

OCEAN SCIENCE

The rise of Rhizaria

Large amoeba-like organisms known as Rhizaria have often been overlooked in studies of ocean biology and biogeochemistry. Underwater imaging and ecological network analyses are revealing their roles.

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Do you know the name and evolutionary affiliation of any of the most conspicuous groups of single-celled organisms in the world's oceans? Did you guess the Rhizaria, or one of the more familiar groups of plankton that make up this supergroup, such as the Radiolaria, Acantharia or Foraminifera? If you didn't, you're not alone — until recently, neither did the vast majority of biological oceanographers. Biard *et al.*¹ report online in *Nature* that the abundance and biomass of these enigmatic species in the ocean are much greater than previously recognized. In addition, Guidi *et al.*² reveal the extent of the Rhizaria's involvement in the export of carbon from the atmosphere to the ocean depths.

Oceanic Rhizaria are protists: single-celled and some colonial organisms that are eukaryotic, meaning they contain nuclei and other membrane-bound organelles. The Rhizaria were formerly thought to be phylogenetically related to the much smaller and better known amoebae, because both groups feed by capturing and engulfing prey with extensions of their cytoplasm called pseudopodia. However, the Rhizaria can produce complex pseudopodial networks that attain sizes of more than a centimetre. Some species can even form cylindrical colonies approximately 1 cm in diameter and greater than 1 m in length³.

These pseudopodial networks, and the intricate mineral skeletal structures of opal (SiO₂), celestite (SrSO₄) or calcite (CaCO₃) that many Rhizaria form, distinguish them from amoebae, as does DNA-sequence information. The supergroup Rhizaria was devised more than a decade ago to contain these morphologically complex forms, and their smaller amoebic cousins have been placed among several eukaryotic supergroups in modern phylogenetic schemes⁴.

The large oceanic Rhizaria entangle and engulf a wide range of prey in their

pseudopodial networks⁵. Many species dwelling in the upper ocean also possess symbiotic algae⁶, which can contribute significantly to host nutrition and to total primary production in the ocean⁷. This nutritional versatility makes amoeboid Rhizaria well adapted for life in the vast stretches of oligotrophic (nutrient-poor) waters of the open ocean.

The renowned nineteenth-century German scientist and artist Ernst Haeckel immortalized these species in drawings that captured their

elegance and complexity (Fig. 1). Much of the material for Haeckel's drawings came from samples returned by the *Challenger* expedition of 1872–76, a circumnavigation of the planet that laid the foundation for modern oceanography⁸. Yet, although the Rhizaria are valued by palaeontologists for climatological reconstructions based on the fossil shell assemblages left by some of these species in deep ocean sediments, they have received only scant attention from biologists.

One of the reasons for their anonymity to oceanographers is the delicate morphologies of living specimens. These structures deteriorate badly as a result of the methods and preservatives that have routinely been used for collection and species identification. Some species contain no skeletal material, and in plankton samples their remains are often not recognizable. Substantial abundances of Rhizaria were detected by divers in the open ocean more than two decades ago^{9,10}, and are visible in earlier underwater images¹¹. However, truly global surveys have never been conducted.

The *Tara* Oceans project has begun to address this gap. The *Tara* schooner has circumnavigated the globe, conducting extensive sampling of the biological communities and surveying the environmental conditions in the upper layer of the ocean, with the goal of enhancing our understanding of its organismal and genetic biodiversity, and the biogeochemical cycles affected by these communities. The data include a variety of oceanographic measurements (such as temperature, salinity and light), as well as the size distributions of plankton and estimates of sinking-particle flux. Biological data obtained include vast numbers of underwater images, genetic 'bar-coding' of all plankton — ranging from viruses to multicellular zooplankton — and combined genomic (metagenomic) data for bacteria, archaea, viruses and minute eukaryotes.

