Microplankton study: Active lipids enable intelligent swimming under nutrient limitation

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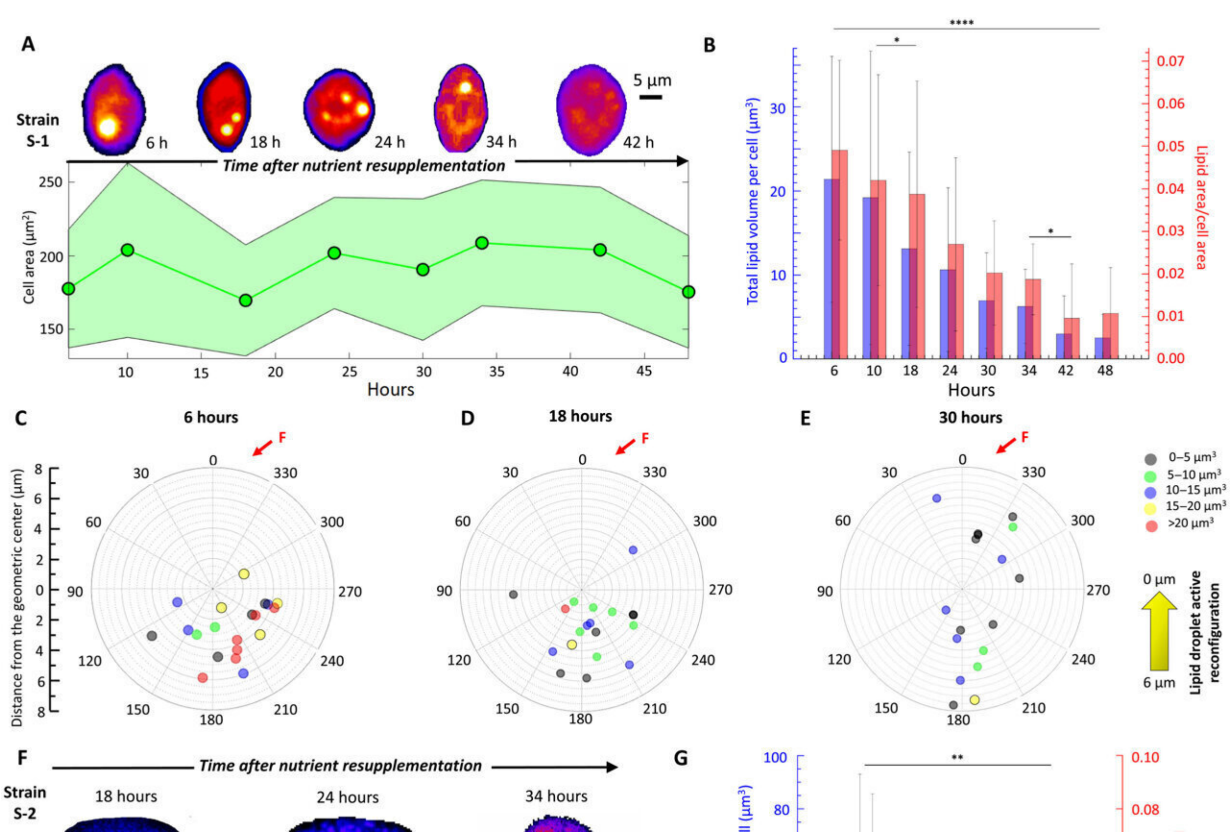

Active reconfiguration of LDs upon nutrient reincorporation.(**A**) Nutrient reincorporation of S-1 leads to LD lipolysis (false color bright spots), while the cell area remains stable over time. LDs translocate from the aft-to-fore direction, reversing the direction of LD mobility under depleted conditions. (**B**) Normalized lipid area, I_{LD}, reduces from 0.049 ± 0.021 to 0.01 ± 0.01 within ~48 hours (inset shows the total LD volume per cell, V_{LD}, over time). One-way

