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Role of Suspended Sediments and Mixing in Reducing Photoinhibition in the Bloom-Forming Cyanobacterium Microcystis

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ABSTRACT

Toxic cyanobacterial blooms are becoming a global problem. Previous research of cyanobacterial bloom development has examined how high nutrient concentrations promote cyanobacteria dominance, and how positive buoyancy provides an ecological advantage over sinking phytoplankton. Tributaries responsible for loading nutrients into lakes often simultaneously contribute high concentrations of suspended sediments. High concentrations of suspended sediments may also influence blooms by affecting the ambient light climate, reducing photodamage, and increasing the efficiency of photosynthesis. We examined the effects of sediments and vertical mixing in potentially reducing photodamage to Microcystis by measuring photosynthetic parameters and pigment content of *Microcystis* in western Lake Erie during the 2008 bloom and in laboratory experiments. Photosynthetic efficiency increased with increasing sediment concentration in the lake and laboratory experiment. Content of photo-protective carotenoid pigments per dry weight decreased with increasing sediment concentrations, while the light-harvesting pigments, chl a and phycocyanin, increased with sediments. These results indicate that suspended sediments reduce photoinhibition for *Microcystis*. Further, photosynthetic damage was higher when *Microcystis* was concentrated on the surface compared to a mixed water column. Measurements of *Microcystis* abundance and light were also recorded, in addition to photosynthetic measurements. Greatest *Microcystis* abundances in Lake Erie were recorded during light-limiting conditions, which offer *Microcystis* both physiological and ecological benefits by reducing photoinhibition and increasing *Microcystis* ' advantage in light competition via buoyancy. Efforts to reduce cyanobacterial blooms may include reducing suspended sediments loads in combination with reducing nutrient loading.

KEYWORDS

Chlorophyll Fluorescence; Cyanobacteria; Harmful Algae Bloom; Lake Erie; *Microcystis*; Suspended Sediments

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References

[1] . H. Smith, S. B. Joye and R. W. Howarth, "Eutrophication of Freshwater and Marine Ecosystems," Limnology and Oceanography, Vol. 51, No. 1, 2006, pp. 351-355. doi:10.4319/lo.2006.51.1_part_2.0351

[2] J. Huisman, H. C. P. Matthijs and P. M. Visser, "Harmful Cyanobacteria," Kluwer Academic Publisher, Dordrecht, 2005. doi:10.1007/1-4020-3022-3

[3] W. K. Dodds, W. W. Bouska, J. L. Eitzmann, T. J. Pilger, K. L. Pitts, A. J. Riley, J. T. Schloesser and D. J. Thornbrugh, "Eutrophication of US Freshwaters: Analysis of Potential Economic Damages," Environmental Science & Technology, Vol. 43, No. 1, 2008, pp. 12-19. doi:10.1021/es801217q

[4] V. H. Smith, "Eutrophication of Freshwater and Coastal Marine Ecosystems: A Global Problem," Environmental Science and Pollution Research, Vol. 10, No. 2, 2003, pp. 126-139.

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[5] N. P. Holm and D. E. Armstrong, "Role of Nutrient Limitation and Competition in Controlling the Populations of Asterionella formosa and *Microcystis* aeruginosa in Semicontinuous Culture," Limnology and Oceanography, Vol. 26, No. 4, 1981, pp. 622-634. doi:10.4319/lo.1981.26.4.0622

[6] J. A. Downing, S. B. Watson and E. McCauley, "Predicting Cyanobacteria Dominance in Lakes," Canadian Journal of Fisheries and Aquatic Sciences, Vol. 58, No. 10, 2001, pp. 1905-1908. doi:10.1139/f01-143

[7] V. H. Smith, "Low Nitrogen to Phosphorus Ratios Favor Dominance by Blue-Green Algae in Lake Phytoplankton," Science, Vol. 221, No. 4611, 1983, pp. 669-671. doi:10.1126/science.221.4611.669

