PRESS RELEASE

Source: ELSI, Institute of Science Tokyo, Japan

For immediate release: 23 January 2025

Title: Solving the evolutionary puzzle of polyploidy: how genome duplication shapes adaptation

Subtitle:
New research explores how polyploidy slows gradual evolution yet accelerates innovation

Release summary:
A recent study at Earth-Life Science Institute (ELSI) at Institute of Science Tokyo has developed a theoretical model that uncovers the dual role of polyploidy—organisms carrying extra genome copies—in evolution. Their findings reveal that polyploidy can stabilise populations in predictable environments, where the evolution of novel traits is not required, enabling organisms to adapt and thrive in challenging conditions by accelerating evolutionary innovation. This breakthrough offers fresh insights into evolutionary mechanisms and their implications for microbiology, biotechnology, and medicine.

Full-text release:
Evolution is the basis of biological diversity, driven by mechanisms that allow organisms to adapt and survive. One such mechanism is polyploidy, where organisms carry extra copies of their genomes. While polyploidy provides genetic redundancy by allowing mutations without affecting survival, it can also slow evolutionary progress by diluting beneficial mutations. This paradox has intrigued scientists for many years now, and a recent study from Earth-Life Science Institute (ELSI) at Institute of Science Tokyo offers new insights into polyploidy's role in evolution. Led by ELSI's Specially Appointed Associate Professor Tetsuhiro Hatakeyama, with contributions from the co-author, Associate Professor of Tokyo Metropolitan University Ryudo Ohbayashi, the study combines theoretical models and biological observations to explore how polyploidy affects genetic variance and evolution. The team's findings suggest that polyploidy can be both, a barrier and a driver of evolutionary change, depending on how innovative evolution is required to adapt to the environment.

Hatakeyama's interest in polyploidy traces back to his early work in molecular biology during his master's course, where he studied cyanobacteria experimentally. At the time, he wondered why these organisms had multiple copies of their genome. Though he couldn't resolve the mystery, his later work in theoretical physics led him and Ohbayashi to propose an answer after over 15 years. Hatakeyama explains, "We constructed a theoretical model in the simplest form we could imagine, and through this model, we found that polyploidy slows evolution in stable environments, where gradual evolution is required, but drives evolutionary innovation required to adapt to extreme conditions."

The study distinguishes between smooth fitness landscapes, where organisms' phenotype changes gradually, and rugged landscapes, where organisms must undergo significant phenotypic shifts to survive. Polyploid organisms evolve more slowly in the smooth fitness landscapes due to reduced genetic variance, making it harder for beneficial mutations to take hold. Ohbayashi adds, "However, in rugged landscapes, polyploidy accelerates the development of novel traits by increasing the probability of significant genetic shifts."

The researchers suggest that two major evolutionary theories—Fisher's fundamental theorem of natural selection and Susumu Ohno’s neofunctionalisation by gene duplication—are not mutually exclusive. Instead, both theories play critical roles depending on whether rare evolutionary events are required for survival.

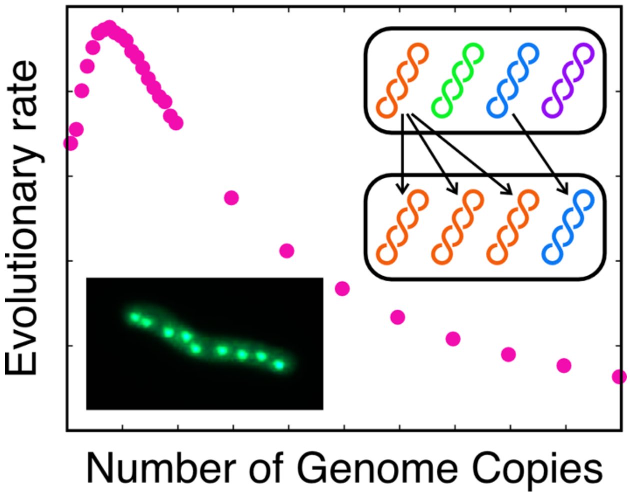
A key mechanism behind this accelerated evolution is "skewness"—the biased distribution of genetic information across multiple copies of genomes. This allows polyploid cells to harbour beneficial mutations in some genomes while maintaining overall fitness, facilitating the development of new traits without compromising survival. The study pioneers a groundbreaking application of large deviation theory, a concept that explains rare events. It shows how rare but significant evolutionary changes are more likely in polyploid organisms by explaining the contribution of biased information to rare evolutionary events.

The findings are particularly relevant to studying microbes living in extreme environments, many of which are polyploid. In addition, these insights can help explain why polyploidy is advantageous for adaptation to harsh conditions, offering valuable implications for fields like genetic engineering, industrial microbial production, drug resistance, and cancer treatment. The research connects theoretical and empirical perspectives for Hatakeyama, deepening our understanding of polyploidy’s evolutionary role. "This research illuminates how polyploidy influences evolution and sets the stage for future applications in areas like engineering and medicine," he says.

The study also points to the importance of experimental verification. Future research will need to test the theoretical models, and there may be further exploration of how other mechanisms, beyond polyploidy, drive evolutionary innovation. Looking ahead, the researchers emphasise the importance of experimental studies to validate their model. Hatakeyama concludes: "This study bridges theoretical physics and evolutionary biology, shedding light on the interplay between genetic architecture and adaptability, with applications ranging from microorganisms to cancer cells."

