



UvA-DARE (Digital Academic Repository)

Colourful coexistence : a new solution to the plankton paradox

Stomp, M.

Publication date
2008

[Link to publication](#)

Citation for published version (APA):

Stomp, M. (2008). *Colourful coexistence : a new solution to the plankton paradox*. [Thesis, fully internal, Universiteit van Amsterdam].

General rights

It is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), other than for strictly personal, individual use, unless the work is under an open content license (like Creative Commons).

Disclaimer/Complaints regulations

If you believe that digital publication of certain material infringes any of your rights or (privacy) interests, please let the Library know, stating your reasons. In case of a legitimate complaint, the Library will make the material inaccessible and/or remove it from the website. Please Ask the Library: <https://uba.uva.nl/en/contact>, or a letter to: Library of the University of Amsterdam, Secretariat, Singel 425, 1012 WP Amsterdam, The Netherlands. You will be contacted as soon as possible.

References

- Abrams PA (1999) The adaptive dynamics of consumer choice. *American Naturalist* **153**: 83-97.
- Abrams PA (2006a) The prerequisites for and likelihood of generalist-specialist coexistence. *American Naturalist* **167**: 329-342.
- Abrams PA (2006b) Adaptive change in the resource-exploitation traits of a generalist consumer: the evolution and coexistence of generalists and specialists. *Evolution* **60**: 427-439.
- Acinas SG, Klepac-Ceraj V, Hunt DE, Pharino C, Ceraj I, Distel DL, Polz MF (2004) Fine-scale phylogenetic architecture of a complex bacterial community. *Nature* **430**: 551-554.
- Acinas SG, Haverkamp THA, Huisman J, Stal LJ (2008) Phenotypic and genetic diversification of *Pseudanabaena* spp. (Cyanobacteria). *ISME Journal* (in press).
- Agawin NSR, Rabouille S, Veldhuis MJW, Servatius L, Hol S, van Overzee HMJ, Huisman J (2007) Competition and facilitation between unicellular nitrogen-fixing cyanobacteria and non-nitrogen-fixing phytoplankton species. *Limnology and Oceanography* **52**: 2233-2248.
- Agrawal AA (2001) Phenotypic plasticity in the interactions and evolution of species. *Science* **294**: 321-326.
- Albertano P, DiSomma D, Capucci E (1997) Cyanobacterial picoplankton from the Central Baltic Sea: cell size classification by image-analyzed fluorescence microscopy. *Journal of Plankton Research* **19**: 1405-1416.
- Altschul SF, Gish W, Miller W, Myers EW, Lipman DJ (1990) Basic Local Alignment Search Tool. *Journal of Molecular Biology* **215**: 403-410.
- Armstrong RA, McGehee R (1980) Competitive exclusion. *American Naturalist* **115**: 151-170.
- Atamna-Ismaeel N, Sabehi G, Sharon I, Witzel KP, Labrenz M, Jürgens K, Barkay T, Stomp M, Huisman J, Béjà O (2008) Widespread distribution of proteorhodopsins in freshwater and brackish ecosystems. *ISME Journal* **2**: 656-662.
- Balogh KV, Koncz E, Vörös L (2000) An empirical model describing the contribution of colour, algae and particles to the light climate of shallow lakes. *Verhandlungen International Vereinigung Limnologie* **27**: 2678-2681.
- Banerjee T, Ghosh TC (2006) Gene expression level shapes the amino acid usages in *Prochlorococcus marinus* MED4. *Journal of Biomolecular Structure & Dynamics* **23**: 547-553.
- Béjà O, Aravind L, Koonin EV, Suzuki MT, Hadd A, Nguyen LP, Jovanovich S, Gates CM, Feldman RA, Spudich JL, Spudich EN and DeLong EF (2000) Bacterial rhodopsin: evidence for a new type of phototrophy in the sea. *Science* **289**: 1902-1906.
- Béjà O, Spudich EN, Spudich JL, Leclerc M, DeLong EF (2001) Proteorhodopsin phototrophy in the ocean. *Nature* **411**: 786-789.
- Béjà O, Suzuki MT, Heidelberg JF, Nelson WC, Preston CM, Hamada T, Eisen JA, Fraser CM, DeLong EF (2002) Unsuspected diversity among marine aerobic anoxygenic phototrophs. *Nature* **415**: 630-633.
- Boomer SM, Pierson BK, Austinhirst R, Castenholz RW (2000) Characterization of novel bacteriochlorophyll-*a*-containing red filaments from alkaline hot springs in Yellowstone National Park. *Archives of Microbiology* **174**: 152-161.
- Bouman HA, Ulloa O, Scanlan DJ, Zwirgmaier K, Li WKW, Platt T, Stuart V, Barlow R, Leth O, Clementson L, Lutz V, Fukasawa M, Watanabe S, Sathyendranath S (2006) Oceanographic basis of the global surface distribution of *Prochlorococcus* ecotypes. *Science* **312**: 918-921.
- Braun CH, Smirnov SN (1993) Why is water blue? *Journal of Chemical Education* **70**: 612-614.

