



Characteristics of Phytoplankton as Monitors of the Physical Environment

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John J. Cullen
Bigelow Laboratory for Ocean Sciences
McKown Point, West Boothbay Harbor, Maine 04575

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The goal of this project was to understand the responses of phytoplankton to variations in irradiance so as to describe how physiological and optical characteristics of phytoplankton reflect physical forcing and particle dynamics. The application of this understanding is in using optical measurements to describe physical-biological coupling in the sea. The objectives of the program were to interpret measurements of fluorescence, beam attenuation, and photosynthesis versus irradiance (P-I) in terms of primary productivity, photoadaptation and particle dynamics in the euphotic zone. The context was photic variability induced by vertical mixing. Consideration was also given to the artifacts of experimental work at sea, including those associated with static bottle incubations that do not mimic vertical mixing in nature.

Effort was expended principally on novel analysis of previously-collected data from laboratory experiments and field sampling. Some collaborative experiments were also performed, and measurements were made during a multidisciplinary cruise to study a Gulf Stream meander. In addition, the principal investigator acted as co-chair of and contributor to an international scientific symposium to examine the controversial hypothesis that iron limits the growth of phytoplankton in large parts of the ocean. This contract also supported a continuing and productive collaboration with Marlon R. Lewis of Dalhousie University.

Good progress was made toward describing the responses of phytoplankton to environmental variability. Results of laboratory experiments were used to describe physiological and biochemical changes of phytoplankton induced by changing irradiance on time scales from seconds to days. Responses were analyzed in the context of vertical mixing to describe procedures for estimating the rate of vertical exchange by measuring the distributions with optical depth of different biological properties. This approach was employed to demonstrate that vertical motions in the photic zone of the equator and northwest Atlantic were relatively slow compared to the rate of adaptation of phytoplankton, except in wind-mixed surface layers. As a result, phytoplankton were generally well adapted to their ambient photic environment, so that steady-state models of photosynthesis and growth could reasonably be applied. Theoretical studies complemented this work by attempting to describe growth and light absorption as a function of daylength, irradiance, nutrients and temperature. Other studies focused on the optical changes of phytoplankton induced by bright light, and how these changes would influence the interpretation of optical measurements with *in situ* fluorometers, transmissometers, and flow cytometers. Detailed analysis of data from the equatorial Pacific, complemented by results of laboratory experiments, showed how changes in the optical properties of phytoplankton could substantially influence estimates of photosynthesis, growth rates and particle dynamics as determined from changes in beam attenuation. Several other optical estimates of near-surface properties were shown to be influenced by light-induced changes in phytoplankton. Interpretations are further complicated by the large potential error in conventional measurements of near-surface photosynthesis during vertical mixing. Directions for future research were clearly described.

This project paralleled and complemented major developments in technologies for bio-optical measurements in the ocean. Many of the observations, analyses, ideas, and caveats resulting from this contract are likely to be considered as the interpretations of optical measurements are developed and refined in the coming decade.

PUBLICATIONS RESULTING FROM THIS CONTRACT:

Publications in Refereed Journals:

Cullen, J.J. and M.R. Lewis. 1988. The kinetics of algal photoadaptation in the context of vertical mixing. *J. Plankton Res.* 10: 1039-1063.

Neale, P.J., J.J. Cullen, and C.M. Yentsch 1989. Bio-optical inferences from *in vivo* fluorescence: What kind of fluorescence is measured in flow cytometry? *Limnol. Oceanogr.* 34: 1739-1748.

Cullen, J.J. 1990. On models of growth and photosynthesis in phytoplankton. *Deep-Sea Res.* 37: 667-683.

Weiler, C.S. W.M. Balch, S.W. Chisholm, J.J. Cullen, W.G. Harrison, P.A. Matrai, J.J. McCarthy, J.R. Nelson, M.J. Perry, D.G. Redalje, J.H. Sharp and M.M. Sinclair. 1990. Richard W. Eppley's contributions to phytoplankton physiology and biological oceanography. *Oceanogr. Mag.* 3 (2): 42-46.

Cullen, J.J. and M.P. Lesser. 1991. Inhibition of photosynthesis by ultraviolet radiation as a function of dose and dosage rate: Results for a marine diatom. *Mar. Biol.* 111: 183-190.

Lewis, M.R. and J.J. Cullen. 1991. From cells to the ocean: Satellite ocean color. In, "Individual cell and particle analysis in oceanography". S. Demers, ed., NATO ASI Series G27: 325-337.

Cullen, J.J. 1991. Hypotheses to explain high-nutrient conditions in the open sea. *Limnol. Oceanogr.* 36: 1578-1599.

Cullen, J.J., M.R. Lewis, C.O. Davis and R.T. Barber. 1992. Photosynthetic characteristics and estimated growth rates indicate grazing is the proximate control of primary production in the equatorial Pacific. *J. Geophys. Res.* 97: 639-654.

Stegmann, P.M., M.R. Lewis, C.O. Davis and J.J. Cullen. 1992. Primary production estimates from recordings of solar-stimulated fluorescence in the equatorial Pacific at 150° W. *J. Geophys. Res.* 97: 627-638.

Kiefer, D.A. and J.J. Cullen. 1992. A discussion of phytoplankton growth and light absorption as regulated by light, temperature, and nutrients. *Polar Biology* (in press).

Cullen, J.J., X. Yang, and H.L. MacIntyre 1992. Nutrient limitation of marine photosynthesis. In: "Primary Productivity and Biogeochemical Cycles in the Sea." P.G. Falkowski and A. Woodhead (eds.), Plenum, New York 69-88.

