Phytoplankton evolution

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Duplicating genomes to survive the heat

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Marine diatoms, tiny algae that underpin ocean food webs, face rising ocean temperatures. Now, a study shows that genome duplication helps diatoms adapt faster to warming, reshaping our understanding of phytoplankton resilience in a changing ocean.

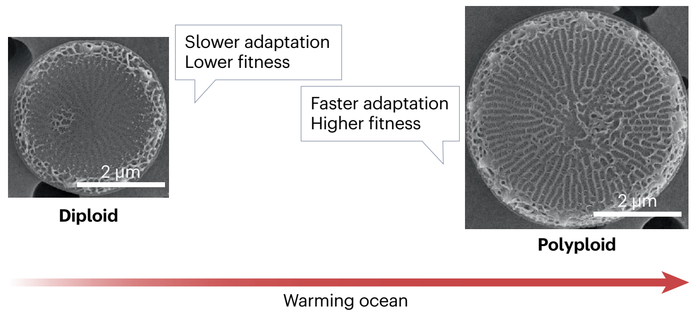

Fig. 1 | Polyploidization helps diatoms keep pace with ocean warming. Genome duplication enables faster adaptation and competitive advantage under elevated temperatures. Diploid diatoms (*Thalassiosira pseudonana*; left) have smaller cells with slower adaptation and lower fitness. Polyploid diatoms (right) have larger cells with faster adaptation and higher fitness. Credit: Zhengke Li.

The oceans are warming at an unprecedented pace, reshaping the foundation of marine life. Heatwaves, shifting circulation and nutrient stress are already altering plankton communities, with widespread concern that rising temperatures could shrink phytoplankton populations and weaken the biological pump that regulates Earth's climate. Among these microscopic drifters, diatoms stand out: they contribute around one-fifth of global primary production, support marine food webs, and drive key carbon and nutrient cycles. The vulnerability of these organisms to ocean warming is therefore a critical question. Writing in *Nature Climate Change*, Li and colleagues[1] report that diatoms may possess an unexpected ally in the race against rising temperatures: polyploidization, the duplication of their entire genome, which can speed up adaptation to warming and strengthen competitive advantage.

Evolutionary change is often overlooked in projections of climate impacts on the ocean. Most models assume that phytoplankton traits are fixed, and thus warming will inevitably reduce biomass and therefore primary production[2,3]. Yet phytoplankton reproduce quickly, reach immense population sizes and maintain high levels of genetic variation, making them capable of evolutionary change over years to decades. Laboratory experiments have already shown that diatoms can adjust their thermal tolerance over hundreds of generations, although usually within limits that suggest trade-offs between growth and versatility[4,5]. More recently, field evidence suggests natural diatom populations have already shifted their thermal optima as global warming proceeds[6]. A key unknown is which molecular mechanisms underlie this adaptation and whether they can unfold rapidly enough to keep pace with the changing ocean.

Polyploidization is one such mechanism. Common in flowering plants and well studied in agriculture, genome duplication is associated with bursts of diversification and resilience to stress[7]. In plants, polyploidy often arises after environmental disruption and is linked to enhanced tolerance of drought, salinity or temperature extremes[8]. By contrast, the role of polyploidy in marine microorganisms has remained obscure, even though diatoms exhibit a wide range of genome sizes and polyploid lineages have been detected in both laboratory and field studies[9]. Genome duplication may provide evolutionary 'raw material', as extra copies of genes can mutate, diversify and take on new functions, while buffering against harmful mutations. Until now, however, its role in shaping diatom responses to warming has been largely speculative.

Li and colleagues investigated this possibility using experimental evolution with the marine diatom *Thalassiosira pseudonana*, a model species in phytoplankton research. They exposed cultures to both moderately suboptimal (20 °C) and supra-optimal (28.5 °C) temperatures for more than 500 generations. During these experiments, they observed the spontaneous emergence of enlarged cells, which genomic analysis confirmed to be tetraploids, carrying twice the DNA of their diploid ancestors (Fig. 1). By maintaining these polyploid and diploid lineages in parallel, the authors could directly compare how genome duplication influenced adaptation to warming.

The results were striking. Polyploid lineages exhibited faster increases in growth rates, higher competitive fitness and greater upward shifts in optimal growth temperature than their diploid counterparts. After 500 generations, polyploid cells grew faster than diploids at elevated temperature and quickly outcompeted them in co-culture experiments. Gene expression analyses revealed profound shifts: polyploids showed altered regulation of the cell cycle, stress response pathways and nutrient assimilation genes. Particularly under warming, polyploids upregulated transporters for nitrogen and phosphorus, potentially supporting their faster growth. These findings suggest that polyploidization provides both physiological and molecular flexibility that accelerates evolutionary responses to thermal stress.

The broader implications are twofold. First, the study provides a plausible explanation for the evolutionary success of diatoms over millions of years. Like flowering plants, another group where polyploidy is pervasive, diatoms may have repeatedly used genome duplication to expand their ecological range and endure environmental upheavals. Second, it raises the possibility that models of ocean ecosystems may underestimate the resilience of phytoplankton populations. If diatoms can rapidly generate polyploid lineages under stress, then predictions of large-scale declines in primary productivity could be too pessimistic. At the same time, polyploidization may alter not just growth rates but also cell size, nutrient demands and ecological interactions, with consequences for marine food webs and biogeochemical cycles.

Yet important caveats remain. The experiments were conducted in the laboratory, with a single species and controlled conditions.

In the real ocean, warming is accompanied by declining nutrient supply, acidification and ecological competition, all of which could influence the costs and benefits of polyploidy. Larger polyploid cells may be less efficient at nutrient uptake in oligotrophic waters, where small cell size is advantageous. Furthermore, genome duplication can introduce instability, including chromosome mis-segregation, which may hinder long-term persistence. Whether polyploidization consistently benefits diatoms across diverse ocean regimes remains to be tested.

The study also highlights the complexity of evolutionary trade-offs. Polyploids adapted more quickly to high temperatures but showed a narrowing of their thermal tolerance, becoming more specialized. Such specialization could leave them vulnerable to fluctuating environments, such as those shaped by marine heatwaves. Moreover, adaptation in one lineage did not follow a uniform trajectory: different polyploid lineages exhibited distinct gene expression patterns and physiological responses, underlining the unpredictability of evolutionary outcomes even under similar conditions.

Nevertheless, the message is clear: genome duplication can act as a hidden catalyst of adaptation in marine phytoplankton. By reshaping cell physiology and providing genetic flexibility, polyploidization may give diatoms a crucial edge in a warming ocean. If this process is widespread across phytoplankton, it could alter how marine ecosystems respond to climate change, reshaping productivity, food web dynamics and carbon cycling.

The findings of Li and colleagues underscore the need to integrate evolutionary potential into climate impact models and to consider polyploidy as a powerful, if underappreciated, force in the resilience of the ocean's smallest, but most essential, inhabitants.

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Competing interests

The author declares no competing interests.