References

- Bricaud A, Morel A, Prieur L (1981) Absorption by dissolved organic matter of the sea (yellow substance) in the UV and visible domains. *Limnology and Oceanography* **26**: 43-53.
- Bricaud A, Morel A, Prieur L (1983) Optical efficiency factors of some phytoplankters. *Limnology and Oceanography* **28**: 816-832.
- Callieri C, Amicucci E, Bertoni R, Vörös L (1996) Fluorometric characterization of two picocyanobacteria strains from lakes of different underwater light quality. *Internationale Revue der gesamten Hydrobiologie* **81**: 13-23.
- Campbell L, Carpenter EJ (1987) Characterization of phycoerythrin-containing *Synechococcus* spp. populations by immunofluorescence. *Journal of Plankton Research* **9**: 1167-1181.
- Campbell L, Vaultot D (1993) Photosynthetic picoplankton community structure in the subtropical North Pacific Ocean near Hawaii (station Aloha). *Deep-Sea Research Part I* **40**: 2043-2060.
- Carbone A, Kepes F, Zinovyev A (2005) Codon bias signatures, organization of microorganisms in codon space, and lifestyle. *Molecular Biology and Evolution* **22**: 547-561.
- Caumette P, Guyoneaud R, Imhoff JF, Süling J, Gorenko V (2004) *Thiocapsa marina* sp. nov., a novel, okenone-containing, purple sulfur bacterium isolated from brackish coastal and marine environments. *International Journal of Systematic and Evolutionary Microbiology* **54**: 1031-1036.
- Chao A, Lee SM (1992) Estimating the number of classes via sample coverage. *Journal of the American Statistical Association* **87**: 210-217.
- Chen F, Wang K, Kan JJ, Suzuki MT, Wommack KE (2006) Diverse and unique picocyanobacteria in Chesapeake Bay, revealed by 16S-23S rRNA internal transcribed spacer sequences. *Applied and Environmental Microbiology* **72**: 2239-2243.
- Chesson P, Gebauer RLE, Schwinning S, Huntly N, Wiegand K, Ernest MSK, Sher A, Novoplansky A, Weltzin JF (2004) Resource pulses, species interactions, and diversity maintenance in arid and semi-arid environments. *Oecologia* **141**: 236-253.
- Chisholm SW, Olson RJ, Zettler ER, Goericke R, Waterbury JB, Welschmeyer NA (1988) A novel free-living prochlorophyte abundant in the oceanic euphotic zone. *Nature* **334**: 340-343.
- Cleveland JS, Weidemann AD (1993) Quantifying absorption by aquatic particles: a multiple scattering correction for glass-fiber filters. *Limnology and Oceanography* **38**: 1321-1327.
- Cole JR, Chai B, Farris RJ, Wang Q, Kulam SA, McGarrell DM, Garrity GM, Tiedje JM (2005) The Ribosomal Database Project (RDP-II): sequences and tools for high-throughput rRNA analysis. *Nucleic Acids Research* **33**: D294-D296.
- Collins JR (1925) Change in the infra-red absorption spectrum of water with temperature. *Physical Review* **26**: 771-779.
- Comeron JM, Aguade M (1998) An evaluation of measures of synonymous codon usage bias. *Journal of Molecular Evolution* **47**: 268-274.
- Connell JH (1978) Diversity in tropical rain forests and coral reefs. *Science* **199**: 1302-1310.
- Cordi B, Depledge MH, Price DN, Salter LF, Donkin ME (1997) Evaluation of chlorophyll fluorescence, in vivo spectrophotometric pigment absorption and ion leakage as biomarkers of UV-B exposure in marine macroalgae. *Marine Biology* **130**: 41-49.
- Crosbie ND, Pöckl M, Weisse T (2003) Dispersal and phylogenetic diversity of nonmarine picocyanobacteria, inferred from 16S rRNA gene and *cpbA*-intergenic spacer sequence analyses. *Applied and Environmental Microbiology* **69**: 5716-5721.
- Darwin C (1859) *On the Origin of Species by Means of Natural Selection*. John Murray, London, UK.
- Delorimier R, Wilbanks SM, Glazer AN (1993) Genes of the R-phycoyanin-II locus of marine *Synechococcus*-spp. and comparison of protein-chromophore interactions in phycocyanins differing in bilin composition. *Plant Molecular Biology* **21**: 225-237.

- Denman KL, Gargett AE (1983) Time and space scales of vertical mixing and advection of phytoplankton in the upper ocean. *Limnology and Oceanography* **28**: 801-815.
- Des Marais DJ (2000) Evolution - When did photosynthesis emerge on earth? *Science* **289**: 1703-1705.
- Dokulil MT, Teubner K (2000) Cyanobacterial dominance in lakes. *Hydrobiologia* **438**: 1-12.
- Dolganov N, Grossman AR (1999) A polypeptide with similarity to phycocyanin alpha-subunit phycocyanobilin lyase involved in degradation of phycobilisomes. *Journal of Bacteriology* **181**: 610-617.
- Dring MJ (1981) Chromatic adaptation of photosynthesis in benthic marine algae: an examination of its ecological significance using a theoretical model. *Limnology and Oceanography* **26**: 271-284.
- Egas M, Dieckmann U, Sabelis MW (2004) Evolution restricts the coexistence of specialists and generalists: The role of trade-off structure. *American Naturalist* **163**: 518-531.
- Egas M, Sabelis MW, Dieckmann U (2005) Evolution of specialization and ecological character displacement of herbivores along a gradient of plant quality. *Evolution* **59**: 507-520.
- Elliott JA, Jones ID, Thackeray SJ (2006) Testing the sensitivity of phytoplankton communities to changes in water temperature and nutrient load, in a temperate lake. *Hydrobiologia* **559**: 401-411.
- Engelmann TW (1882) Über Sauerstoffausscheidung von Pflanzenzellen im Mikrospectrum. *Botanische Zeitschrift* **40**: 419-426.
- Engelmann TW (1883) *Bacterium photometricum*: ein Beitrag zur vergleichenden Physiologie des Licht- und Farbensinnes. *Archiv Gesamte Physiologie Bonn.* **30**: 95-124.
- Engelmann TW (1883) Farbe und Assimilation. *Botanische Zeitschrift* **41**: 1-13.
- Ernst A, Becker S, Wollenzien UIA, Postius C (2003) Ecosystem-dependent adaptive radiations of picocyanobacteria inferred from 16S rRNA and ITS-1 sequence analysis. *Microbiology* **149**: 217-228.
- Everroad C, Six C, Partensky F, Thomas JC, Holtzendorff J, Wood AM (2006) Biochemical bases of type IV chromatic adaptation in marine *Synechococcus* spp. *Journal of Bacteriology* **188**: 3345-3356.
- Everroad RC, Wood AM (2006) Comparative molecular evolution of newly discovered picocyanobacterial strains reveals a phylogenetically informative variable region of beta-phycoerythrin. *Journal of Phycology* **42**: 1300-1311.
- Falkowski PG, Raven JA (1997) *Aquatic Photosynthesis*, 2nd Ed, Blackwell Science, London, UK.
- Falkowski PG, Katz ME, Knoll AH, Quigg A, Raven JA, Schofield O, Taylor FJR (2004) The evolution of modern eukaryotic phytoplankton. *Science* **305**: 354-360.
- Felsenstein J (1989) PHYLIP - Phylogeny Inference Package (Version 3.2). *Cladistics* **5**: 164-166.
- Flöder S, Urabe J, Kawabata Z (2002) The influence of fluctuating light intensities on species composition and diversity of natural phytoplankton communities. *Oecologia* **133**: 395-401.
- Foerstner KU, von Mering C, Hooper SD, Bork P (2005) Environments shape the nucleotide composition of genomes. *EMBO Reports* **6**: 1208-1213.
- Freeman C, Evans CD, Monteith DT, Reynolds B, Fenner T (2001) Export of organic carbon from peat soils. *Nature* **412**: 785.
- Fuller NJ, Marie D, Partensky F, Vault D, Post AF, Scanlan DJ (2003) Clade-specific 16S ribosomal DNA oligonucleotides reveal the predominance of a single marine *Synechococcus* clade throughout a stratified water column in the Red Sea. *Applied and Environmental Microbiology* **69**: 2430-2443.

