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References

- Ackman RG, Dale J, Hingley J (1966) Deposition of dimethyl- β -propiothetin in Atlantic cod during feeding experiments. *J Fish Res Bd Can* 23: 487-496
- Ackman RG, Hingley HJ (1968) The occurrence and retention of dimethyl- β -propiothetin in some filter-feeding organisms. *J Fish Res Bd Can* 25: 267-284
- Ackman RG, Tocher CS (1966) Occurrence of dimethyl- β -propiothetin in marine phytoplankton. *J Fish Res Bd Can* 23: 357-364
- Admiraal W (1978) Experiments with mixed populations of benthic estuarine diatoms in laboratory microecosystems. *Bot Mar* 20: 479-485
- Admiraal W, Laane RWPM, Peletier H (1984) Participation of diatoms in the amino acid cycle of coastal waters; uptake and excretion in cultures. *Mar Ecol Prog Ser* 15: 303-306
- Admiraal W, Peletier H (1979) Sulphide tolerance of benthic diatoms in relation to their distribution in an estuary. *Br Phycol J* 14: 185-196
- Admiraal W, Peletier H, Zomer H (1982) Observations and experiments on the population dynamics of epipellic diatoms from an estuarine mudflat. *Estuarine, Coastal and Shelf Sciences* 14: 471-487
- Andreae MO (1980) Dimethyl sulfoxide in marine and freshwaters. *Limnol Oceanogr* 25: 1054-1063
- Andreae MO (1986) The ocean as a source of atmospheric sulphur compounds. In: Buat-Menard P (ed) *The role of air-sea exchange in geochemical cycling*. Reidel, Dordrecht, p 331-362
- Andreae MO (1990) Ocean-atmosphere interactions in the global biochemical sulfur cycle. *Mar Chem* 30: 1-29
- Andreae MO, Elbert W, Demora SJ (1995) Biogenic sulfur emissions and aerosols over the tropical South- Atlantic .3. Atmospheric dimethylsulfide, aerosols and cloud condensation nuclei. *J Geophys Res* 100: 11335-11356
- Ayers GP, Cainey JM, Gillet RW, Ivey JP (1997) Atmospheric sulphur and cloud condensation nuclei in marine air in the Southern Hemisphere. *Phil Trans Royal Soc London B* 352: 203-211
- Ayers GP, Ivey JP, Gillet RW (1991) Coherence between seasonal cycles of dimethyl sulphide, methanesulphonate and sulphate in marine air. *Nature* 349: 404-406
- Bak F, Finster K, Rothfuß F (1992) Formation of dimethylsulfide and methanethiol from methoxylated aromatic compounds and inorganic sulfide by newly isolated anaerobic bacteria. *Arch Microbiol* 64: 106-111
- Barranguet C, Herman PMJ, Sinke JJ (1997) Microphytobenthos biomass and community composition studied by pigment biomarkers: importance and fate in the carbon cycle of a tidal flat. *J Sea Res* 38: 59-70

- Barranguet C, Kromkamp J, Peene J (1998) Factors controlling primary production and photosynthetic characteristics of intertidal microphytobenthos. *Mar Ecol Prog Ser* 73:117-126
- Bates TS, Lamb BK, Guenther A, Dignon J, Stoiber RE (1992) Sulfur emissions to the atmosphere from natural sources. *J Atm Chem* 14: 315-317
- Battarbee RW (1986) Diatom analysis. In: Berglund BE (ed) *Handbook of Holocene Palaeoecology and Palaeohydrology*. John Wiley & Sons Ltd., London, p 527-570
- Baumann MEM, Brandini FP, Staubes R (1994) The influence of light and temperature on carbon-specific DMS release by cultures of *Phaeocystis antarctica* and three antarctic diatoms. *Mar Chem* 45: 129-136
- Bechard MJ, Rayburn R (1979) Volatile organic sulfides from freshwater algae. *J Phycol* 15: 379-383
- Blanchard GF, Guarini J-M, Gros P, Richard P (1997) Seasonal effect on the relationship between the photosynthetic capacity of intertidal microphytobenthos and temperature. *J Phycol* 33: 723-728
- Blunden G, Smith BE, Irons MW, Yang M-h, Roch OG, Patel AV (1992) Betaines and tertiary sulphonium compounds from 62 species of marine algae. *Biochem Syst Ecol* 20: 373-388
- Bodenbender J, Wassmann R, Papen H, Rennenberg H (1999) Temporal and spatial variation of sulfur-gas-transfer between coastal marine sediments and the atmosphere. *Atm Environ* 33: 3487-3502
- Brimblecombe P, Shooter D (1986) Photo-oxidation of dimethylsulfide in aqueous solution. *Mar Chem* 19: 343-353
- Brown AD, Mackenzie KF, Singh KK (1986) Selected aspects of microbial osmoregulation. *FEMS Microbiol Rev* 39: 31-36
- Brugger A, Slezak D, Obernosterer I, Herndl GJ (1998) Photolysis of dimethylsulfide in the northern Adriatic Sea: Dependence on substrate concentration, irradiance and DOC concentration. *Mar Chem* 59: 321-331
- Brunold C (1990) Reduction of sulfate to sulfide. In: Rennenberg H, Brunold C, De Kok LJ, Stulen I (eds) *Sulfur nutrition and sulfur assimilation in higher plants*. SPB Academic Publishers, The Hague, p 13-32