[8] P. M. Visser, B. W. Ibelings, B. Vanderveer, J. Koedood and L. R. Mur, "Artificial Mixing Prevents Nuisance Blooms of the Cyanobacterium *Microcystis* in Lake Nieuwe Meer," Freshwater Biology, Vol. 36, No. 2, 1996, pp. 435-450. doi:10.1046/j.1365-2427.1996.00093.x

[9] J. Huisman, J. Sharples, J. M. Stroom, P. M. Visser, W. E. A. Kardinaal, J. M. H. Verspagen and B. Sommeijer, "Changes in Turbulent Mixing Shift Competition for Light between Phytoplankton Species," Ecology, Vol. 85, No. 11, 2004, pp. 2960-2970. doi:10.1890/03-0763

[10] K. D. J?hnk, J. Huisman, J. Sharples, B. Sommeijer, P. M. Visser and J. M. Stroom, "Summer Heatwaves Promote Blooms of Harmful Cyanobacteria," Global Change Biology. Vol. 14, No. 3, 2008, pp. 495-512. doi:10.1111/j.1365-2486.2007.01510.x

[11] H. W. Paerl and J. Huisman, "Blooms Like It Hot," Science, Vol. 320, No. 5872, 2008, pp. 57-58. doi:10.1126/science.1155398

[12] H. A. Vanderploeg, J. R. Liebig, W. W. Carmichael, M. A. Agy, T. H. Johengen, G. L. Fahnenstiel and T. F. Nalepa, "Zebra Mussel (Dreissena polymorpha) Selective Filtration Promoted Toxic *Microcystis* Blooms in Saginaw Bay (Lake Huron) and Lake Erie," Canadian Journal of Fisheries and Aquatic Sciences, Vol. 58, No. 6, 2001, pp. 1208-1221. doi:10.1139/f01-066

[13] D. B. Baker and R. P. Richards, "Phosphorus Budgets and Riverine Phosphorus Export in Northwestern Ohio Watersheds," Journal of Environmental Quality, Vol. 31, No. 1, 2002, pp. 96-108. doi:10.2134/jeq2002.0096

[14] R. P. Richards, D. B. Baker, J. P. Crumrine, J. W. Kramer, D. E. Ewing and B. J. Merryfield, "Thirty-Year Trends in Suspended Sediment in Seven Lake Erie Tributaries," Journal of Environmental Quality, Vol. 37, No. 5, 2008, pp. 1894-1908. doi:10.2134/jeq2007.0590

[15] I. Donohue and J. Garcia Molinos, "Impacts of Increased Sediment Loads on the Ecology of Lakes," Biological Reviews, Vol. 84, No. 4, 2009, pp. 517-531. doi:10.1111/j.1469-185X.2009.00081.x

[16] J. T. O. Kirk, "Light and Photosynthesis in Aquatic Eco- systems," 2nd Edition, Cambridge University Press, Canberra, 1994. doi:10.1017/CBO9780511623370

[17] H. L. MacIntyre, T. M. Kana, T. Anning and R. J. Geider, "Photoacclimation of Photosynthesis Irradiance Response Curves and Photosynthetic Pigments in Microalgae and Cyanobacteria," Journal of Phycology, Vol. 38, No. 1, 2002, pp. 17-38. doi:10.1046/j.1529-8817.2002.00094.x

[18] A. E. Alpine and J. E. Cloern, "Phytoplankton Growth Rates in a Light-Limited Environment, San Francisco Bay," Marine Ecology-Progress Series, Vol. 44, No. 2, 1988, pp. 167-173. doi:10.3354/meps044167

[19] P. A. Soranno, "Factors Affecting the Timing of Surface Scum and Epilimnetic Blooms of Blue-Green Algae in a Eutrophic Lake," Canadian Journal of Fisheries and Aquatic Sciences, Vol. 54, No. 9, 1997, pp. 1965-1975. doi:10.1139/cjfas-54-9-1965

[20] B. W. Ibelings and S. C. Maberly, "Photoinhibition and the Availability of Inorganic Carbon Restrict Photosynthesis by Surface Blooms of Cyanobacteria," Limnology and Oceanography, Vol. 43, No. 3, 1998, pp. 408-419. doi:10.4319/lo.1998.43.3.0408