References

- Gabriel W (2005) How stress selects for reversible phenotypic plasticity. *Journal of Evolutionary Biology* **18**: 873-883.
- Gabriel W (2006) Selective advantage of irreversible and reversible phenotypic plasticity. *Archiv für Hydrobiologie* **167**: 1-20.
- Gaedeke A, Sommer U (1986) The influence of the frequency of periodic disturbances on the maintenance of phytoplankton diversity. *Oecologia* **71**: 25-28.
- Gaiducov N (1902) Über den Einfluss farbigen Lichtes auf die Färbung lebender Oscillarien. *Abhandlungen der Königlich-Preussischen Akademie der Wissenschaften* **5**: 1-36.
- Gause GF (1934) *The Struggle for Existence*. Williams and Wilkins, Baltimore, MD.
- Gelinas M, Pinel-Alloul B, Slusarczyk M (2007) Alternative antipredator responses of two coexisting *Daphnia* species to negative size selection by YOY perch. *Journal of Plankton Research* **29**: 775-789.
- Glaeser J, Overmann J (1999) Selective enrichment and characterization of *Roseospirillum parvum*, gen. nov. and sp. nov., a new purple nonsulfur bacterium with unusual light absorption properties. *Archives of microbiology* **171**: 405-416.
- Glover HE, Keller MD, Spinrad RW (1987) The effects of light quality and intensity on photosynthesis and growth of marine eukaryotic and prokaryotic phytoplankton clones. *Journal of Experimental Marine Biology and Ecology* **105**: 137-159.
- Gómez-Consarnau L, González JM, Coll-Lladó M, Gourdon P, Pascher T, Neutze R *et al.* (2007) Light stimulates growth of proteorhodopsin-containing marine Flavobacteria. *Nature* **445**: 210-213.
- Goo YA, Roach J, Glusman G, Baliga NS, Deutsch K, Pan M, Kennedy S, DasSarma S, Ng WV, Hood L (2004) Low-pass sequencing for microbial comparative genomics. *BMC Genomics* **5**: 3.
- Good IJ (1953) The population frequencies of species and the estimation of population parameters. *Biometrika* **40**: 237-264.
- Granéli E, Wallström K, Larsson U, Granéli W, Elmgren R (1990) Nutrient limitation of primary production in the Baltic Sea area. *AMBIO* **19**: 142-151.
- Granéli W (2008) The brownification of Swedish lakes: caused by increased precipitation, decreased sulfur deposition or changed land use? Abstract, Ocean Sciences Meeting 2008, Orlando, Florida.
- Grant PR, Grant BR (2002) Adaptive radiation of Darwin's finches. *American Scientist* **90**: 130-139.
- Grasshoff K, Ehrhardt M, Kremling K (1983) *Methods of Sea Water Analysis*, 2nd Ed, Verlag Chemie, Weinheim, Germany.
- Grossman AR, Schaeffer MR, Chiang GG, Collier JL (1993) The phycobilisome, a light-harvesting complex responsive to environmental conditions. *Microbiological Reviews* **57**: 725-749.
- Grover JP (1988) Dynamics of competition in a variable environment: experiments with two diatom species. *Ecology* **69**: 408-417.
- Grover JP (1990) Resource competition in a variable environment: phytoplankton growing according to Monod's model. *American Naturalist* **136**: 771-789.
- Grover JP (1991) Dynamics of competition among microalgae in variable environments: experimental tests of alternative models. *Oikos* **62**: 231-243.
- Grover JP (1997) *Resource Competition*. Chapman and Hall, London.
- Hale GM, Querry MR (1973) Optical constants of water in the 200-nm to 200- μ m wavelength region. *Applied Optics* **12**: 555-663.