- Burden RL, Faires JD (1989) *Numerical analysis*. PSW-KENT, Boston, MA
- Caumette P, Castel J, Herbert R (1996) Coastal Lagoon Eutrophication and Anaerobic Processes (CLEAN). *Developments in Hydrobiology* 117. Dordrecht, Kluwer Academic
- Cerqueira MA, Pio CA (1999) Production and release of dimethylsulphide from an estuary in Portugal. *Atm Environ* 33: 3355-3366
- Challenger F (1951) Biological methylation. *Adv Enzymol* 12: 429-491
- Challenger F, Bywood R, Thomas P, Hayward BJ (1957) Studies on biological methylation. XVII. The natural occurrence and chemical reactions of some thietins. *Arch Biochem Biophys* 69: 514-523
- Challenger F, Simpson MI (1948) Studies on biological methylation. Part XII. A precursor of the dimethyl sulfide evolved by *Polysiphonia fastigiata*. Dimethyl-2-carboxyethyl sulphonium hydroxide and its salts. *J Chem Soc* 43: 1591-1597
- Chambers ST, Kunin CM, Miller D, Hamada A (1987) Dimethylthetin can substitute for glycine betaine as an osmoprotectant molecule for *Escherichia coli*. *J Bact* 169: 4845-4847

- Charlson RJ, Lovelock JE, Andreae MO, Warren SG (1987) Oceanic phytoplankton, atmospheric sulphur, cloud albedo and climate. *Nature* 326: 655-661
- Charlson RJ, Wigley TML (1994) Sulfate aerosol and climatic change. *Sci Amer* 270: 28-35
- Chin M, Jacob DJ (1996) Anthropogenic and natural contributions to tropospheric sulfate: a global model analysis. *J Geophys Res* 101: 18691-18699
- Christaki U, Belviso S, Dolan JR, Corn M (1996) Assessment of the role of copepods and ciliates in the release to solution of particulate DMSP. *Mar Ecol Prog Ser* 141: 119-127
- Cohen Y, Rosenberg E (1989) Microbial Mats. *Physiological Ecology of Benthic Microbial Communities*. American Society for Microbiology, Washington D.C.
- Colmer TD, Fan TW-M, Läuchli A, Higashi RM (1996) Interactive effects of salinity, nitrogen and sulphur on the organic solutes in *Spartina alterniflora* leaf blades. *J Exp Bot* 47: 369-375
- Corn M, Belviso S, Partensky F, Simon N, Christaki U (1996) Origin and importance of picoplanktonic DMSP. In: Kiene RP, Visscher PT, Keller MD, Kirst GO (eds) *Biological and environmental chemistry of DMSP and related sulfonium compounds*. Plenum Press, New York, p 191-201
- Cosquer A, Pichereau V, Pocard JA, Minet J, Cormier M, Bernard T (1999) Nanomolar levels of dimethylsulfoniopropionate, dimethylsulfonioacetate, and glycine betaine are sufficient to confer osmoprotection to *Escherichia coli*. *Appl Environ Microbiol* 65: 3304-3311
- Dacey JWH, Blough NV (1987) Hydroxide decomposition of dimethylsulfoniopropionate to form dimethylsulfide. *Geophys Res Lett* 14: 1246-1249
- Dacey JWH, Howse FA, Michaels AF, Wakeham SG (1998) Temporal variability of dimethylsulfide and dimethylsulfoniopropionate in the Sargasso Sea. *Deep Sea Res Pt I Oceanogr* 45: 2085+
- Dacey JWH, King GM, Wakeham SG (1987) Factors controlling emission of dimethylsulfide from salt marshes. *Nature* 330: 643-645
- Dacey JWH, Wakeham SG (1986) Oceanic dimethylsulfide: production during zooplankton grazing. *Science* 233: 1314-1316
- Dacey JWH, Wakeham SG (1986) Oceanic dimethylsulfide: production during zooplankton grazing on phytoplankton. *Science* 233: 1314-1316
- Daly KL, DiTullio GR (1996) Particulate dimethylsulfoniopropionate removal and dimethylsulfide production by zooplankton in the Southern ocean. In: Kiene RP, Visscher PT, Keller MD, Kirst GO (eds) *Biological and environmental chemistry of DMSP and related sulfonium compounds*. Plenum Press, New York, p 223-238
- Dauwe B, Middelburg JJ (1998) Amino acids and hexosamines as indicators of organic matter degradation state in North Sea sediments. *Limnol Oceanogr* 43: 782-798
- De Jong DJ, Nienhuis PH, Kater BJ (1994) Microphytobenthos in the Oosterschelde estuary (The Netherlands), 1981-1990; consequences of a changed tidal regime. *Hydrobiol* 282/283: 183-195
- De Souza MP, Chen YP, Yoch DC (1996) Dimethylsulfoniopropionate lyase from the marine macroalga *Ulva curvata*: purification and characterization of the enzyme. *Planta* 199: 433-438
- De Souza MP, Yoch DC (1995a) Comparative physiology of dimethyl sulfide production by dimethylsulfoniopropionate lyase in *Pseudomonas doadoroffii* and *Alcaligenes* sp. strain M3A. *Appl Environ Microbiol* 61: 3986-3991

- De Souza MP, Yoch DC (1995b) Purification and characterization of dimethylsulfoniopropionate lyase from an *Alcaligenes*-like dimethyl sulfide-producing marine isolate. *Appl Environ Microbiol* 61: 21-26
