The ocean's first large swimming apex predators had exceptionally rapid growth, fossil study finds

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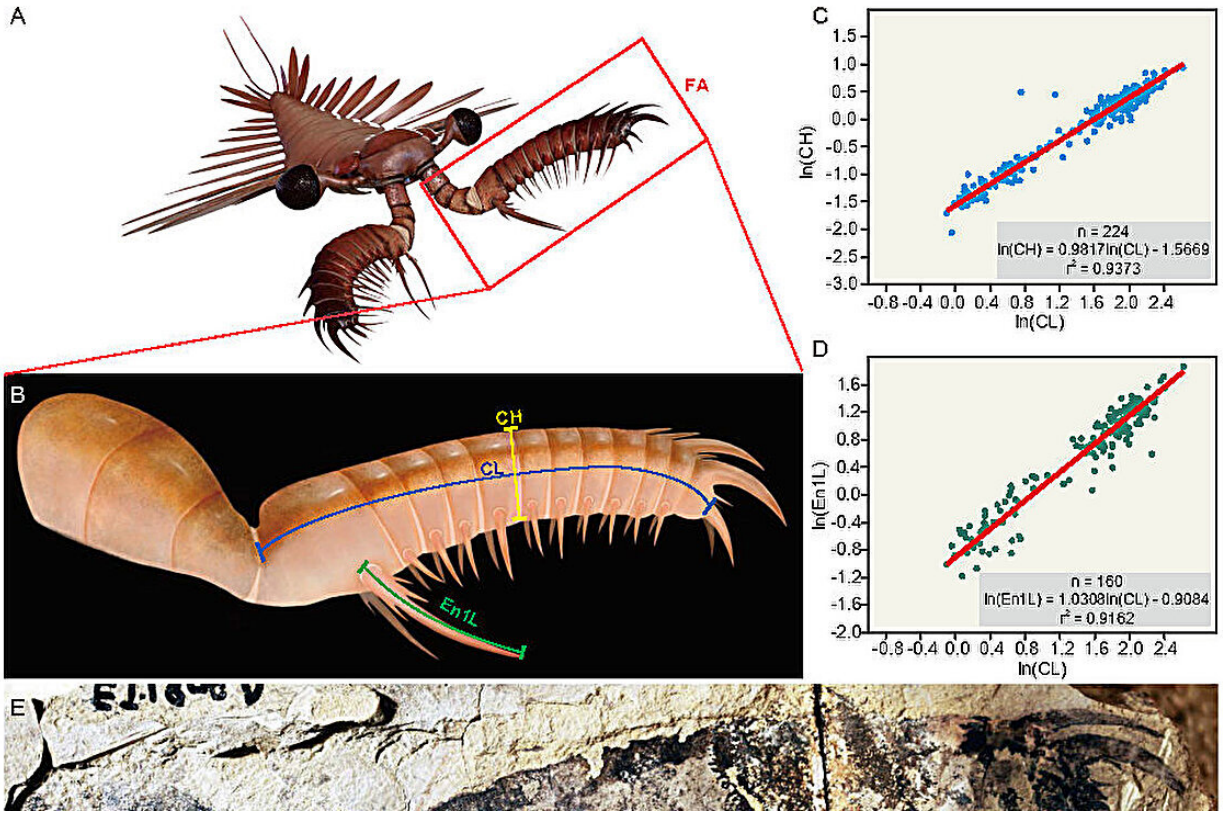


(A) General morphology of A. symbrachiata. (B) Morphology of frontal appendages (FA) and explanations of measurements taken for main analysis: claw length (CL), claw height (CH) and En1 length (En1L). (C and D) Scatter plots of the ontogenetic relationship between the independent variables of CL, CH and En1L, showing that CL, CH and En1L increase in size proportionally. n, number of specimens. (C) In(CL) regressed against In(CH). (D) In(CL)

regressed against In(En1L). (E–G) Specimens of frontal appendages with different sizes. (E) The largest appendage (EJ-1908) and the smallest juvenile appendage (JS-0850), emphasizing the great size difference. (F) The adult appendage with medium size (SJZ-281). (G) Enlarged view of the smallest appendage (JS-0850). Credit: Science China Press

