Shape-shifting plankton: How plankton cope with turbulence

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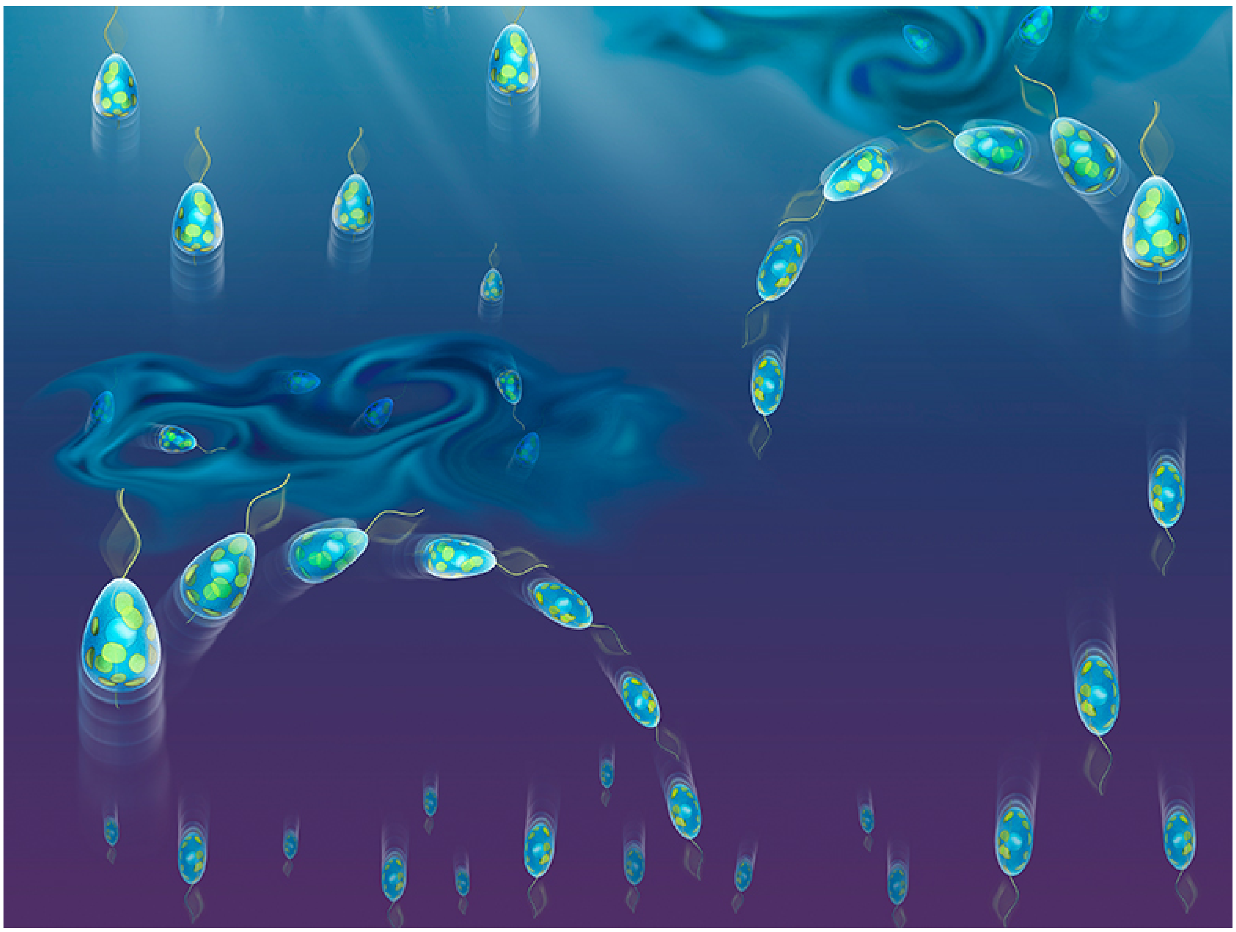

Algal population split into two equally sized groups when exposed to turbulence. Downward swimming cells become egg-shaped, while those swimming upwards are pear-shaped. This change of shape involves a difference of just one micrometre. Credit: © ETH Zürich

Microscopic marine plankton are not helplessly adrift in the ocean. They can perceive cues that indicate turbulence, rapidly respond to regulate their behaviour and actively adapt. ETH researchers have demonstrated for the first time how they do this .