- De Souza MP, Yoch DC (1996) N-Terminal amino acid sequences and comparison of DMSP lyases from *Pseudomonas doboroffii* and *Alcaligenes* strain M3A. In: Kiene RP, Visscher PT, Keller MD, Kirst GO (eds) Biological and environmental chemistry of DMSP and related sulfonium compounds. Plenum Press, New York, p 293-304
- De Winder B, Staats N, Stal LJ, Paterson DM (1999) Carbohydrate secretion by phototrophic communities in tidal sediments. *J Sea Res* 42: 131-146
- De Wit R, Jonkers HM, Van Den Ende FP, Van Gemerden H (1989) *In situ* fluctuations of oxygen and sulphide in marine microbial sediment ecosystems. *Neth J Sea Res* 23: 271-281
- De Zwart J, M.M., Nelisse PN, Kuenen JG (1996) Isolation and characterization of *Methylophaga sulfidovorans*, sp. nov.; an obligately methylotrophic, aerobic, dimethylsulfide oxidizing bacterium from a microbial mat. *FEMS Microbiol Ecol* 20: 261-270
- De Zwart JMM, Kuene JG (1995) Compartment model for biological conversions of DMS in a microbial mat: effect of pH on DMS fluxes. *FEMS Microbiol Ecol* 18: 247-255
- De Zwart JMM, Kuenen GJ (1992) C₁-cycle of sulfur compounds. *Biodegradation* 3: 37-59
- Diaz MR, Visscher PT, Taylor BF (1992) Metabolism of dimethylsulfoniopropionate and glycine betaine by a marine bacterium. *FEMS Microbiol Lett* 96: 61-65
- Dickson DM, Wyn Jones RG, Davenport J (1980) Steady state osmotic adaptation in *Ulva lactuca*. *Planta* 150: 158-165
- Dickson DMJ, Kirst GO (1986) The role of b-dimethylsulphoniopropionate, glycine betaine and homarine in the osmoacclimation of *Platymonas subcordiformis*. *Planta* 167: 536-543
- Dickson DMJ, Kirst GO (1987) Osmotic adjustment in marine eukaryotic algae: the role of inorganic ions, quarternary ammonium, tertiary sulphonium and carbohydrate solutes. I. Diatoms and a rhodophyte. *New Phytol* 106: 645-655
- Dickson DMJ, Wyn Jones RG, Davenport J (1982) Osmotic adaptation in *Ulva lactuca* under fluctuating salinity regimes. *Planta* 155: 409-415
- Doonan SA, Gooday GW (1982) Ecological studies of symbiosis in *Convolvula roscoffensis*. *Mar Ecol Prog Ser* 8: 69-73
- Douglas AE (1983) Establishment of the symbiosis in *Convolvula roscoffensis*. *J Mar Biol Ass UK* 63: 419-434
- Douglas AE (1985) Growth and reproduction of *Convolvula roscoffensis* containing different naturally occurring algal symbionts. *J Mar Biol Ass UK* 65: 871-879
- Eaton JW, Moss B (1966) The estimation of numbers and pigment content in epipelagic algal populations. *Limnol Oceanogr* 11: 584-595
- Edwards DM, Reed RH, Stewart WDP (1988) Osmoacclimation in *Enteromorpha intestinales*: long-term effects of osmotic stress on organic solute accumulation. *Mar Biol* 98: 467-476
- Finstler K, King GM, Bak F (1990) Formation of methylmercaptan and dimethylsulfide from methoxylated aromatic compounds in anoxic marine and fresh water sediments. *FEMS Microbiol Ecol* 74: 295-302
- Finstler K, Tanimoto Y, Bak F (1992) Fermentation of methanethiol and dimethylsulfide by a newly isolated methanogenic bacterium. *Archives of Microbiology* 157: 425-530

- Flynn KJ, Flynn K (1992) Non-protein free amines in microalgae: consequences for the measurement of intracellular amino acids and of the glutamine/glutamate ratio. *Mar Ecol Prog Ser* 89: 73-79
- Fujii S, Nishimoto Naoki, Notoya A, Hellebust JA (1995) Growth and osmoregulation of *Chaetoceros muelleri* in relation to salinity. *Plant Cell Physiol* 36: 759-764
- Gage DA, Hanson AD (1996) Characterization of 3-dimethylsulfoniopropionate (DMSP) and its analogs with mass spectrometry. In: Kiene RP, Visscher PT, Keller MD, Kirst GO (eds) Biological and environmental chemistry of DMSP and related sulfonium compounds. Plenum Press, New York, p 29-44
- Gage DA, Rathinasabapathi B (1999) Role of glycine betaine and dimethylsulfoniopropionate in water-stress tolerance. In: Shinozaki K, Yamaguchi-Shinozaki K (eds) Molecular responses to cold, drought, heat and salt stress in higher plants. R.G. Landes Company, Austin, p 125-152
- Gage DA, Rhodes D, Nolte KD, Hicks WA, Leustek T, Cooper AJL, Hanson AD (1997) A new route for synthesis of dimethylsulfoniopropionate in marine algae. *Nature* 387: 891-894
- Galinski EA (1995) Osmoadaptation in bacteria. *Adv Microbial Physiol* 37: 273-328
- Gamble FW, Keeble F (1903) The bionomics of *Convolvula roscoffensis*, with special reference to its green cells. *Quart J Microsc Sci* 47: 364-431