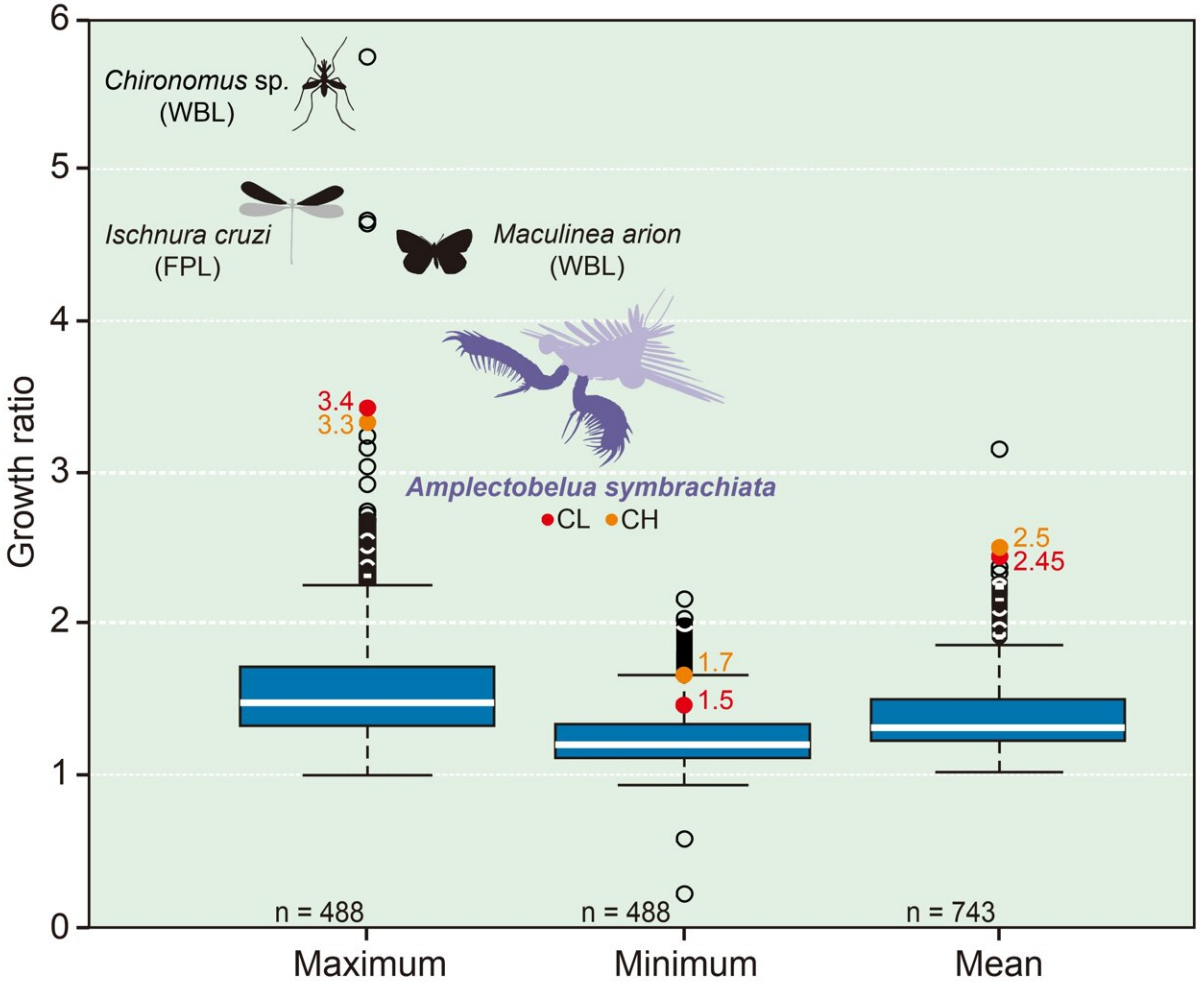
The rapid diversification of animals over 500 million years ago—often referred to as the Cambrian Explosion—saw the appearance of the first large swimming predators in our oceans. Amplectobelua symbrachiata, a member of the group Radiodonta, which are relatives of modern arthropods, was the largest of these, reaching nearly one meter in length, and can be easily recognized by their fearsome spiny feeding appendages.

However, despite recent studies revealing a huge diversity of radiodonts, our understanding of how these animals grew and their changing ecological role throughout their life has been distinctly lacking. That is, until now.

Hundreds of fossil specimens of the feeding appendages of Amplectobelua symbrachiata (ranging from less than 1 cm to more than 10 cm in length) collected from the famous fossil deposits of Chengjiang in China were carefully studied and statistically analyzed by an international team of researchers based at Northwest University, China, Cambridge University, UK, and University of British Columbia, Canada.

Combining statistical methods with growth modeling methods commonly used in modern fisheries analyses, the team determined both how the relative proportions of parts of the feeding appendages changed with size and quantified the growth rates in these animals for the first time. All analyses revealed that Amplectobelua symbrachiata displayed

an unusual and rapid growth strategy when compared to its modern arthropod relatives.