- Hall TA (1999) BioEdit: a user-friendly biological sequence alignment editor and analysis program for Windows 95/98/NT. *Nucleic Acids Symposium Series* **41**: 95-98.
- Hauschild CA, McMurter HJG, Pick FR (1991) Effect of spectral quality on growth and pigmentation of picocyanobacteria. *Journal of Phycology* **27**: 698-702.
- Haverkamp T, Acinas SG, Doeleman M, Stomp M, Huisman J, Stal LJ (2008) Diversity and phylogeny of Baltic Sea picocyanobacteria inferred from their ITS and phycobiliprotein operons. *Environmental Microbiology* **10**: 174-188.
- Herdman M, Castenholz RW, Iteman I, Waterbury JB, Rippka R. (2001) Subsection I: Order "Chroococcales" Wettstein 1924, emend. Rippka, Deruelles, Waterbury, Herdman and Stanier 1979. *Bergey's Manual of Systematic Bacteriology* **1**: 493-514.
- Hessen DO, Van Donk E (1993) Morphological changes in *Scenedesmus* induced by substances released from *Daphnia*. *Archiv für Hydrobiologie* **127**: 129-140.
- Holdsworth ES (1985) Effects of growth factors and light quality on the growth, pigmentation and photosynthesis of two diatoms, *Tbalassiosira gravida* and *Phaeodactylum tricoratum*. *Marine Biology* **86**: 253-262.
- Huisman J, Weissing FJ (1994) Light-limited growth and competition for light in well-mixed aquatic environments: an elementary model. *Ecology* **75**: 507-520.
- Huisman J, Weissing FJ (1995) Competition for nutrients and light in a mixed water column: a theoretical analysis. *American Naturalist* **146**: 536-564.
- Huisman J, Jonker RR, Zonneveld C, Weissing FJ (1999a) Competition for light between phytoplankton species: experimental tests of mechanistic theory. *Ecology* **80**: 211-222.
- Huisman J, van Oostveen P, Weissing FJ (1999b) Critical depth and critical turbulence: two different mechanisms for the development of phytoplankton blooms. *Limnology and Oceanography* **44**: 1781-1787.
- Huisman J, Weissing FJ (1999c) Biodiversity of plankton by species oscillations and chaos. *Nature* **402**: 407-410.
- Huisman J, Sharples J, Stroom JM, Visser PM, Kardinaal WEA, Verspagen JMH, Sommeijer B (2004) Changes in turbulent mixing shift competition for light between phytoplankton species. *Ecology* **85**: 2960-2970.
- Huisman J, Pham Thi NN, Karl DM, Sommeijer B (2006) Reduced mixing generates oscillations and chaos in the oceanic deep chlorophyll maximum. *Nature* **439**: 322-325.
- Hutchinson GE (1961) The paradox of the plankton. *American Naturalist* **95**: 137-145.
- Hutchinson GE (1978) *An Introduction to Population Ecology*. Yale University Press, New Haven.
- Irigoiien X, Huisman J, Harris RP (2004) Global biodiversity patterns of marine phytoplankton and zooplankton. *Nature* **429**: 863-867.
- Iteman I, Rippka R, Tandeau de Marsac N, Herdman M (2000) Comparison of conserved structural and regulatory domains within divergent 16S rRNA-23S rRNA spacer sequences of cyanobacteria. *Microbiology* **146**: 1275-1286.
- Jöhnk KD, Huisman J, Sharples J, Sommeijer B, Visser PM, Stroom JM (2008) Summer heatwaves promote blooms of harmful cyanobacteria. *Global Change Biology* **14**: 495-512.
- Johnson ZI, Zinser ER, Coe A, McNulty NP, Woodward EMS, Chisholm SW (2006) Niche partitioning among *Prochlorococcus* ecotypes along ocean-scale environmental gradients. *Science* **311**: 1737-1740.
- Jonker RR, Meulemans JT, Dubelaar GBJ, Wilkins MF, Ringelberg J (1995) Flow cytometry: a powerful tool in analysis of biomass distributions in phytoplankton. *Water Science and Technology* **32**: 177-182.