[21] J. Huisman, P. van Oostveen and F. J. Weissing, "Critical Depth and Critical Turbulence: Two Different Mechanisms for the Development of Phytoplankton Blooms," Limnology and Oceanography. Vol. 44, No. 7, 1999, pp. 1781-1787. doi:10.4319/lo.1999.44.7.1781

[22] I. T. Webster and P. A. Hutchinson, "Effect of Wind on the Distribution of Phytoplankton Cells in Lakes Revisited," Limnology and Oceanography, Vol. 39, No. 2, 1994, pp. 365-373. doi:10.4319/lo.1994.39.2.0365

[23] P. M. Visser, B. W. Ibelings, L. R. Mur and A. E. Walsby, "The Ecophysiology of the Harmful Cyanobacterium Microcystis," In: J. Huisman, H. C. P. Matthijs and P. M. Visser, Eds., Harmful Cyanobacteria, Kluwer Academic Publisher, Dordrecht, 2005, pp. 109-142. doi:10.1007/1-4020-3022-3_6

[24] B. W. Ibelings, B. M. A. Kroon and L. R. Mur, "Acclimation of Photosystem II in a Cyanobacterium and a Eukaryotic Green Alga to High and Fluctuating Photosynthetic Photon Flux Densities, Simulating Light Regimes Induced by Mixing in Lakes," New Phytologist, Vol. 128, No. 3, 1994, pp. 407-424. doi:10.1111/j.1469-8137.1994.tb02987.x

[25] J. D. Brookes, R. H. Regel and G. G. Ganf, "Changes in the Photo-Chemistry of *Microcystis* aeruginosa in Response to Light and Mixing," New Phytologist, Vol. 158, No. 1, 2003, pp. 151-164. doi:10.1046/j.1469-8137.2003.00718.x

[26] T. H. Johengen, B. A. Biddanda and J. B. Cotner, "Stimulation of Lake Michigan Plankton Metabolism by Sediment Resuspension and River Runoff," Journal of Great Lakes Research, Vol. 34, No. 2, 2008, pp. 213-227. doi:10.3394/0380-1330(2008)34[213:SOLMPM]2.0.CO;2

[27] J. D. Chaffin, T. B. Bridgeman, S. A. Heckathorn and S. Mishra, "Assessment of *Microcystis* Growth Rate Potential and Nutrient Status Across a Trophic Gradient in Western Lake Erie," Journal of Great Lakes Research, Vol. 37, No. 1, 2011, pp. 92-100. doi:10.1016/j.jglr.2010.11.016

[28] B. Binding, G. Greenberg and B. Bukata, "An Analysis of MODIS-Derived Algal and Mineral Turbidity in Lake Erie," Journal of Great Lakes Research, Vol. 38, No. 1, 2012, pp. 107-116. doi:10.1016/j.jglr.2011.12.003

[29] H. Han, N. Bosch and J. D. Allan, "Spatial and Temporal Variation in Phosphorus Budgets for 24 Watersheds in the Lake Erie and Lake Michigan Basins," Biogeochemistry, Vol. 102, No. 1-3, 2011, pp. 45-58. doi:10.1007/s10533-010-9420-y

[30] F. Peng and S. W. Effler, "Characterizations of Individual Suspended Mineral Particles in Western Lake Erie: Implications for Light Scattering and Water Clarity," Journal of Great Lakes Research, Vol. 36, No. 4, 2010, pp. 686-698. doi:10.1016/j.jglr.2010.08.003

[31] J. D. Ackerman, M. R. Loewen and P. F. Hamblin, "Benthic-Pelagic Coupling Over a Zebra Mussel Reef in Western Lake Erie," Limnology and Oceanography, Vol. 46, No. 4, 2001, pp. 892-904. doi:10.4319/lo.2001.46.4.0892

[32] L. Boegman, M. R. Loewen, P. F. Hamblin and D. A. Culver, "Vertical Mixing and Weak Stratification over Zebra Mussel Colonies in Western Lake Erie," Limnology and Oceanography, Vol. 53, No. 3, 2008, pp. 1093-1110. doi:10.4319/lo.2008.53.3.1093