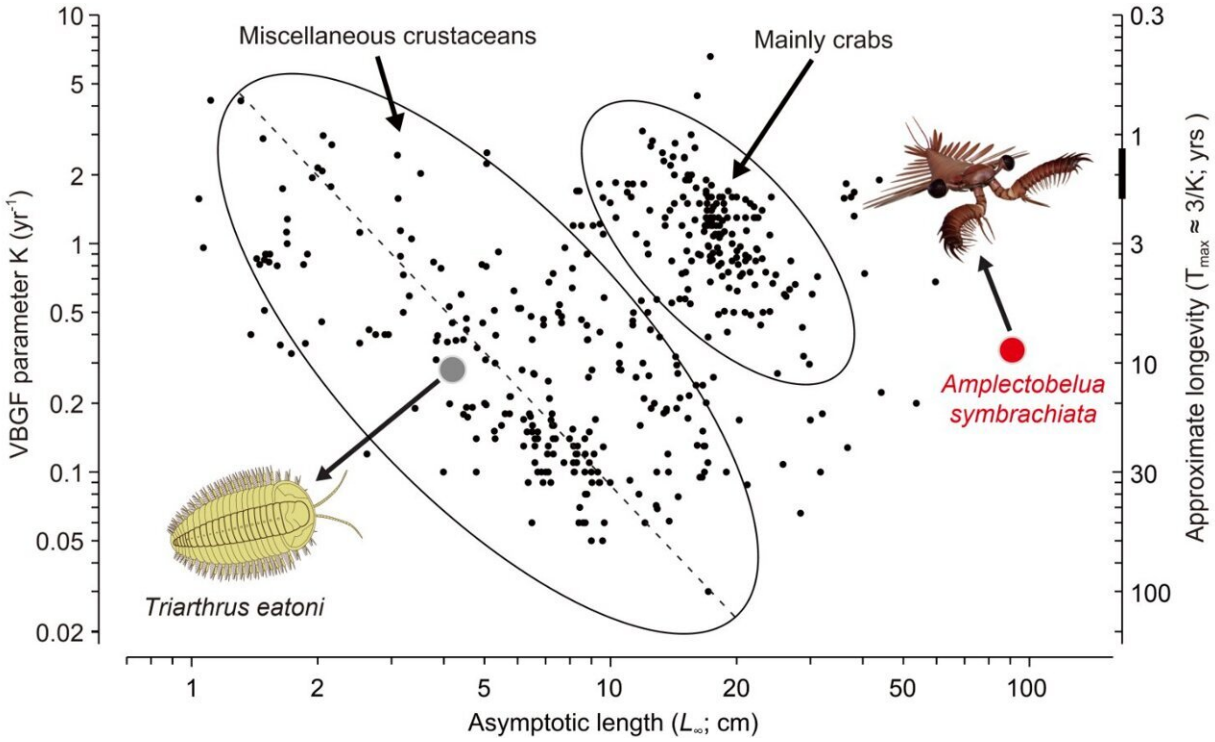
Boxplots show comparisons of maximum, minimum and mean growth ratio between stages in total group euarthropods (data gathered from literature). Note how A. symbrachiata displays among the highest maximum growth ratios of any euarthropod in the literature (except for chironomid Chironomus, coenagrionid Ischnura cruzi, and lycaenid Maculinea arion). The diagram is collated from various body parts of large number of modern and extinct euarthropods. Credit: Science China Press

Amplectobelua symbrachiata appendages display isometric growth—the proportions in the shape of individual podomeres and the relative length of spines to the appendage length and height were the same for small juveniles as for large adults. This implies that the overall function of the appendage was similar for the animal's whole life. However, the greater size of adult A. symbrachiata appendages would have made new food sources available. "The larger size of

adult appendages, alongside faster swimming speeds, would have allowed larger prey to be captured and subdued. Similarity in form must be placed in the context of the scaling up of muscle power and forces with size," said Dr. Yu Wu, one of the leaders from Northwest University, Xi'an.

Growth and mortality parameters for Amplectobelua symbrachiata were estimated using ELEFAN—a model based on size-frequency distributions commonly used in studies of modern arthropods and fish.

"These results show that Amplectobelua symbrachiata were extremely active animals in Cambrian ecosystems and had exceptionally rapid growth when compared to modern marine arthropods," said Prof. Pauly, British Columbia University, who led the ELEFAN analyses. consideration of peaks in size-frequency data suggests that this rapid growth might have been achieved over very few growth stages.