- Gauthier MJ, Le Rudulier D (1990) Survival in seawater of *Escherichia coli* cells grown in marine sediments containing glycine betaine. *Appl Environ Microbiol* 56: 2915-2918
- Giovanelli J (1990) Regulatory aspects of cysteine and methionine biosynthesis. In: Rennenberg H, Brunold C, De Kok LJ, Stulen I (eds) Sulfur nutrition and sulfur assimilation in higher plants. SPB Academic Publishing, The Hague, p 33-48
- Gröne T (1991) Untersuchungen zum DMSP-Metabolismus von *Tetraselmis subcordiformis* (Prasinophyceae). University of Bremen, Bremen
- Gröne T (1995) Biogenic production and consumption of dimethylsulfide (DMS) and dimethylsulfoniopropionate (DMSP) in the marine epipelagic zone: a review. *J Mar Sys* 6: 191-209
- Gröne T, Kirst GO (1991) Aspects of dimethylsulfoniopropionate effects on enzymes isolated from the marine phytoplankter *Tetraselmis subcordiformis*. *J Plant Physiol* 138: 85-91
- Gröne T, Kirst GO (1992) The effect of nitrogen deficiency, methionine and inhibitors of methionine metabolism on the DMSP contents of *Tetraselmis subcordiformis* (Stein). *Mar Biol* 112: 497-503
- Hanlon SP, Holt RA, Moore GR, McEwan AG (1994) Isolation and characterization of a strain of *Rhodobacter sulfidophilus*: a bacterium which grows autotrophically with dimethylsulphide as electron donor. *Microbiology* 140: 1953-1958
- Hanson AD, Gage DA (1996) 3-Dimethylsulfoniopropionate biosynthesis and use by flowering plants. In: Kiene RP, Visscher PT, Keller MD, Kirst GO (eds) Biological and environmental chemistry of DMSP and related sulfonium compounds. Plenum Press, New York, p 75-86
- Hanson AD, Rivoal J, Paquet L, Gage DA (1994) Biosynthesis of 3-dimethylsulfoniopropionate in *Wollastonia biflora* (L.) DC. Evidence that S-methylmethionine is an intermediate. *Plant Physiol* 105: 103-110
- Harrison RM, Nedwell DB, Shabbeer MT (1992) Factors influencing the atmospheric flux of reduced sulfur compounds from North Sea inter-tidal areas. *Atm Environ* 26: 2381-2387

- Herbert D, Phipps PJ, Strange RE (1971) Chemical analysis of microbial cells. In: Norris JR, Ribbons DW (eds) *Methods in Microbiology*. Academic Press, London, New York, p 209-344
- Hill R, Dacey J, Krupp D (1995) Dimethylsulfoniopropionate in Reef Corals. *Bull Mar Sci* 57: 489-494
- Holligan PM, Gooday GW (1975) Symbiosis in *Convoluta roscoffensis*. In: Jennings DH, Lee DL (eds) *Symposia of the Society for Experimental Biology*. Cambridge University Press, Cambridge, p 205-227
- Houghton JT, Meira Filho LG, Callander BA, Harris N, Kattenberg A, Maskell K (1996) *Climate Change 1995. The Science of Climate Change. Contribution of working group I. Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge
- Howard AG, Russell DW (1995) HPLC-FPD instrumentation for the measurement of the atmospheric dimethyl sulfide precursor beta-(dimethylsulfonio)propionate. *Anal Chem* 67: 1293-1295
- Iida H, Tokunaga T (1986) Dimethyl sulfide and dimethyl- β -propiothetin in shellfish. *Bull Jap Soc Sci Fish* 52: 557-563
- Ishida Y, Kadota H (1967) Isolation and identification of dimethyl-propiothetin from *Gyrodinium cobnii*. *Agr Biol Chem* 31: 699-705
- Iverson RL, Nearhoof FL, Andreae MO (1989) Production of dimethylsulfonium propionate and dimethylsulfide by phytoplankton in estuarine and coastal waters. *Limnol Oceanogr* 34: 53-67
- Jackson AE, Ayer SW, Laycock MV (1992) The effect of salinity on growth and amino acid composition in the marine diatom *Nitzschia pungens*. *Can J Bot* 70: 2198-2201
- James F, Paquet L, Sparace SA, Gage DA, Hanson AD (1995) Evidence implicating dimethylsulfoniopropionaldehyde as an intermediate in dimethylsulfoniopropionate biosynthesis. *Plant Physiol* 108: 1439-1448
- Jenkins D, Medsker LL, Thomas JF (1967) Odorous compounds in natural waters. Some sulfur compounds associated with blue-green algae. *Environ Sci Technol* 1: 731-735
- Jonkers HM, van der Maarel MJEC, van Gemerden H, Hansen TA (1996) Dimethylsulfoxide reduction by marine sulfate-reducing bacteria. *FEMS Microbiol Lett* 136: 283-287
- Jonkers HM, Koopmans GF, van Gemerden H (1998a) Dynamics of dimethyl sulfide in a marine microbial mat. *Microb Ecol* 36: 93-100
- Jonkers HM, de Bruin S, van Gemerden H (1998b) Turnover of dimethylsulfoniopropionate (DMSP) by the purple sulfur bacterium *Thiocapsa roseopersicina* M11: Ecological implications. *FEMS Microbiol Ecol* 27: 281-290
- Jonkers HM, van Bergeijk SA, van Gemerden H (2000) Microbial production and consumption of dimethyl sulfide (DMS) in a sea grass (*Zostera noltii*)-dominated marine intertidal sediment ecosystem (Bassin d'Arcachon, France). *FEMS Microbiol Ecol* 31: 163-172