References

- Katano T, Nakano S, Ueno H, Mitamura O, Anbutsu K, Kihira M, Satoh Y, Drucker V, Sugiyama M (2005) Abundance, growth and grazing loss rates of picophytoplankton in Barguzin Bay, Lake Baikal. *Aquatic Ecology* **39**: 431-438.
- Katano T, Kaneda A, Kanzaki N, Obayashi Y, Morimoto A, Onitsuka G, Yasuda H, Mizutani S, Kon Y, Hata K, Takeoka H, Nakan S (2007) Distribution of prokaryotic picophytoplankton from Seto Inland Sea to the Kuroshio region, with special reference to 'Kyucho' events. *Aquatic Microbial Ecology* **46**: 191-201.
- Kehoe DM, Gutu A (2006) Responding to colour: the regulation of complementary chromatic adaptation. *Annual Review of Plant Biology* **57**: 127-150.
- Kiang NY, Siefert J, Govindjee, Blankenship RE (2007) Spectral signatures of photosynthesis. I. Review of Earth organisms. *Astrobiology* **7**: 222-251.
- Kirk JTO (1994) *Light and Photosynthesis in Aquatic Ecosystems*, 2nd Ed, Cambridge University Press, Cambridge, UK.
- Klausmeier CA, Litchman E (2001) Algal games: the vertical distribution of phytoplankton in poorly mixed water columns. *Limnology and Oceanography* **46**: 1998-2007.
- Kolber ZS, VanDover CL, Niederman RA, Falkowski PG (2000) Bacterial photosynthesis in surface waters of the open ocean. *Nature* **407**: 177-179.
- Kolber ZS, Plumley FG, Lang AS, Beatty JT, Blankenship RE, VanDover CL, Vetriani C, Koblizek M, Rathgeber C, Falkowski PG (2001) Contribution of aerobic photoheterotrophic bacteria to the carbon cycle in the ocean. *Science* **292**: 2492-2495.
- Kühl M, Jørgensen BB (1994) The light field of microbenthic communities: radiance distribution and microscale optics of sandy coastal sediments. *Limnology and Oceanography* **39**: 1368-1398.
- Kühl M, Chen M, Ralph PJ, Schreiber U, Larkum AWD (2005) A niche for cyanobacteria containing chlorophyll *d*. *Nature* **433**: 820.
- Kumar S, Tamura K, Nei M (2004) MEGA3: Integrated software for molecular evolutionary genetics analysis and sequence alignment. *Briefings in Bioinformatics* **5**: 150-163.
- Lack D (1974) *Darwin's Finches*. Cambridge University Press, Cambridge, UK.
- Laforsch C, Tollrian R (2004) Inducible defenses in multipredator environments: cyclomorphosis in *Daphnia cucullata*. *Ecology* **85**: 2302-2311.
- Laloui W, Palinska KA, Rippka R, Partensky F, Tandeau de Marsac N, Herdman M, Itean I (2002) Genotyping of axenic and non-axenic isolates of the genus *Prochlorococcus* and the OMF-'*Synechococcus*' clade by size, sequence analysis or RFLP of the Internal Transcribed Spacer of the ribosomal operon. *Microbiology* **148**: 453-465.
- Lampert W, Rothhaupt KO, von Elert E (1994) Chemical induction of colony formation in a green alga (*Scenedesmus acutus*) by grazers (*Daphnia*). *Limnology and Oceanography* **39**: 1543-1550.
- Lavallée BF, Pick FR (2002) Picocyanobacteria abundance in relation to growth and loss rates in oligotrophic to mesotrophic lakes. *Aquatic Microbial Ecology* **27**: 37-46.
- Lenski RE, Rose MR, Simpson SC, Tadler SC. 1991. Long-term experimental evolution in *Escherichia coli*. I. Adaptation and divergence during 2,000 generations. *American Naturalist* **138**: 1315-1341.
- Lenski RE, Travisano M (1994) Dynamics of adaptation and diversification: A 10000-generation experiment with bacterial populations. *Proceedings of the National Academy of Sciences USA* **91**: 6808-6814.
- Letelier RM, Bidigare RR, Hebel DV, Ondrusek M, Winn CD, Karl DM (1993) Temporal variability of phytoplankton community structure based on pigment analysis. *Limnology and Oceanography* **38**: 1420-1437.

- Lewis MR, Warnock RE, Platt T (1985) Absorption and photosynthetic action spectra for natural phytoplankton populations: implications for production in the open ocean. *Limnology and Oceanography* **30**: 794-806.
- Li WKW, Subba Rao DV, Harrison WG, Smith JC, Cullen JJ, Irwin B, Platt T (1983) Autotrophic picoplankton in the tropical ocean. *Science* **219**: 292-295.
- Litchman E (1998) Population and community responses of phytoplankton to fluctuating light. *Oecologia* **117**: 247-257.
- Litchman E, Klausmeier CA (2001) Competition of phytoplankton under fluctuating light. *American Naturalist* **157**: 170-187.
- Litchman E (2003) Competition and coexistence of phytoplankton under fluctuating light: experiments with two cyanobacteria. *Aquatic Microbial Ecology* **31**: 241-248.
- Lopez-Lopez A, Bartual SG, Stal LJ, Onyshchenko O, Rodriguez-Valera F (2005) Genetic analysis of housekeeping genes reveals a deep-sea ecotype of *Alteromonas macleodii* in the Mediterranean Sea. *Environmental Microbiology* **7**: 649-659.
- MacArthur R, Levins R (1967) The limiting similarity, convergence, and divergence of coexisting species. *American Naturalist* **101**: 377-385.
- Magurran AE (1988) Ecological diversity and its measurement. *Princeton University Press, Princeton, N.J.*
- Man D, Wang W, Sabehi G, Aravind L, Post AF, Massana R *et al.* (2003) Diversification and spectral tuning in marine proteorhodopsins. *EMBO Journal* **22**: 1725-1731.
- Markowitz VM, Korzeniewski F, Palaniappan K, Szeto E, Werner G, Padki A, Zhao XL, Dubchak I, Hugenholtz P, Anderson I, Lykidis A, Mavromatis K, Ivanova N, Kyrpides NC (2006) The integrated microbial genomes (IMG) system. *Nucleic Acids Research* **34**: D344-D348.
- Massana R, Murray AE, Preston CM, DeLong EF (1997) Vertical distribution and phylogenetic characterization of marine planktonic Archaea in the Santa Barbara Channel. *Applied and Environmental Microbiology* **63**: 50-56.
- May RM, MacArthur RH (1972) Niche overlap as a function of environmental variability. *Proceedings of the National Academy of Sciences USA* **69**: 1109-1113.
- McGinnis S, Madden TL (2004) BLAST: at the core of a powerful and diverse set of sequence analysis tools. *Nucleic Acids Research* **32**: W20-W25.
- Metz JAJ, Nisbet RM, Geritz SAH (1992) How should we define fitness for general ecological scenarios? *Trends in Ecology & Evolution* **7**: 198-202.
- Miner BG, Sultan SE, Morgan SG, Padilla DK, Relyea RA (2005) Ecological consequences of phenotypic plasticity. *Trends in Ecology & Evolution* **20**: 685-692.
- Monteith DT, Stoddard JL, Evans CD, de Wit H, Forsius M, Høgåsen T, Wilander A, Skjelkvåle BL, Jeffries, Vuorenmaa J, Keller B, Kopáček J, Vesely J (2007) Dissolved organic carbon trends resulting from changes in atmospheric deposition chemistry. *Nature* **450**: 537-540.
- Montesinos E, Guerrero R, Abella C, Esteve I (1983) Ecology and physiology of the competition for light between *Chlorobium limicola* and *Chlorobium phaeobacteroides* in natural habitats. *Applied and Environmental Microbiology* **46**: 1007-1016.
- Moon-van der Staay SY, De Wachter R, Vaulot D (2001) Oceanic 18S rDNA sequences from picoplankton reveal unsuspected eukaryotic diversity. *Nature* **409**: 607-610.
- Moore LR, Rocap G, Chisholm SW (1998) Physiology and molecular phylogeny of coexisting *Prochlorococcus* ecotypes. *Nature* **393**: 464-467.
- Morel A, Gentili B, Claustre H, Babin M, Bricaud A, Ras J, Tièche F (2007) Optical properties of the "clearest" natural waters. *Limnology and Oceanography* **52**: 217-229.