Plankton in the ocean are constantly on the move. By day, these tiny organisms, one-tenth the diameter of a human hair, actively migrate towards the sunlit ocean surface to carry out photosynthesis. At night, they make their way to depths of tens of metres, where the supply of nutrients is greater.

During their regular trips between well-lit and nutrient-rich zones, plankton cells frequently encounter turbulent layers, which disrupt this essential migratory pattern. It is still a mystery how these minute organisms can navigate through the dangers of turbulent waters. Plankton cells are whirled around by turbulence—particularly by the smallest, millimetre-sized flow vortices—as if they were in a miniature washing machine, which can induce permanent damage to their propulsion appendages and cell envelope. In the worst case, they can perish in turbulence.

Migratory behaviour observed in micro-chambers

Certain microalgae have, however, developed a sophisticated response to such turbulent cues. Post-doctoral researchers Anupam Sengupta and Francesco Carrara, together with their advisor Roman Stocker, Professor at the ETH Zurich Institute of Environmental Engineering, have shown this in a study recently published in the journal *Nature*.

Using laboratory experiments, the three scientists "brought the ocean into the lab" and examined the migratory behaviour of Heterosigma akashiwo, an alga known for forming toxic algal blooms. To examine swimming behaviour, the researchers used a microfabricated chamber, just a few cubic millimetres in volume, in which they introduced the Heterosigma cells. The chamber could be rotated along its axis using a computer-controlled motor, exposing cells to periodic flips in orientation replicating how tiny turbulent vortices flip the cells upside down in the ocean.

Diving with foresight

The scientists were able to observe that an algal population moving upwards split into two equally sized groups over a period of 30 minutes after the chamber was repeatedly flipped by 180 degrees. One group of cells continued to strive upwards, whereas the other group switched behaviour and began to swim in the opposite direction. This population split did not occur with algae in stationary chambers, in which all swam continuously upwards and accumulated near the top surface.

By zooming into single cells, the researchers discovered the reason for the change in swimming behaviour. When exposed to the turbulence-like cues, the cells were able to actively and rapidly change their shape: from asymmetric pear-shaped cells swimming upwards, the cells morphed into egg-shaped structures swimming downwards. Strikingly, this shift involved changes of less than a micrometre. "It is spectacular that a cell barely 10 micrometres in size can adapt its shape to change its swimming direction," says the study's co-author Francesco Carrara.

Perfect adaptation

Roman Stocker does not view this mechanism as just a coincidence. "The algae have adapted perfectly to their ocean habitat: they can actively swim, they perceive a range of different environmental signals, including turbulence, and they rapidly adapt and regulate their behaviour accordingly." Anupam Sengupta adds: "We now better understand how these microorganisms confront potentially detrimental situations, however, at the moment we can only speculate as to why the cells do this."

The researchers argue that splitting into two groups creates an evolutionary advantage for the population: in this manner, the entire population is not lost when it encounters a layer of strong turbulence, but in the worst case, only half. In avoiding the turbulence by diving, the downward-swimming cells suffer the short-term cost of receiving too little light to carry out photosynthesis, meaning that they cannot grow. The researchers also found evidence that the flipping by turbulence has a physiological impact on the algae. Cells that were flipped in their experiment exhibited higher levels of stress than those in the stationary chambers.

Climate change influences turbulence

The researchers now plan to observe the algae in a larger tank, where they will expose the cells not only to flipping but also to real turbulence. Understanding how these minute cells respond to turbulence holds great importance for our understanding of the ocean. "As we now know that global climate change will modify the turbulence landscape in the ocean, it is particularly important to understand how the organisms that are the foundation of the marine food web respond to it. This work contributes a piece of the puzzle, by demonstrating that phytoplankton are not just at the mercy of turbulence, but can actively cope with it," says the ETH professor.

More information: Anupam Sengupta et al, Phytoplankton can actively diversify their migration strategy in response to turbulent cues, *Nature* (2017). DOI: 10.1038/nature21415

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