Smaller than a grain of sand, phytoplankton are key to aquatic health

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Credit: AI-generated image (disclaimer)

Scientists are inching closer to revealing the elusive mechanisms that tiny marine species activate to transform organic contaminants in water into less toxic chemicals.

Cup sea water in your hands and you will be holding a bustling world of single-cell organisms—thousands of them.

Much like creatures of an undersea metropolis, microscopic photosynthetic microbes—phytoplankton—quietly float through the ocean, enhancing water quality. As the foundation for the ocean ecosystem, phytoplankton work tirelessly to fuel marine food webs and consume large amounts of carbon dioxide on scales equivalent to forests. But this is not all they can do. These tiny plants may turn organic contaminants into less toxic chemicals.

Sounds simple, but it's not. The processes involved remain elusive.

Synthetic chemicals in the environment

Water pollution, once an invisible, silent threat, is now a top environmental concern worldwide.

"Millions of tons of synthetic organic chemicals are used for industrial, agricultural and consumers' purposes annually. These compounds partially find their way to the aquatic environment, impairing water quality and undermining aquatic life," said Giulia Cheloni, an environmental scientist studying phytoplankton's responses to carbon-based contaminants.

These pollutants are described as contaminants of emerging concern because of their potential risk to human health and ecological impacts. They can be found in personal care products like fragrances, disinfectants and sunscreen agents, as well as household items such as solvents, fabric protectors and flame retardants.

Can powerful phytoplankton clean up contaminants?

Scientists are studying how organic contaminants affect phytoplankton.

"Phytoplankton are not defenseless against chemical pollution: when exposed to contaminants, they may activate cellular responses to reduce their toxicity," said Cheloni, who is conducting research under PHYCOCYP, a project undertaken with the support of the Marie Skłodowska-Curie Actions program.

This process is called biotransformation. Xenobiotic molecules, namely molecules that are not naturally produced within the organisms, such as pesticides, could be metabolized by phytoplanktonic cells. The latter activate specific enzymes that cause contaminants to become less toxic and more easily eliminated from the organism.

Until now, exactly how this happens has remained elusive. "The aim of PHYCOCYP is to further mechanistic understanding of the biotransformation processes in phytoplankton and investigate how they affect their tolerance to organic contaminants," noted Cheloni.

Dissecting the biotransformation pathways will boost scientists' understanding about which enzymes are activated in the process and what kind of chemicals they may transform.

This information is vital to understanding exactly how phytoplankton transforms different classes of organic contaminants in natural environments.

"The ability to transform organic contaminants into safer products renders phytoplankton a promising candidate in water treatment plants," added Cheloni.

Preparing the ground for CYP

To better understand this process, PHYCOCYP will probe how a family of enzymes called Cytochrome P450 (CYP) affects the phytoplankton's ability to transform organic contaminants. Found in all kingdoms of life including animals, plants, bacteria and even in a few viruses, CYPs play a prominent role in stress responses and xenobiotic degradation.

However, our knowledge of how CYPs act in phytoplankton lags far behind that of other organisms. This is why researchers will build on earlier genetic advances into phytoplankton and apply a genome editing approach to generate mutant species without active CYPs.

"In a first, our study engages a unique genome editing tool called CRISPR-Cas9 in phytoplankton for environmental toxicology research," said Cheloni. This technology enables researchers to edit genome parts by removing, adding or altering sections of the DNA sequence.

These mutants will then be exposed to organic contaminants to figure out the role of CYPs in stress response and organic contaminant tolerance.

Researchers will use a comparative approach to investigate the ability of phytoplankton to transform organic contaminants and the role of CYPs in this biotransformation process.

"Our metabolomics approach will enable us to conduct a comparative analysis between wild-type and mutant phenotypes. Such a comparative approach to exploring biotransformation pathways has never been applied before," highlighted Cheloni.

Far-reaching implications

Over the last few years, environmental toxicology studies have mainly focused on how contaminants affect organisms (the biota), but not the opposite. PHYCOCYP findings will shed further insight on how the biotransformation processes of microorganisms may affect the contaminants' fate and persistence in the ecosystems.

In the realm of environmental biotechnology, identifying enzymes involved in key steps of contaminant degradation is particularly important for wastewater treatment. Such enzymes could greatly aid in selecting natural strains that can more efficiently transform organic contaminants or help generate synthetic strains that can transform persistent contaminants.

'PHYCOCYP is a collaborative and interdisciplinary project that will bring together the expertise of three French laboratories specialized in the fields of marine microbial ecology (MARBEC), aquatic analytical chemistry (HydroSciences Montpellier), phytoplankton physiology and cell biology (UMR7141)," said Cheloni.

Advanced materials to the rescue

While the water treatment role of tiny phytoplankton is being further explored, scientists are also studying another important ally in the fight against ocean pollution: advanced materials and processes.

Undertaken with the support of the Marie Skłodowska-Curie program, MAT4TREAT developed advanced materials and processes to protect natural waters from contaminants of emerging concern (CECs) like pharmaceutical active compounds and other chemicals, as well as antibiotic resistant bacteria and viruses, due to their potential impact on public health.

The novelty here is the integration of the three advanced water treatment technologies: adsorption, membranes and photo or thermal catalysis.

In the first two approaches, the pollutants are trapped by high-surfacearea materials or are separated by sieves that allow only the passage of clean water.

In photo and thermal catalysis, sunlight and heat trigger the formation of chemical species that convert the pollutants in less harmful products—carbon dioxide and water in the best-case scenario, explains Giuliana Magnacca associate professor of Physical Chemistry at the Department of Chemistry, University of Torino.

From putting tiny organisms to work to the development of advanced materials, the goal of the research is one and the same: to enable better, cleaner and more sustainable use of water that is crucial for all critical societal functions. This is also in line with the EU's target of having 100 percent of the EU's freshwater ecosystems in good health by 2027, up from 40 percent currently.

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