- Jørgensen BB, Okholm-Hansen B (1985) Emissions of biogenic sulfur gases from a Danish estuary. *Atm Environ* 19: 1737-1749
- Kanagawa T, Kelly DP (1986) Breakdown of dimethyl sulphide by mixed cultures and by *Thiobacillus thioparus*. *FEMS Microbiol Lett* 34: 13-19

- Kanagawa T, Mikami E (1989) Removal of methanethiol, dimethyl sulfide, dimethyl disulfide, and hydrogen sulfide from contaminated air by *Thiobacillus thioparus* TK-m. *Appl Environ Microbiol* 55: 555-558
- Karsten U, Kirst G, O. (1989) Intracellular solutes, photosynthesis and respiration of the green macroalga *Blidingia minima* in response to salinity stress. *Bot Acta* 102: 123-128
- Karsten U, Wiencke C, Kirst GO (1990) The effect of light intensity and daylength on the β -dimethylsulphoniopropionate (DMSP) content of marine green macroalgae from Antarctica. *Plant Cell Environ* 13: 989-993
- Karsten U, Wiencke C, Kirst GO (1992) Dimethylsulphoniopropionate (DMSP) accumulation in green macroalgae from polar to temperate regions: interactive effects of light versus salinity and light versus temperature. *Polar Biol* 12: 603-607
- Karsten U, Kück K, Vogt C, Kirst GO (1996) Dimethylsulphoniopropionate production in phototrophic organisms and its physiological function as a cryoprotectant. In: Kiene RP, Visscher PT, Keller MD, Kirst GO (eds) *Biological and environmental chemistry of DMSP and related sulfonium compounds*. Plenum Press, New York, p 143-153
- Keeble F (1910) *Plant-animals: a study in symbiosis*. Cambridge University Press, Cambridge
- Keeble F, Gamble FW (1907) The origin and nature of the green cells of *Convolvula roscoffensis*. *Quart J Microsc Sci* 51: 167-219
- Keller MD, Bellows WK, Guillard RRL (1989) Dimethyl sulfide production in marine phytoplankton. In: Saltzman ES, Cooper WJ (eds) *Biogenic sulfur in the environment*. American Chemical Society, Washington DC., p 167-200
- Keller MD, Korjeff-Bellows W (1996) Physiological aspects of the production of dimethylsulphoniopropionate (DMSP) by marine phytoplankton. In: Kiene RP, Visscher PT, Keller MD, Kirst GO (eds) *Biological and environmental chemistry of DMSP and related sulfonium compounds*. Plenum Press, New York, p 131-142
- Keller MD, Kiene RP, Matrai PA, Bellows WK (1999a) Production of glycine betaine and dimethylsulphoniopropionate in marine phytoplankton. I. Batch cultures. *Mar Biol* 135: 237-248
- Keller MD, Kiene RP, Matrai PA, Bellows WK (1999b) Production of glycine betaine and dimethylsulphoniopropionate in marine phytoplankton. II. N-limited chemostat cultures. *Mar Biol* 135: 249-257
- Kelly DP (1996) A global perspective on sources and sinks of biogenic trace gases: an atmospheric system driven by microbiology. In: Murrell JC, Kelly DP (eds) *Microbiology of Atmospheric Trace Gases*. Springer-Verlag, Berlin Heidelberg, p 1-16
- Kelly DP, Smith NA (1990) Organic sulfur compounds in the environment. Biogeochemistry, microbiology, and ecological aspects. In: Marshall KC (ed) *Advances in microbial ecology*. Plenum Press, New York and London, p 345-385
- Kester DR, Duedall IW, Connors N, Pytkowics RM (1967) Preparation of artificial seawater. *Limnol Oceanogr* 12: 176-179
- Kieber DJ, Jiao J, Kiene RP, Bates TS (1996) Impact of dimethylsulfide photochemistry on methyl sulfur cycling in the equatorial Pacific Ocean. *J Geophys Res* 101: 3715-3772
- Kiene RP (1988) Dimethyl sulfide metabolism in salt marsh sediments. *FEMS Microbiol Ecol* 53: 71-78
- Kiene RP (1990) Dimethyl sulfide production from dimethylsulphoniopropionate in coastal seawater samples and bacterial cultures. *Appl Environ Microbiol* 56: 3292-3297
- Kiene RP (1996a) Turnover of dissolved DMSP in estuarine and shelf waters of the Northern Gulf of Mexico. In: Kiene RP, Visscher PT, Keller MD, Kirst GO (eds)

- Biological and environmental chemistry of DMSP and related sulfonium compounds. Plenum Press, New York, p 337-349
- Kiene RP (1996b) Microbiological controls on dimethylsulfide emissions from wetlands and the ocean. In: Murrell CJ, Kelly D, P. (eds) *Microbiology of Atmospheric Trace Gases*. Springer-Verlag, Berlin, p 205-225
- Kiene RP, Bates TS (1990) Biological removal of dimethyl sulphide from sea water. *Nature* 345: 702-705
- Kiene RP, Hines ME (1995) Microbial formation of dimethyl sulfide in anoxic Shagnum peat. *Appl Environ Microbiol* 61: 2720-2726