[33] T. B. Bridgeman, D. W. Schloesser and A. E. Krause, "Recruitment of Hexagenia Mayfly Nymphs in Western Lake Erie Linked to Environmental Variability," Ecological Applications, Vol. 16, No. 2, 2006, pp. 601-611. doi:10.1890/1051-0761(2006)016[0601:ROHMNI]2.0.CO;2

[34] D. Moorhead, T. Bridgeman and J. Morris, "Changes in Water Quality of Maumee Bay 1928-2003," In: M. Munawar and R. Heath, Eds., Checking the Pulse of Lake Erie, Goodword Books, Baltimore, 2008, pp.123-158.

[35] D. F. Millie, G. L. Fahnenstiel, J. Dyble Bressie, R. J. Pigg, R. R. Rediske, D. M. Klarer, P. A. Tester and R. W. Litaker, "Late-Summer Phytoplankton in Western Lake Erie (Laurentian Great Lakes): Bloom Distributions, Toxicity, and Environmental Influences," Aquatic Ecology, Vol. 43, No. 4, 2009, pp. 915-934. doi:10.1007/s10452-009-9238-7

[36] K. Maxwell and G. N. Johnson, "Chlorophyll Fluorescence—A Practical Guide," Journal of Experimental Botany, Vol. 51, No. 345, 2000, pp. 659-668. doi:10.1093/jexbot/51.345.659

[37] G. H. Krause, "Photoinhibition of Photosynthesis. An Evaluation of Damaging and Protective Mechanisms," Physiologia Plantarum, Vol. 74, No. 566-574, 1988, pp. 566-574. doi:10.1111/j.1399-3054.1988.tb02020.x

[38] B. Genty, J. M. Briantais and N. R. Baker, "The Relationship Between the Quantum Yield of Photosynthetic Electron Transport and Quenching of Chlorophyll Fluorescence," Biochimica et Biophysica Acta, Vol. 990, No. 1, 1989, pp. 87-92. doi:10.1016/S0304-4165(89)80016-9

[39] C. A. Marwood, R. E. H. Smith, J. A. Furgal, M. N. Charlton, K. R. Solomon and B. M. Greenberg, "Photoinhibition of Natural Phytoplankton Assemblages in Lake Erie Exposed to Solar Ultraviolet Radiation," Canadian Journal of Fisheries and Aquatic Sciences, Vol. 57, No. 2, 2000, pp. 371-379.

doi:10.1139/f99-258

[40] D. Campbell, V. Hurry, A. K. Clarke, P. Gustafsson and G. Oquist, "Chlorophyll Fluorescence Analysis of Cyano-bacterial Photosynthesis and Acclimation," Microbiology and Molecular Biology Reviews, Vol. 62, No. 3, 1998, pp. 667-683.

[41] S. A. Heckathorn, S. L. Ryan, J. A. Baylis, D. Wang, E. W. Hamilton, L. Cundiff and D. S. Luthe, "In Vivo Evidence From an Agrostis stolonifera Selection Genotype That Chloroplast Small Heat-Shock Proteins can Protect Photo-system II During Heat Stress," Functional Plant Biology, Vol. 29, No. 8, 2002, pp. 933-944. doi:10.1071/PP01191

[42] U. Schreiber, W. Bilger and C. Neubauer, "Chlorophyll Fluorescence as a Nonintrusive Indicator for Rapid Assessment of in Vivo Photosynthesis," In: E. Schulze and M. M. Caldwell, Eds., Ecophysiology of Photosynthesis, Springer-Verlag, Berlin, 1994, pp. 49-70.