Image information:

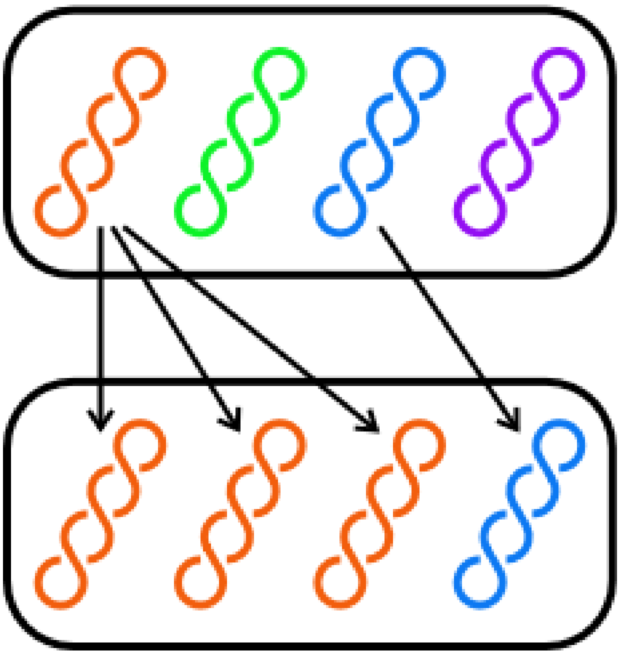
Image 1:



Title: Acceleration of novel traits in polyploid organisms based on environmental conditions
Caption: Dependence of evolution on the number of genome copies.

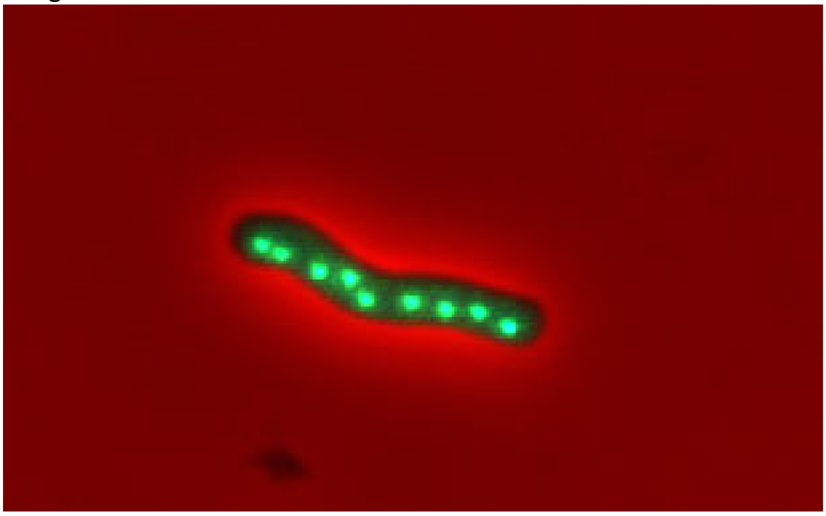
Credit: Reproduced from Hatakeyama and Ohbayashi *PRX life*

Image 2:



Title: Schematic illustration of the simplest model of the polyploid organism
Caption: Each cell randomly inherits genome copies of the mother cell. Each genome is duplicated multiple times and is neutrally selected.
Credit: Reproduced from Hatakeyama and Ohbayashi *PRX life*

Image 3:



Title: Cyanobacterial cell with multiple genome copies

Caption: Each bright spot is a single copy of a genome.
Credit: Hatakeyama and Ohbayashi

Reference:

Tetsuhiro S. Hatakeyama[1]*, Ryudo Ohbayashi[2], Evolutionary Innovation by Polyploidy, *PRX Life*, DOI: 10.1103/PRXLife.2.043021

1. Earth-Life Science Institute, Institute of Science Tokyo, 2-12-1-IE-1 Ookayama, Meguro-ku, Tokyo 152-8550, Japan

2. Department of Biological Sciences, Graduate School of Science, Tokyo Metropolitan University, 1-1 Minami-Osawa, Hachioji-shi, Tokyo 192-0397, Japan

*Corresponding author's email: hatakeyama@elsi.jp

Contacts:

Thilina Heenatigala
Director of Communications
Earth-Life Science Institute (ELSI),
Institute of Science Tokyo
E-mail: thilinah@elsi.jp
Tel: +81-3-5734-3163

Tetsuhiro Hatakeyama
Specially Appointed Associate Professor
Earth-Life Science Institute (ELSI),
Institute of Science Tokyo
E-mail: hatakeyama@elsi.jp
Tel: +81-3-5734-2187

More information

Institute of Science Tokyo (Science Tokyo) was established on October 1, 2024, following the merger between Tokyo Medical and Dental University (TMDU) and Tokyo Institute of Technology (Tokyo Tech), with the mission of "Advancing science and human wellbeing to create value for and with society."

The Earth-Life Science Institute (ELSI) is one of Japan's ambitious World Premiere International research centers, whose aim is to achieve progress in broadly inter-disciplinary scientific areas by inspiring the world's greatest minds to come to Japan and collaborate on the most challenging scientific problems. ELSI's primary aim is to address the origin and co-evolution of the Earth and life.

The World Premier International Research Center Initiative (WPI) was launched in 2007 by Japan's Ministry of Education, Culture, Sports, Science and Technology (MEXT) to foster globally visible research centers boasting the highest standards and outstanding research environments. Numbering more than a dozen and operating at institutions throughout the country, these centers are given a high degree of autonomy, allowing them to engage in innovative modes of management and research. The program is administered by the Japan Society for the Promotion of Science (JSPS).

Tokyo Metropolitan University is striving to realize an ideal metropolitan human society, serving as the center of scholarship in Tokyo and working in close collaboration with educational institutions and research institutes in the greater Tokyo metropolitan area. In addition to teaching and researching both broad field knowledge and specialized disciplines, we are generating educational and research results based on metropolitan realities and fostering human resources that are rich in humanity and creativity. Through these efforts, we aim to contribute to the improvement and development of urban life and culture.