally contain fewer carbonate ions. Deep-living, cold-water corals are particularly at risk. Shallow species, such as tropical corals and pteropods, should not be affected yet. But this summer, strong currents forced corrosive waters all the way to the surface of the ocean off the California coast. Suddenly, surface-dwelling pteropods were in dangerous territory. But that is not the only worry: Reducing calcification could have significant consequences for global climate change because calcification is one way that oceans sequester carbon dioxide over long periods of time by storing it as calcium carbonate in shells and coral reefs.

Carbon dioxide is a small molecule that easily passes through the skin of aquatic life, accumulating internally and making cells more acidic. While current pH changes are mostly nonfatal, any change requires energy to readjust the internal acid-base balance. This leaves organisms with less energy to spend on growth, reproduction, or maintenance of basic activity levels. In organisms as diverse as fish, squids, worms, and sea stars, everything from immune function to oxygen delivery to cells shows diminished returns with lower pH. Fertilization success and developmental rates are also affected, as has been recently shown with sea urchins. Deep-sea animals are especially at risk: Evolved to live in very stable environments, they have less capacity to adapt to change.

Squeezed between warming waters above and low-oxygen waters below, faced with potential acid-base battles within and shifting food supplies without, marine life is in a real pickle. We cannot see this when we gaze out to sea. The ocean surface remains a mirrored reflection of sky, belying the enormous changes occurring below its surface. These changes cannot be ignored. Reduced seafood supplies, reduced coastal protection, and reduced climate regulation will negatively affect millions of people around the world. But there are other reasons why we should care. At the International Coral Reef Symposium this summer, Dr. Joan Kleypas, a renowned coral reef scientist, offered this sentiment: The world without corals is like a Van Gogh painting without color. We must act now, as a global community, to stem the tide of rising carbon dioxide and shoulder this burden. No ocean, no matter how mighty, can do it alone. TAP

Marah J. Hardt *is a research fellow with the Blue Ocean Institute. Her background is in coral reef ecology and the history of science.*

Imagining the Oceans in 2025

Entire ecosystems teeter on the brink of extinction as slime and dead zones take over.

BY JEREMY B.C. JACKSON

As recently as the 1950s, very smart people like Rachel Carson and Jacques Cousteau believed the oceans were so vast that fish stocks and the ocean's capacity to absorb human wastes were for all practical purposes unlimited. In reality, though, overfishing and degradation of water quality had long been apparent in places like the North Sea and New England. But no one took the problems seriously until the collapse of the legendarily abundant Newfoundland cod fisheries in 1992. The news has been unrelentingly bad ever since. Unfettered exploitation, pollution, and now climate change have brought entire ocean ecosystems to the brink of extinction, and we are left scrambling to figure out what to do.

Recent reports by the Pew Ocean Commission and the U. S. Ocean Commission, as well as innumerable National Research Council reports, clearly summarize the causes and consequences of ocean degradation. But they have failed to capture public attention. To do this we need to distill the seemingly endless litany of problems and threats into four basic questions: How and why are the oceans changing for the worse? What will happen to the oceans if degradation is allowed to continue? What can we do to stem the tide?

The answers to the how and why are all too clear. Most fishery species, including tunas, swordfish, and snappers, are fished