- Kiene RP, Oremland RS, Catena A, Miller LG, Capone DG (1986) Metabolism of reduced methylated sulfur compounds in anaerobic sediments and by a pure culture of an estuarine methanogen. *Appl Environ Microbiol* 52: 1037-1045
- Kiene RP, Linn LJ, González J, Moran MA, Bruton J, A. (1999) Dimethylsulfoniopropionate and methanethiol are important precursors of methionine and protein-sulfur in marine bacterioplankton. *Appl Environ Microbiol* 65: 4549-4558
- Kirst GO (1980) Mannitol accumulation in *Platymonas subcordiformis* after osmotic stresses and the effect of inhibitors. *Zeitschrift für Pflanzenphysiologie* 98: 35-42
- Kirst GO (1989) Salinity tolerance of eukaryotic marine algae. *Ann Rev Plant Physiol Plant Mol Biol* 40: 21-53
- Kirst GO (1996) Osmotic adjustment in phytoplankton and macroalgae. The use of dimethylsulfoniopropionate (DMSP). In: Kiene RP, Visscher PT, Keller MD, Kirst GO (eds) *Biological and environmental chemistry of DMSP and related sulfonium compounds*. Plenum Press, New York, p 121-129
- Kitaguchi H, Uchida A, Ishida Y (1999) Purification and characterization of L-methionine decarboxylase from *Cryptocodinium cohnii*. *Fisheries Sciences* 65: 613-617
- Kocsis MG, Nolte KD, Rhodes D, Shen TL, Gage DA, Hanson AD (1998) Dimethylsulfoniopropionate biosynthesis in *Spartina alterniflora* - Evidence that S-methylmethionine and dimethylsulfoniopropylamine are intermediates. *Plant Physiol* 117: 273-281
- Kromkamp J, Peene J, Van Rijswijk P, Sandee A, Goosen N (1995) Nutrients, light and primary production by phytoplankton and microphytobenthos in the eutrophic, turbid Westerschelde estuary (The Netherlands). *Hydrobiol* 311: 9-19
- Kwint R, L.J., Kramer K, J.M. (1995) DMS production by plankton communities. *Mar Ecol Prog Ser* 121: 227-237
- Kwint RLJ, Irigoien X, Kramer KJM (1996) Copepods and DMSP. In: Kiene RP, Visscher PT, Keller MD, Kirst GO (eds) *Biological and environmental chemistry of DMSP and related sulfonium compounds*. Plenum Press, New York, p 239-252
- Laher F, Hamelin J, Stewart GR (1977) L'acide diméthylsulfonium-3 propanoïque de *Spartina anglica*. *Phytochemistry* 16: 2019-2020
- Laroche D, Vézina AF, Levasseur M, Gosselin M, Stefels J, Keller MD, Matrai PA, Kwint RLJ (1999) DMSP synthesis and exudation in phytoplankton: a modeling approach. *Mar Ecol Prog Ser* 180: 37-49
- Lawrence MG (1993) An empirical analysis of the strength of the phytoplankton-dimethylsulfide-cloud-climate feedback cycle. *J Geophys Res* 98: 20663-20673
- Le Rudulier D, Pocard J-A, Boncompagni E, Poggi MC (1996) Osmoregulation in bacteria and transport of onium compounds. In: Kiene RP, Visscher PT, Keller MD, Kirst GO

- (eds) Biological and environmental chemistry of DMSP and related sulfonium compounds. Plenum Press, New York, p 253-263
- Ledyard KM, Dacey JWH (1994) Dimethylsulfide production from dimethylsulfoniopropionate by a marine bacterium. *Mar Ecol Prog Ser* 110: 95-103
- Ledyard KM, Dacey JWH (1996) Kinetics of DMSP-lyase activity in coastal seawater. In: Kiene RP, Visscher PT, Keller MD, Kirst GO (eds) Biological and environmental chemistry of DMSP and related sulfonium compounds. Plenum Press, New York, p 325-335
- Lee PA, De Mora SJ (1999) Intracellular dimethylsulfoxide (DMSO) in unicellular marine algae: speculations on its origin and possible biological role. *J Phycol* 35: 8-18
- Levasseur M, Gosselin M, Michaud S (1994) A new source of dimethylsulfide (DMS) for the arctic atmosphere: ice diatoms. *Mar Biol* 121: 381-387
- Liss PS, Hatton AD, Malin G, Nightingale PD, Turner SM (1997) Marine sulphur emissions. *Philosophical Transactions of the Royal Society of London B* 352: 159-169
- Liss PS, Slater PG (1974) Flux of gases across the air-sea interface. *Nature* 247: 181-184
- Lomans BP, den Camp HJMO, Pol A, Vogels GD (1999a) Anaerobic versus aerobic degradation of dimethyl sulfide and methanethiol in anoxic freshwater sediments. *Appl Environ Microbiol* 65: 438-443
- Lomans BP, Op den Camp HJM, Pol A, Van der Drift C, Vogels G (1999b) Role of methanogens and other bacteria in degradation of dimethyl sulfide and methanethiol in anoxic freshwater sediment. *Appl Environ Microbiol* 65: 2116-2121
- Lovelock J (1979) GAIA. A new look at life on Earth. Oxford University Press, Oxford
- Lovelock J (1988) The ages of GAIA: a biography of our living earth. W.W. Norton & Company Ltd., New York
- Lovelock JE, Maggs RJ, Rasmussen RA (1972) Atmospheric dimethyl sulphide and the natural sulphur cycle. *Nature* 237: 452-453