References

- Mózes A, Présing M, Vörös L (2006) Seasonal dynamics of picocyanobacteria and picoeukaryotes in a large shallow lake (Lake Balaton, Hungary). *International Review of Hydrobiology* **91**: 38-50.
- Murrell MC, Lores EM (2004) Phytoplankton and zooplankton seasonal dynamics in a subtropical estuary: importance of cyanobacteria. *Journal of Plankton Research* **26**: 371-382.
- Nee S, Colegrave N (2006) Ecology: paradox of the clumps. *Nature* **441**: 417-418.
- Nei M, Kumar S, Takahashi K (1998) The optimization principle in phylogenetic analysis tends to give incorrect topologies when the number of nucleotides or amino acids used is small. *Proceedings of the National Academy of Sciences USA* **95**: 12390-12397.
- Neilan BA, Jacobs D, Goodman AE (1995) Genetic diversity and phylogeny of toxic cyanobacteria determined by DNA polymorphisms within the phycocyanin locus. *Applied and Environmental Microbiology* **61**: 3875-3883.
- Nusch EA (1980) Comparison of different methods for chlorophyll and phaeopigment determination. *Archiv für Hydrobiologie Beib Ergebn Limnology* **14**: 14-36.
- Ohki K, Gannt E, Lippschultz CA, Ernst MC (1985) Constant phycobilisome size in chromatically adapted cells of the cyanobacterium *Tohyothrix tenuis*, and variation in *Nostoc* sp. *Plant Physiology* **79**: 943-948.
- Olson RJ, Chisholm SW, Zettler ER, Armbrust EV (1990) Pigments, size and distribution of *Synechococcus* in the North Atlantic and Pacific Oceans. *Limnology and Oceanography* **35**: 45-58.
- Overmann J, Pfennig N (1989) *Pelodictyon phaeoclatratiforme* sp. nov., a new brown coloured member of the Chlorobiaceae forming net-like colonies. *Archives of Microbiology* **152**: 401-406.
- Overmann J, Beatty T, Hall KJ, Pfennig N, Northcote TG (1991) Characterization of a dense, purple sulfur bacterial layer in a meromictic salt lake. *Limnology and Oceanography* **36**: 846-859.
- Padilla DK, Adolph SC (1996) Plastic inducible morphologies are not always adaptive: the importance of time delays in a stochastic environment. *Evolutionary Ecology* **10**: 105-117.
- Paerl HW, Huisman J (2008) Blooms like it hot. *Science* **320**: 57-58.
- Palenik B (2001) Chromatic adaptation in marine *Synechococcus* strains. *Applied and Environmental Microbiology* **67**: 991-994.
- Parkin TB, Brock TD (1980) The effects of light quality on the growth of phototrophic bacteria in lakes. *Archives of Microbiology* **125**: 19-27.
- Passarge J, Hol S, Escher M, Huisman J (2006) Competition for nutrients and light: stable coexistence, alternative stable states, or competitive exclusion? *Ecological Monographs* **76**: 57-72.
- Pegau WS, Gray D, Zaneveld JRV (1997) Absorption and attenuation of visible and near-infrared light in water: dependence on temperature and salinity. *Applied Optics* **36**: 6035-6046.
- Pfennig N (1967) Photosynthetic bacteria. *Annual Review of Microbiology* **21**: 285-324.
- Pick FR (1991) The abundance and composition of fresh-water picocyanobacteria in relation to light penetration. *Limnology and Oceanography* **36**: 1457-1462.
- Pierson BK, Sands VM, Frederick JL (1990) Spectral irradiance and distribution of pigments in a highly layered marine microbial mat. *Applied and Environmental Microbiology* **56**: 2327-2340.
- Platt T, Subba Rao DV, Irwin B (1983) Photosynthesis of picoplankton in the oligotrophic ocean. *Nature* **301**: 702-704.
- Pope RM, Fry ES (1997) Absorption spectrum (380-700 nm) of pure water. II. Integrating cavity measurements. *Applied Optics* **36**: 8710-8723.

