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In situ Oxygen Measurements of the Microenvironment Around Algal Cells: The Phycosphere and Consequences for Marine Biogeochemical Cycling

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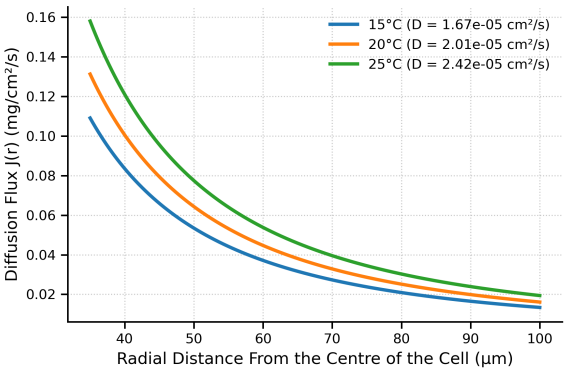

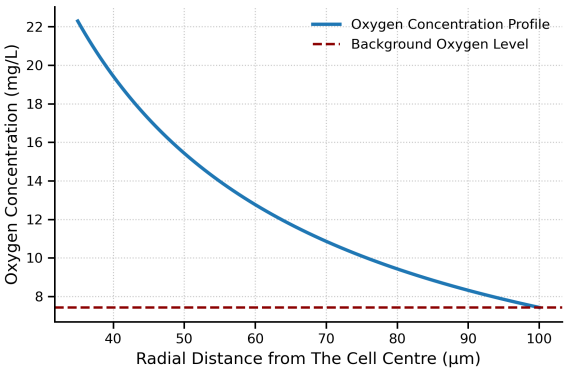

Dissolved oxygen is a master variable in aqueous environments which determines metal speciation, and their environmental fate. The interdependence of oxygen on elemental fate means that understanding oxygen dynamics in marine systems is important when investigating biogeochemical cycling. Phytoplankton serve as the major producers of oxygen in the marine environment and have an associated microenvironment around them rich in exudates called the phycosphere. The phycosphere itself has a unique chemistry distinct from bulk solution, however, investigating the physicochemical parameters of the phycosphere has been limited by technological availability. For example, oxygen production in algae, and the associated oxygen-rich phycosphere, have previously been determined only from bulk properties and theoretical models.

For the first time we present here the in-situ oxygen production rate from single cells, the spatial extent of the oxygen-rich-phycosphere, the rate of diffusion outside the phycosphere, and the associated oxygen concentration profile. Additionally, the effect of light conditions on the photosynthetic rate, and oxygen levels around the cell surface were determined. The photoinhibition point was determined for single cells, and oxygen at the cell surface was 2-3 times background levels. These results were achieved using novel nanoprobes developed within the Nanomedicine Laboratory at Imperial College London. Using the single-cell photosynthetic data condition data, simple regressive models from the cell surface report that the oxygen production rate is 26,000 fmol/hour/cell if the chloroplast is treated as a point source, a phycosphere of approximately 100 microns from modelling where oxygen levels return to background levels, and an efflux of oxygen of 13.363 µg/cm2/s at 15°C determined from the 3D diffusion equation. Furthermore, the impact of turbulence, cell size, and temperature were modelled- and the impact of climate change on phycospheric oxygen has been considered.

We predict that the oxidation of metal species in the phycosphere occurs at increased rates of reaction. Estimates on the elemental cycling of both oxygen-sensitive elements and redox-sensitive species in the photic marine environment should therefore consider phycospheric processes. These findings provide quantitative and experimentally based evidence that phytoplankton directly impacts the global biogeochemical cycling of both oxygen and other metals in marine environments.