

This Week's Citation Classic

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Fogg G E. The extracellular products of algae.
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A variety of substances is released from healthy algal cells. The extent of release varies according to whether the substance is a low molecular weight metabolite or an end product of metabolism. The ecological significance of glycolic acid and various other extracellular products is discussed. [The SCI® indicates that this paper has been cited in over 155 publications since 1966, making it the 3rd most-cited paper ever published in this journal.]

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"I began research in 1939 with a study of nitrogen fixation in blue-green algae. This was the time of the Russian invasion of Finland and, becoming interested in things Finnish, I acquired a lasting love for the music of Sibelius and read extensively the work of the biochemist A.I. Virtanen. The latter had proposed a mechanism, now superseded, for biological nitrogen fixation which was based on the nature of the extracellular products found in media in which nodulated legumes had been cultured.¹ It seemed to me that a similar approach might be made with blue-green algae. Little came of this as far as nitrogen fixation was concerned but I did find that apparently healthy cells of these organisms liberated relatively large amounts of organic matter, principally polypeptides and polysaccharides, in dissolved form into the medium in which they grew. This was against the accepted doctrine of the time; the theory of Pütter, put forward in

1909,² that marine algae released dissolved organic matter in amounts substantial enough to be a principal support for aquatic animal life, having been discredited a few years earlier.

"After learning radiocarbon techniques in the laboratory of H. Gaffron in Chicago, I sought to determine to what extent freshwater phytoplankton liberated extracellular products under natural conditions, by adding ¹⁴C-bicarbonate to water samples, allowing them to photosynthesize *in situ* in the lake, then determining the radioactivity in particulate matter and dissolved organic matter after a few hours. By chance the first experiments of this sort were done on a visit to Finland and Sweden in 1957. The results of this and subsequent work showed that release of extracellular products during photosynthesis was usual and that, according to circumstances, it varied from less than one to 50 percent or over of the total product of photosynthesis. There seemed to be a quasi-equilibrium determining the extent of release of these substances, contrasting with the irreversible accumulation of higher molecular weight substances, such as polypeptides and polysaccharides, in long-term cultures. Tolbert and Zill³ had shown in 1956 that in short-term experiments with *Chlorella*, a considerable proportion of the photosynthetic product escaped from the cells as glycolic acid so the field experiments were followed up by examining the possibility that this substance was the major extracellular product under natural conditions. Work by my collaborators, principally C. Nalewajko, W.D. Watt, L. Ignatiades, N.M. Shah, A. Pant, and R. Al Hasan, established that although it is not the only such product, it is often the principal one and that it is a normal constituent of natural waters.^{4,5} The ecological importance of this and similar extracellular products of algae, which seems to be mainly as energy sources for bacteria, is discussed in a recent review.⁶ The popularity and citation of the 1966 publication seem to depend on its having been the first review to deal with the subject in a comprehensive and systematic manner."

1. Virtanen A I. Cattle fodder and human nutrition: with special reference to biological nitrogen fixation. Cambridge, England: Cambridge University Press, 1938. 108 p.
2. Pütter A. *Die Ernährung der Wasserthiere*. Jena: J. Fischer, 1909. 168 p.
3. Tolbert N E & Zill L P. Excretion of glycolic acid by algae during photosynthesis. *J. Biol. Chem.* 222:895-906, 1956.
4. Fogg G E. Extracellular products of algae in freshwater. *Arch. Hydrobiol.* 5:1-25, 1971.
5. -----, Biochemical pathways in unicellular plants. (Cooper J P, ed.) *Photosynthesis and productivity in different environments*. Cambridge, England: Cambridge University Press, 1975. p. 437-57.
6. -----, The ecological significance of extracellular products of phytoplankton photosynthesis. *Botanica Marina*. In press, 1983.