- Polz MF, Cavanaugh CM (1998) Bias in template-to-product ratios in multitemplate PCR. *Applied and Environmental Microbiology* **64**: 3724-3730.
- Pommier T, Canback B, Riemann L, Boström KH, Simu K, Lundberg P, Tunlid A, Hagström A (2007) Global patterns of diversity and community structure in marine bacterioplankton. *Molecular Ecology* **16**: 867-880.
- Ramus J (1983) A physiological test of the theory of complementary chromatic adaptation. II. Brown, green and red seaweeds. *Journal of Phycology* **19**: 173-178.
- Robertson BR, Tezuka N, Watanabe MM (2001) Phylogenetic analyses of *Synechococcus* strains (cyanobacteria) using sequences of 16S rDNA and part of the phycocyanin operon reveal multiple evolutionary lines and reflect phycobilin content. *International Journal of Systematic and Evolutionary Microbiology* **51**: 861-871.
- Rocap G, Distel DL, Waterbury JB, Chisholm SW (2002) Resolution of *Prochlorococcus* and *Synechococcus* ecotypes by using 16S-23S ribosomal DNA internal transcribed spacer sequences. *Applied and Environmental Microbiology* **68**: 1180-1191.
- Rocap G, Larimer FW, Lamerdin J, Malfatti S, Chain P, Ahlgren NA, Arellano A *et al.* (2003) Genome divergence in two *Prochlorococcus* ecotypes reflects oceanic niche differentiation. *Nature* **424**: 1042-1047.
- Rozas J, Sanchez-DelBarrio JC, Messeguer X, Rozas R (2003) DnaSP, DNA polymorphism analyses by the coalescent and other methods. *Bioinformatics* **19**: 2496-2497.
- Rusch DB, Halpern AL, Sutton G, Heidelberg KB, Williamson S, Yooseph S, *et al.* (2007) The Sorcerer II Global Ocean Sampling Expedition: Northwest Atlantic through Eastern Tropical Pacific. *PLoS Biology* **5**: 398-432.
- Rueffler C, Van Dooren TJM, Leimar O, Abrams PA (2006) Disruptive selection and then what? *Trends in Ecology & Evolution* **21**: 238-245.
- Sabehi G, Kirkup BC, Rozenberg M, Stambler N, Polz MF, Béjà O (2007) Adaptation and spectral tuning in divergent marine proteorhodopsins from the eastern Mediterranean and the Sargasso Seas. *ISME Journal* **1**: 48-55.
- Sathyendranath S, Platt T (1989) Computation of aquatic primary production: extended formalism to include effect of angular and spectral distribution of light. *Limnology and Oceanography* **34**: 188-198.
- Schloss PD, Handelsman J (2005) Introducing DOTUR, a computer program for defining operational taxonomic units and estimating species richness. *Applied and Environmental Microbiology* **71**: 1501-1506.
- Schluter D (2000) Ecological character displacement in adaptive radiation. *American Naturalist* **156**: S4-S16.
- Segelstein DJ (1981) *The complex refractive index of water*. Ph.D. thesis, University of Missouri-Kansas City, USA.
- Simis SGH, Peters SWM, Gons HJ (2005) Remote sensing of the cyanobacterial pigment phycocyanin in turbid inland water. *Limnology and Oceanography* **50**: 237-245.
- Singh VK, Mangalam AK, Dwivedi S, Naik S (1998) Primer premier: Program for design of degenerate primers from a protein sequence. *Biotechniques* **24**: 318-319.
- Singleton DR, Furlong MA, Rathbun SL, Whitman WB (2001) Quantitative comparisons of 16S rDNA sequence libraries from environmental samples. *Applied and Environmental Microbiology* **67**: 4373-4376.
- Sogandares FM, Fry ES (1997) Absorption spectrum (340-640 nm) of pure water. I Photothermal measurements. *Applied Optics* **33**: 8699-8709.
- Sommer U (1984) The paradox of the plankton: fluctuations of phosphorus availability maintain diversity in flow-through cultures. *Limnology and Oceanography* **29**: 633-636.

References

- Sommer U (1985) Competition between steady state and non-steady state competition: experiments with natural phytoplankton. *Limnology and Oceanography* **30**: 335-346.
- Sommer U (1993) Phytoplankton competition in Plußsee: a field test of the resource-ratio hypothesis. *Limnology and Oceanography* **38**: 838-845.
- Stal LJ, Staal M, Villbrandt M (1999) Nutrient control of cyanobacterial blooms in the Baltic Sea. *Aquatic Microbial Ecology* **18**: 165-173.
- Stal LJ, Walsby AE (2000) Photosynthesis and nitrogen fixation in a cyanobacterial bloom in the Baltic Sea. *European Journal of Phycology* **35**: 97-108.
- Stal LJ, Albertano P, Bergman B, von Brockel K, Gallon JR, Hayes PK, Sivonen K, Walsby AE (2003) BASIC: Baltic Sea cyanobacteria. An investigation of the structure and dynamics of water blooms of cyanobacteria in the Baltic Sea - responses to a changing environment. *Continental Shelf Research* **23**: 1695-1714.
- Stomp M, Huisman J, de Jongh F, Veraart AJ, Gerla D, Rijkeboer M, Ibelings BW, Wollenzien UIA, Stal LJ (2004) Adaptive divergence in pigment composition promotes phytoplankton biodiversity. *Nature* **432**: 104-107.
- Stomp M, Huisman J, Vörös L, Pick FR, Laamanen M, Haverkamp T, Stal LJ (2007a) Colourful coexistence of red and green picocyanobacteria in lakes and seas. *Ecology Letters* **10**: 290-298.
- Stomp M, Huisman J, Stal LJ, Matthijs HCP (2007b) Colourful niches of phototrophic microorganisms shaped by vibrations of the water molecule. *ISME Journal* **1**: 271-282.
- Sultan SE, Bazzaz FA (1993) Phenotypic plasticity in *Polygonum persicaria*. II. Norms of reaction to soil moisture and the maintenance of genetic diversity. *Evolution* **47**: 1032-1049.
- Tam AC, Patel CKN (1979) Optical absorptions of light and heavy water by laser optoacoustic spectroscopy. *Applied Optics* **18**: 3348-3358.
- Tamura K, Nei M, Kumar S (2004) Prospects for inferring very large phylogenies by using the neighbor-joining method. *Proceedings of the National Academy of Sciences USA* **101**: 11030-11035.
- Tandeau de Marsac N (1977) Occurrence and nature of chromatic adaptation in cyanobacteria. *Journal of Bacteriology* **130**: 82-91.
- Taton A, Grubisic S, Brambilla E, De Wit R, Wilmotte A (2003) Cyanobacterial diversity in natural and artificial microbial mats of Lake Fryxell (McMurdo dry valleys, Antarctica): A morphological and molecular approach. *Applied and Environmental Microbiology* **69**: 5157-5169.
- Terauchi K, Montgomery BL, Grossman AR, Lagarias JC, Kehoe DM (2004) RcaE is a complementary chromatic adaptation photoreceptor required for green and red light responsiveness. *Molecular Microbiology* **51**: 567-577.
- Thompson JD, Higgins DG, Gibson TJ (1994) Clustal-W - improving the sensitivity of progressive multiple sequence alignment through sequence weighting, position-specific gap penalties and weight matrix choice. *Nucleic Acids Research* **22**: 4673-4680.
- Tilman D (1982) *Resource Competition and Community Structure*. Princeton University Press, Princeton.
- Ting CS, Rocap G, King J, Chisholm SW (2002) Cyanobacterial photosynthesis in the oceans: the origins and significance of divergent light-harvesting strategies. *Trends in Microbiology* **10**: 134-142.
- Toledo G, Palenik B, Brahmsha B (1999) Swimming marine *Synechococcus* strains with widely different photosynthetic pigment ratios from a monophyletic group. *Applied and Environmental Microbiology* **65**: 5247-5251.
- Tsuji T, Yanagita T (1981) Improved fluorescent microscopy for measuring the standing stock of phytoplankton including fragile components. *Marine Biology* **64**: 207-211.