- Lucas CH, Holligan PM (1999) Nature and ecological implications of algal pigment diversity on the Molenplaat tidal flat (Westerschelde estuary, SW Netherlands). *Mar Ecol Prog Ser* 180: 51-64
- Macdonald CJ, Little R, Moore GR, Malin G (1996) NMR Spectroscopy as a probe for DMSP and glycine betaine in phytoplankton cells. In: Kiene RP, Visscher PT, Keller MD, Kirst GO (eds) Biological and environmental chemistry of DMSP and related sulfonium compounds. Plenum Press, New York, p 45-54
- Malin G, Kirst GO (1997) Algal production of dimethyl sulfide and its atmospheric role. *J Phycol* 33: 889-896
- Malin G, Wilson WH, Bratbak G, Liss PS, Mann NH (1998) Elevated production of dimethylsulfide resulting from viral infection of cultures of *Phaeocystis pouchetii*. *Limnol Oceanogr* 43: 1389-1393
- Matrai PA, Keller MD (1994) Total organic sulfur and dimethylsulfoniopropionate in marine phytoplankton: intracellular variations. *Mar Biol* 119: 61-68
- Matrai PA, Vernet M, Hood R, Jennings A, Brody E, Saemundsdóttir S (1995) Light-dependence of carbon and sulfur production by polar clones of the genus *Phaeocystis*. *Mar Biol* 124: 157-167
- McFarlane AE (1982) Two species of algal symbiont in naturally occurring populations of *Convoluta roscoffensis*. *J Mar Biol Ass UK* 62: 235
- Meyerdierks D (1997) Ecophysiology of the dimethylsulfoniopropionate (DMSP) content of temperate and polar phytoplankton communities in comparison with cultures of the

- coccolithophore *Emiliania huxleyi* and the antarctic diatom *Nitzschia lecontei*. Reports on Polar Research 233, Bremerhaven, Germany
- Nguyen BC, Belviso S, Mihalopoulos N, Gostan J, Nival P (1988) Dimethyl sulfide production during natural phytoplankton blooms. *Mar Chem* 24: 133-141
- Nilsson C, Sundbäck K (1996) Amino acid uptake in natural microphytobenthic assemblages studied by microautoradiography. *Hydrobiol* 332: 119-129
- Nishigushi MK, Goff LJ (1995) Isolation, purification, and characterization of DMSP lyase (dimethylpropiothetin dethiomethylase (4.4.1.3)) from the red alga *Polysiphonia paniculata*. *J Phycol* 31: 567-574
- Nishigushi MK, Somero GN (1992) Temperature and concentration dependence of compatibility of the organic osmolyte beta-dimethylsulfoniopropionate. *Cryobiology* 29: 118-124
- Nothnagel J (1995) The effects of salinity and light intensity on the osmolyte concentrations, cell volumes and growth rates of the Antarctic sea-ice diatoms *Chaetoceros* sp. and *Navicula* sp. with emphasis on the amino acid proline. Reports on Polar Research 161, Bremerhaven, Germany
- Pacquet L, Rathinasabapathi B, Saini HS, Zamir L, Gage D, Huang Z-H, Hanson AD (1994) Accumulation of the compatible solute 3-dimethylsulfoniopropionate in sugarcane and its relatives, but not other gramineous crops. *Aust J Plant Physiol* 21: 37-48
- Paul JS (1979) Osmoregulation in the marine diatom *Cylindrotheca fusiformis*. *J Phycol* 15: 280-284
- Pichereau V, Pocard JA, Hamelin J, Blanco C, Bernard T (1998) Differential effects of dimethylsulfoniopropionate, dimethylsulfonioacetate, and other S-methylated compounds on the growth of *Sinorhizobium meliloti* at low and high osmolarities. *Appl Environ Microbiol* 64: 1420-1429
- Putaud J-P, Nguyen BC (1996) Assessment of dimethylsulfide sea-air exchange rate. *J Geophys Res* 101: 4403-4411
- Quinn PK, Covert DS, Bates TS, Kapustin VN, Ramsey-Bell DC, McInnes LM (1993) Dimethylsulfide/cloud condensation nuclei/climate system: relevant size-resolved measurements of the chemical and physical properties of atmospheric aerosol particles. *J Geophys Res* 98: 10411-10427
- Reed RH (1983) Measurement and osmotic significance of β -dimethylsulphoniopropionate in marine macroalgae. *Mar Biol Lett* 4: 173-181
- Revsbech NP (1989) Diffusion characteristics of microbial communities determined by the use of oxygen microsensors. *J Microbiol Meth* 9: 11-122
- Revsbech NP, Sørensen J, Blackburn TH, Lomholt JP (1980) Distribution of oxygen in marine sediments measured with microelectrodes. *Limnol Oceanogr* 25: 403-411
- Rippka R, Deruelles J, Waterbury JB, Herdman M, Stanier RY (1979) Generic assignment, strain histories and properties of pure cultures of cyanobacteria. *J Gen Microbiol* 111: 1-61
- Round FE, Crawford RM, Mann DG (1990) The diatoms. Cambridge University Press, Cambridge
- Russell DW, Howard AG (1996) The determination of DMSP in marine algae and salt marsh plants. In: Kiene RP, Visscher PT, Keller MD, Kirst GO (eds) Biological and environmental chemistry of DMSP and related sulfonium compounds. Plenum Press, New York, p 155-163