[43] M. Zhang, X. Shi, Y. Yu and F. Kong, "The Acclimative Changes in Photochemistry After Colony Formation of the Cyanobacteria *Microcystis* aeruginosa," Journal of Phycology, Vol. 47, No. 3, 2011, pp. 524-532. doi:10.1111/j.1529-8817.2011.00987.x

[44] A. R. Wellburn, "The Spectral Determination of Chlorophyll a and Chlorophyll b, as well as Total Carotenoids, Using Various Solvents with Spectrophotometers of Different Resolution," Journal of Plant Physiology, Vol. 144, No. 3, 1994, pp. 307-313. doi:10.1016/S0176-1617(11)81192-2

[45] P. Sampath-Wiley and C. D. Neefus, "An Improved Method for Estimating R-Phycoerythrin and R-Phycocyanin Contents from Crude Aqueous Extracts of Porphyra (Bangiales, Rhodophyta)," Journal of Applied Phycology, Vol. 19, No. 2, 2007, pp. 123-129. doi:10.1007/s10811-006-9118-7

[46] R. R. L. Guillard and C. J. Lorenzen, "Yellow-Green Algae with Chlorophyllide c," Journal of Phycology, Vol. 8, No. 1, 1972, pp. 10-14. doi:10.1111/j.1529-8817.1972.tb03995.x

[47] M. H. Kutner, C. J. Nachtsheim, J. Neter and W. Li, "Applied Linear Statistical Model," 5th Edition, McGraw-Hill/ Irwin, New York, 2004.

[48] M. S?ndergaard, P. Kristensen and E. Jeppesen, "Phosphorus Release from Resuspended Sediment in the Shallow and Wind-Exposed Lake Arreso, Denmark," Hydrobiologia, Vol. 228, No. 1, 1992, pp. 91-99. doi:10.1007/BF00006480

[49] C. S. Reynolds, S. W. Wiseman and M. J. O. Clarke, "Growth-and Loss-Rate Responses of Phytolankton to Intermittent Artificial Mixing and their Potential Application to the Control of Planktonic Algal Biomass," Journal of Applied Ecology, Vol. 21, No. 1, 1984, pp. 11-39. doi:10.2307/2403035

[50] J. K?hler, "Influence of Turbulent Mixing on Growth and Primary Production of *Microcystis* aeruginosa in the Hypertrophic Bautzen Reservoir," Archiv Für Hydrobiologie, Vol. 123, No. 4, 1992, pp. 413-429.

[51] M. Schagerl and B. Müller, "Acclimation of Chlorophyll a and Carotenoid Levels to Different Irradiances in Four Freshwater Cyanobacteria," Journal of Plant Physiology, Vol. 163, No. 7, 2006, pp. 709-716. doi:10.1016/j.jplph.2005.09.015

[52] Z. Dubinsky and N. Stambler, "Photoacclimation Processes in Phytoplankton: Mechanisms, Consequences, and Applications," Aquatic Microbial Ecology, Vol. 56, No. 2-3, 2009, pp. 163-176. doi:10.3354/ame01345

[53] K. Izydorczyk, M. Tarczynska, T. Jurczak, J. Mrowczynski and M. Zalewski, "Measurement of Phycocyanin Fluorescenceas an Online Early Warning System for Cyanobacteria in Reservoir Intake Water," Environmental Toxicology, Vol. 20, No. 4, 2005, pp. 425-430. doi:10.1002/tox.20128

[54] N. McQuaid, A. Zamyadi, M. Prévost, D. F. Bird and S. Dorner, "Use of in Vivo Phycocyanin Fluorescence to Monitor Potential Microcystin-Producing Cyanobacterial Biovolume in a Drinking Water Source," Journal of Environmental Monitoring, Vol. 13, No. 2, 2010, pp. 455-463. doi:10.1039/c0em00163e

[55] H. W. Paerl, J. Tucker and P. T. Bland, "Carotenoid Enhancement and its Role in Maintaining Blue-Green Algal (*Microcystis* Aeruginosa) Surface Blooms," Limnology and Oceanography, Vol. 28, No. 5, 1983, pp. 847-857. doi:10.4319/lo.1983.28.5.0847

[56] R. J. Geider, H. L. MacIntyre and T. M. Kana, "A Dynamic Regulatory Model of Phytoplanktonic Acclimation to Light, Nutrients, and Temperature," Limnology and Oceanography, Vol. 43, No. 4,

1998, pp. 679-694. doi:10.4319/lo.1998.43.4.0679