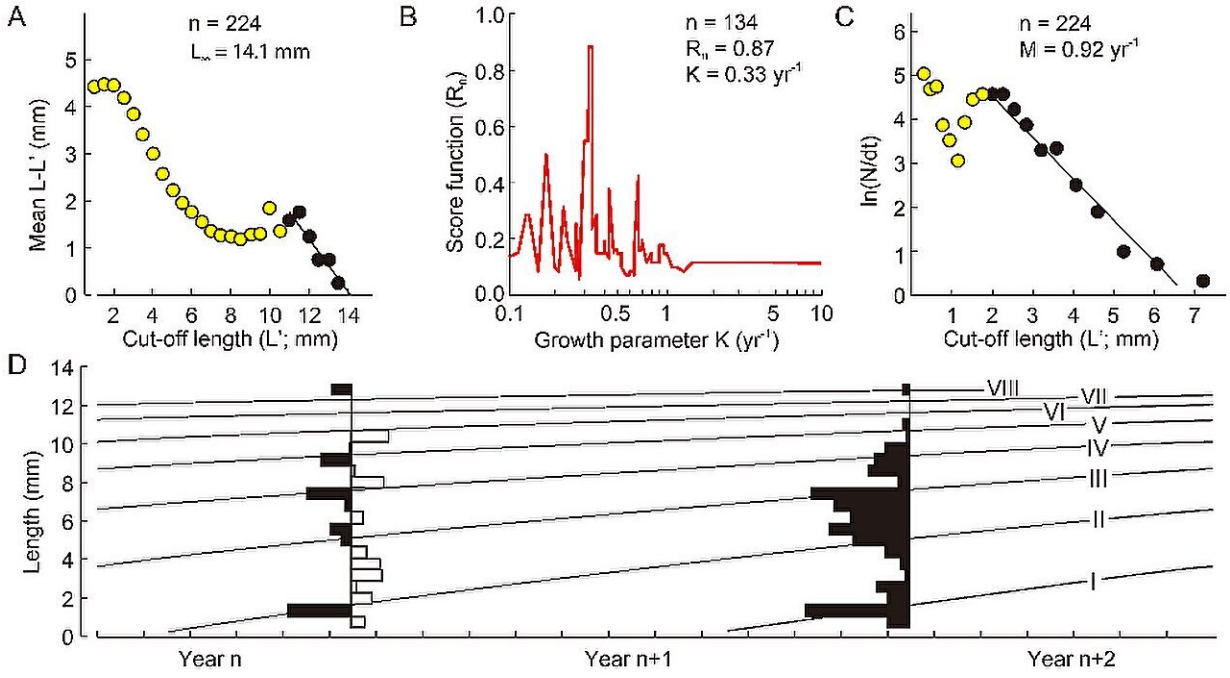
Boxplots Note that the position of the L_∞ and K data pair for *Amplectobelua symbrachiata* is far above the large ellipsoid's main axis (dotted line), suggesting a much faster growth than for recent crustaceans, as well as the Ordovician trilobite *Triarthrus eatoni*. Credit: Science China Press

The large growth ratio may have been facilitated by the unique body plan of radiodonts such as Amplectobelua symbrachiata—the body was soft and not fully arthrodized, with the most toughened part of the skeleton represented by the feeding appendages.

The unique position of A. symbrachiata, as a large, active apex predator in ecosystems with large amounts of predation, without a fully arthropodized or sclerotized body, appears to have facilitated an active, rapid-growing life history strategy.

"The Cambrian is thought to have been a time with high predation pressure, which may have provided a benefit for rapid growth to a large size. Simultaneously, rapid growth to become one of the largest animals in the ecosystem would have also provided benefits in terms of prey capture, making more prey items available," said Dr. Stephen Pates of Cambridge University, UK, who co-led the study.

"This unexpected life history strategy might have been shaped by the escalatory 'arms race' that has been hypothesized to shape the Cambrian Explosion," explained Prof. Fu, one of the corresponding authors of this study. "Only through study and analyses of hundreds of fossil specimens are we able to reveal not just what these animals looked like, but also how—and how quickly—they grew."



(A) Modified Wetherall plot to estimate asymptotic length (L_∞) using data from all sites. (B) Estimating the best K value (associated with highest Rn value), for L_∞ = 14.1 mm, given the DARL L/F data from Jianshan locality; n = 134). (C)

length-converted catch curve for the estimation of instantaneous mortality (M). (D) von Bertalanffy growth curve, with L_∞ = 14 mm and K = 0.33 yr^{-1}, superposed on the original (Year n+1) and the 'restructured' L\F data (Year n). Credit: Science China Press

Taken together, these results show that the animals in today's oceans provide a single snapshot of what evolution can produce—and that the different ecological, environmental, and evolutionary pressures and histories present over the last half a billion years have led to disparate morphologies, body plans and life history strategies that data-rich interdisciplinary studies such as this can reveal.

The work is published in the journal *National Science Review*.

More information: Yu Wu et al, Rapid growth in a large Cambrian apex predator, *National Science Review* (2023). DOI: 10.1093/nsr/nwad284

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