Biard *et al.* analysed nearly 2 million of the underwater images collected during the expedition¹², and concluded that abundances of large Rhizaria in the global ocean have been greatly underestimated by conventional sampling methods. On the basis of abundance and volume, the authors estimate the collective carbon content of these species to be around 10¹⁴ grams of carbon in the upper 200 m of the ocean. If accurate, this biomass places oceanic Rhizaria on a par with other large, 'conventional' zooplankton groups in

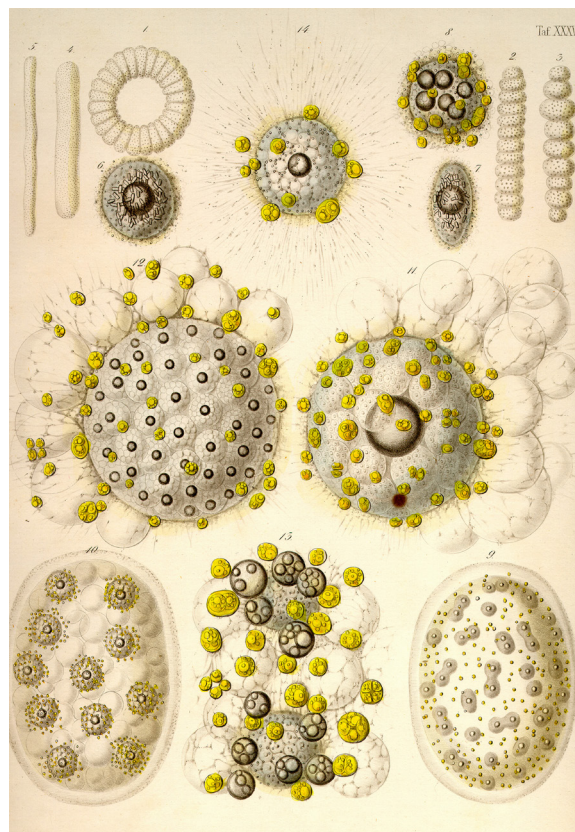


Figure 1 | Abundant plankton. These illustrations by Ernst Haeckel were drawn from samples collected by the oceanic *Challenger* expedition of 1872–76. They depict the colony shape, central capsule structure and symbiotic algae in the colonial plankton *Collozoum inerme*, which belongs to the supergroup Rhizaria. Biard *et al.*¹ and Guidi *et al.*² present analysis of data collected from the *Tara* Oceans expedition that reveals an unexpectedly large abundance of Rhizaria in the ocean, and implicates these organisms in the vital export of carbon from upper ocean layers to the deep ocean.

the ocean, such as krill.

Guidi *et al.* used regression-based modeling and weighted gene-correlation network analysis to determine correlations between the project's genetic information and the sinking of carbon-containing particles. Sinking particles are an important component of the ocean's biological carbon pump — a mechanism by which carbon is removed from surface waters for periods of up to tens of thousands of years, thus helping to reduce atmospheric carbon dioxide concentrations. The analysis revealed some expected relationships, such as a correlation between carbon flux and small crustaceans called copepods, which produce rapidly sinking faecal pellets. Among the surprising results, however, is Guidi and colleagues' implication of large Rhizaria (specifically, the genetic bar codes of several radiolarian groups) as key players in the export of material from the upper ocean.

This finding makes sense, in that large plankton are thought to have a disproportionately greater role in particle flux than small particles and organisms, and because many Rhizaria form dense crystalline structures, which may increase sinking rates. Moreover,

the findings are consistent with the high abundances of Rhizaria established by Biard and colleagues.

Considered together, the two studies provide the first quantitative assessments of the role of large Rhizaria in the ocean: the organisms' abundance, biomass and relationship to sinking particles. Much additional work will be needed to fully characterize the vertical, geographical and seasonal distributions of these species, and how they might respond to changing climatic and oceanic conditions. For example, Biard *et al.* speculate that global abundances of Rhizaria may increase if oligotrophic oceanic realms expand, as predicted in some climate-change scenarios.

For the moment, the studies have created awareness of the global significance of large Rhizaria, and provided evidence of the insufficiency of conventional sampling methods for estimating their abundances. This work is a fitting sequel to Haeckel's seminal work on these beautiful creatures, albeit more than a century later. ■

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