Submitted

Ackleson, S.G., J.J. Cullen, J. Brown and M.P. Lesser. 1991. Effects of marine phytoplankton on beam attenuation: Variability in carbon-specific vs carbon-independent optical properties. *Limnol. Oceanogr.*

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Published Conference Proceedings:

Cullen, J.J., C. M. Yentsch, T. L. Cucci, and H. L. MacIntyre. 1988. Autofluorescence and other optical properties as tools in phytoplankton ecology. In: "Ocean Optics IX." M. A. Blizard, ed., Proc. SPIE 925: 149-156.

Ackleson, S.G., J.J. Cullen, J. Brown and M.P. Lesser. 1990. Some changes in the optical properties of marine phytoplankton in response to high light intensity. Ocean Optics X, SPIE 1302: 238-249.

Cullen, J.J. and M.R. Lewis. 1992. Strategies for using in situ optical and biological measurements to complement remote sensing. "Autonomous Bio-optical Ocean Observing Systems Scientific Symposium, Monterey, CA. Extended Abstract (in press).

Published in unrefereed periodical

Lohrenz, S.E., D.A. Phinney, J.J. Cullen, C.S. Yentsch, and D.B. Olson. 1991. Chlorophyll and primary production distributions in a Gulf Stream meander. The Synoptician 2 (5): 1-5.

Invited Lectures:

1990 Workshop: "Response of marine phytoplankton to natural variations of UV-B flux," San Diego, CA, "The inhibition of marine primary productivity by UV-B radiation: Dose-response, photosynthesis vs irradiance, and vertical mixing."

1991 ASLO Special Symposium, "What Controls Primary Production in Nutrient-Rich Areas of the Open Sea?" San Marcos, CA, "Hypotheses to explain high-nutrient, low-chlorophyll conditions."

1991 Brookhaven Symposium on Primary Productivity and Biogeochemical Cycles in the Sea, Upton, NY, "Nutrient limitation and marine photosynthesis: a good paradigm is hard to find."

1991 Chemical Oceanography Gordon Conference, Meriden, NH, "What phytoplankton tell us about sea-surface slicks."

1991 Lecture Series, First Institute of Oceanography, Qingdao, PRC

1992 ASLO Aquatic Sciences Meeting, Santa Fe, NM, "Using optical measurements from near the surface to describe biogeochemical processes in the sea."

Presentations at Scientific Conferences (Abstract Published):

Cullen, J.J. 1988. Responses of phytoplankton to bright light characteristic of the sea surface. EOS 69: 1102.

Stegmann, P.M., M.R. Lewis, C. Davis, and J.J. Cullen. 1988. Solar-stimulated fluorescence as a possible estimate of primary production: preliminary results from the equatorial Pacific. EOS 69: 1107.

Davis, C.O. and J. Cullen. 1988. Optical estimates of chlorophyll concentrations along a transect from 15°N to 15°S in the equatorial Pacific. EOS 69: 1141.

Cullen, J.J. 1989. Biological interpretations of optical measurements in the ocean. 15th Maine Biomedical Symposium, Univ. of Southern Maine. p. 15.

M.P. Lesser and J. J. Cullen. 1990. The kinetics of UV-B induced photoinhibition of photosynthesis in the context of vertical mixing. EOS 71: 138.

J.J. Cullen and H.L. MacIntyre. 1990. Influence of UV-B radiation on photosynthesis near the sea-surface. EOS 71: 137.

E.J. Bock, D.J. Carlson and J.J. Cullen. 1990. Characterization of hydrodynamic and chemical slicks by simultaneous measurements of time-domain surface-wave spectra, chemical and biological surface enrichments, and near-surface physics. EOS 71: 73.

Cullen, J.J. and M.R. Lewis. 1990. Interpretations of measurements on phytoplankton in the equatorial Pacific Ocean. EOS 71: 1394-1395.

Poster Presentations at Conferences

Ackleson, S.G., J. Cullen and D.B. Robins. 1988. Flow cytometric investigations of phytoplankton optical properties. Society for Analytical Cytology, Breckinridge, Colorado (poster).

Cucci, T.L., C.M. Yentsch, J.J. Cullen and H.L. MacIntyre. 1989. Measurements of metabolic heterogeneity in natural phytoplankton populations at sea. The Oceanography Society, Monterey, CA (poster).

M.R. Lewis, R. Barber, F. Chavez, J. Cullen, C. Davis, D. Halpern, R. Dugdale, F. Wilkerson, and B. Jones. 1989. Why isn't the equator greener? The Oceanography Society, Monterey, CA (poster).

P.M. Stegmann, M.R. Lewis, C.O. Davis and J.J. Cullen. 1989. Primary production estimates from recordings of solar-stimulated fluorescence in the tropical Pacific during the WEC88 cruise. The Oceanography Society, Monterey, CA (poster).

C.O. Davis and J.J. Cullen. 1989. Chlorophyll and optical properties along a cross-equatorial transect during WEC88 cruise, February-March 1988. The Oceanography Society, Monterey, CA (poster).

Cullen, J.J., M.R. Lewis, C.O. Davis and R.T. Barber. 1989. Photosynthetic characteristics of phytoplankton in the central equatorial Pacific during the WEC88 cruise. The Oceanography Society, Monterey, CA (poster).

Public Service and Information Transfer

Convener of Special Session, AGU/ASLO: Biological Interpretations of Optical Measurements, 1988

Editorial Board, Journal of Marine Systems (1990 -), Journal of Plankton Research (1990 -)

National Research Council/National Academy of Sciences Workshop: Commentator and Rapporteur, Nov. 1990

The Oceanographic Society Meetings Committee, 1988 - present.

Co-chair, ASLO Special Symposium, "What Controls Primary Production in Nutrient-Rich Areas of the Open Sea?" San Marcos, CA, 1991.