ANOVA between 10, 18, and 24 hours, t test between 34 and 42 hours, P C to **E**) Evolution of LD size and coordinates within individual S-1 cells after nutrient reincorporation, shown for $t = 6$ hours (C), 18 hours (D), and 30 hours (E), respectively, measured relative to C_B (center of the plot). LDs translocate from the bottom to the top of the cell (F indicates flagellar position). (**F**) Nutrient reincorporation drives lipolysis and LD translocation along the aft-to-fore direction in S-2. (**G**) I_{LD} reduces from 0.06 ± 0.025 before reincorporation to 0.005 ± 0.004 at $t = 36$ hours. Inset shows the total LD volume, V_{LD}, over time. One-way ANOVA between 12, 24, and 36 hours, t test between 24 and 36 hours, P H to **J**) LD coordinates relative to C_B for $t = 6$ hours (H), 24 hours (I), and 36 hours (J) capture the active reconfiguration of the LDs due to nutrient reincorporation. Credit: *Science Advances* (2022). DOI: 10.1126/sciadv.abn6005

Biophysicists from the University of Luxembourg have uncovered how microplankton—key photosynthetic organisms which produce nearly 50% of the oxygen we breathe—adopt a thrifty lifestyle when nutrients turn limiting. They strategically harness internal lipids to regulate swimming properties to maximize their fitness.

Prof. Anupam Sengupta and his team discovered this evolutionary trick by monitoring harmful bloom-forming phytoplankton species, using multi-scale quantitative imaging techniques, analytical and physiological measurements, fluid dynamic simulations and mathematical modeling.

Precise tracking of the intracellular organelles (both size and position within cells) and the swimming behavior reveal an emergent synergy between active lipid movement and cell-shape that ultimately enables microplankton to navigate dynamic nutrient landscapes. The groundbreaking findings appear in *Science Advances*.

Microbial nutrients are turning scarce: An unavoidable consequence of climate change

As open oceans continue to warm, modified currents and enhanced stratification exacerbate nutrient limitation, thus limiting primary production. The ability to migrate vertically offers motile phytoplankton a crucial–yet energetically expensive–advantage that allows vertical redistribution for growth, nutrient uptake and energy storage in nutrient-limited water.

Over the last years, Prof. Sengupta has pioneered discoveries that point toward exquisite biomechanical strategies which phytoplankton employ to adapt to changes in their habitat, for instance, due to ocean turbulence (*Nature* 2017), and early-warning protective mechanisms in face of biophysical stresses (*Proceedings of the National Academy of Sciences* 2021).

How these miniscule yet indispensable microbes adapt to evolving nutrient landscapes—driven substantially by the climate change—has remained unknown. Now researchers from the Physics of Living Matter Group, headed by Prof. Sengupta, reveal the fate of phytoplankton through a multi-scale cross-disciplinary investigation spanning microbiology, physics, mathematics and numerical modeling.

Based on a red-tide forming microplankton, the study uncovers how species harness lipid droplets (LDs)—so far known to serve as energy-storing organelles—double as biomechanical triggers to regulate swimming properties under nutrient limitation. By actively controlling the position and size of the LDs, cells can decide whether to swim up or down: a key survival trait of photosynthetic microbes as their vertical position in the water column determines light and nutrient availability.

Cross-scale and cross-disciplinary approaches were crucial to the discovery

Alongside intracellular tracking and quantification of swimming properties using the custom-built Ocean-in-Lab set up, Prof. Sengupta's team measured changes in the planktons' ability to transform light into energy, and production of oxidative molecules, a key marker for physiological stress. Taken together, the results link intracellular reorganization with biomechanics of swimming, and further provide a mechanistic framework to estimate the underlying energetics of resource acquisition under supply constraints.

The combination of single-cell time-lapse imaging, particle image velocimetry of swimming populations, numerical simulations and continuum modeling, and a host of microbiology and analytical techniques were crucial for this ground-breaking discovery. This cross-disciplinary research opens new vistas in the research of active and intelligent microbial matter, and provides a fresh perspective on microbial adaptation to environmental variations, including those imposed by climate and lifestyle changes.

More information: Anupam Sengupta et al, Active reconfiguration of cytoplasmic lipid droplets governs migration of nutrient-limited phytoplankton, *Science Advances* (2022). DOI: 10.1126/sciadv.abn6005

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

Francesco Carrara et al, Bistability in oxidative stress response determines the migration behavior of phytoplankton in turbulence, *Proceedings of the National Academy of Sciences* (2021). DOI: 10.1073/pnas.2005944118

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