- Van der Stap I, Vos M, Mooij WM (2007) Inducible defenses and rotifer food chain dynamics. *Hydrobiologia* **593**: 103-110.
- Venter JC, Remington K, Heidelberg JF, Halpern AL, Rusch D, Eisen JA, Wu DY *et al* (2004) Environmental genome shotgun sequencing of the Sargasso Sea. *Science* **304**: 66-74.
- Vila X, Abella CA (1994) Effects of light quality on the physiology and the ecology of planktonic green sulfur bacteria in lakes. *Photosynthesis Research* **41**: 53-65.
- Vila X, Abella CA (2001) Light-harvesting adaptations of planktonic phototrophic microorganisms to different light quality conditions. *Hydrobiologia* **452**: 15-30.
- Vives-Rego J, Lebaron P, Nebe-von Caron G (2000) Current and future applications of flow cytometry in aquatic microbiology. *FEMS Microbiology Reviews* **24**: 429-448.
- Vörös L, Callieri C, Balogh KV, Bertonì R (1998) Freshwater picocyanobacteria along a trophic gradient and light quality range. *Hydrobiologia* **370**: 117-125.
- Walsby AE, Hayes PK, Boje R, Stal LJ (1997) The selective advantage of buoyancy provided by gas vesicles for planktonic cyanobacteria in the Baltic Sea. *New Phytologist* **136**: 407-417.
- Walsby AE (2005). Stratification by cyanobacteria in lakes: a dynamic buoyancy model indicates size limitations met by *Planktothrix rubescens* filaments. *The New Phytologist* **168**: 365-376.
- Waterbury JB, Watson S, Guillard RRL, Brand LE (1979) Widespread occurrence of a unicellular, marine, planktonic cyanobacterium. *Nature* **277**: 293-294.
- Weissing FJ, Huisman J (1994) Growth and competition in a light gradient. *Journal of Theoretical Biology* **168**: 323-336.
- Wilson SD, Yoshimura J (1994) On the coexistence of specialists and generalists. *American Naturalist* **144**: 692-707.
- Woltereck R (1909) Weitere experimentelle Untersuchungen über Artveränderung, speziell über das wesen quantitativer artunterschiede bei *Daphnien*. *Verhandlungen der Deutschen Zoologischen Gesellschaft* **19**: 110-173.
- Wood AM (1985) Adaptation of photosynthetic apparatus of marine ultraphytoplankton to natural light fields. *Nature* **316**: 253-255.
- Wood AM, Phinney DA, Yentsch CS (1998) Water column transparency and the distribution of spectrally distinct forms of phycoerythrin-containing organisms. *Marine Ecology Progress Series* **162**: 25-31.
- Wright F (1990) The effective number of codons used in a gene. *Gene* **87**: 23-29.
- Wyman M, Fay P (1986) Underwater light climate and the growth and pigmentation of planktonic blue-green algae (Cyanobacteria). II. The influence of light quality. *Proceedings of the Royal Society of London, Series B* **227**: 381-393.
- Xiong J, Fischer WM, Inoue K, Nakahara M, Bauer CE (2000) Molecular evidence for the early evolution of photosynthesis. *Science* **289**: 1724-1730.
- Yentsch CS (1962) Measurement of visible light absorption by particulate matter in the ocean. *Limnology and Oceanography* **7**: 207-217.
- Zaballos M, Lopez-Lopez A, Ovreas L, Bartual SG, D'Auria G, Alba JC, Legault B, Pushker R, Daae FL, Rodriguez-Valera F (2006) Comparison of prokaryotic diversity at offshore oceanic locations reveals a different microbiota in the Mediterranean Sea. *FEMS Microbiology Ecology* **56**: 389-405.
- Zubova SV, Melzer M, Prokhorenko IR (2005) Effect of environmental factors on the composition of lipopolysaccharides released from the *Rhodobacter capsulatus* cell wall. *Biology bulletin of the Russian Academy of Sciences* **32**: 168-173.