- Sabbe K (1993) Short-term fluctuations in benthic diatom numbers on an intertidal sandflat in the Westerschelde estuary (Zeeland, The Netherlands). *Hydrobiol* 269/270: 275-284
- Santos PJP, Castel J, Souza-Santos LP (1997) Spatial distribution and dynamics of microphytobenthos biomass in the Gironde estuary (France). *Oceanol Acta* 20: 549-556
- Schmidt A (1986) Regulation of sulfur metabolism of plants. *Prog Bot* 48: 133-150
- Schobert B (1980) Proline catabolism, relaxation of osmotic strain and membrane permeability in the diatom *Phaeodactylum tricornerutum*. *Physiol Plant* 50: 37-42
- Shaw G, E. (1983) Bio-controlled thermostasis involving the sulfur cycle. *Climatic Change* 5: 297-303
- Sheets EB, Rhodes D (1996) Determination of DMSP and other onium compounds in *Tetraselmis subcordiformis* by plasma desorption mass spectrometry. In: Kiene RP, Visscher PT, Keller MD, Kirst GO (eds) *Biological and environmental chemistry of DMSP and related sulfonium compounds*. Plenum Press, New York, p 55-63
- Simó R, Pedros-Alió C (1999a) Short-term variability in the open ocean cycle of dimethylsulfide. *Global biogeochemical cycles* 13: 1173-1181
- Simó R, Pedros-Alió C (1999b) Role of vertical mixing in controlling the oceanic production of dimethyl sulphide. *Nature* 402: 396-399
- Spackman DH, Stein WH, Moore S (1958) Automatic recording apparatus for use in the chromatography of amino acids. *Anal Chem* 30: 1190-
- Stal LJ (1991) The metabolic versatility of the mat-building cyanobacteria *Microcoleus chthonoplastes* and *Oscillatoria limosa* and its ecological significance. *Algal Stud* 64: 453-467
- Stal LJ (1995) Physiological ecology of cyanobacteria in microbial mats and other communities. *New Phytol* 131: 1-32
- Stal LJ, Caumette P (1994) *Microbial mats. Structure, Development and Environmental Significance*. NATO ASI Series. 35. Springer-Verlag, Berlin
- Stal LJ, Van Gemerden H, Krumbein WE (1985) Structure and development of a benthic marine microbial mat. *FEMS Microbiol Ecol* 31: 111-125
- Stefels J (2000) Physiological aspects of the production and conversion of DMSP in marine algae and higher plants. *J Sea Res* : in press
- Stefels J, Dijkhuizen L (1996) Characteristics of DMSP-lyase in *Phaeocystis* sp. (Prymnesiophyceae). *Mar Ecol Prog Ser* 131: 307-313
- Stefels J, Dijkhuizen L, Gieskes WWC (1995) DMSP-lyase activity in a spring phytoplankton bloom off the Dutch coast, related to *Phaeocystis* sp. abundance. *Mar Ecol Prog Ser* 123: 235-243
- Stefels J, Gieskes WWC, Dijkhuizen L (1996) Intriguing functionality of the production and conversion of DMSP in *Phaeocystis* sp. In: Kiene RP, Visscher PT, Keller MD, Kirst GO (eds) *Biological and Environmental Chemistry of DMSP and related sulfonium compounds*. Plenum Press, New York, p 305-315
- Stefels J, Van Boekel WHM (1993) Production of DMS from dissolved DMSP in axenic cultures of the marine phytoplankton species *Phaeocystis* sp.. *Mar Ecol Prog Ser* 97: 11-18
- Stefels J, van Leeuwe MA (1998) Effects of iron and light stress on the biochemical composition of Antarctic *Phaeocystis* sp. (Prymnesiophyceae). I. Intracellular DMSP concentrations. *J Phycol* 34: 486-495
- Steinke M, Daniel C, Kirst GO (1996) DMSP lyase in marine macro- and microalgae. Intraspecific differences in cleavage activity. In: Kiene RP, Visscher PT, Keller MD,

- Kirst GO (eds) Biological and environmental chemistry of DMSP and related sulfonium compounds. Plenum Press, New York, p 317-324
- Steinke M, Wolfe GV, Kirst GO (1998) Partial characterisation of dimethylsulfoniopropionate (DMSP) lyase isozymes in 6 strains of *Emiliania huxleyi*. *Mar Ecol Prog Ser* 175: 215-225
- Storey R, Gorham J, Pitman MG, Hanson AD, Gage DA (1993) Response of *Melanthera biflora* to salinity and water stress. *J Exp Bot* 44: 1551-1560
- Summers PS, Nolte KD, Cooper AJL, Borgeas H, Leustek T, Rhodes D, Hanson AD (1998) Identification and stereospecificity of the first three enzymes of 3-dimethylsulfoniopropionate biosynthesis in a chlorophyte alga. *Plant Physiol* 116: 369-378
- Tang KW, Dam HG, Visscher PT, Fenn TD (1999) Dimethylsulfoniopropionate (DMSP) in marine copepods and its relation with diets and salinity. *Mar Ecol Prog Ser* 179: 71-79
- Tanimoto Y, Bak F (1994) Anaerobic degradation of methylmercaptan and dimethyl sulfide by newly isolated thermophilic sulfate-reducing bacteria. *Appl Environ Microbiol* 60: 2450-2455
- Taylor BF, Gilchrist DC (1991) New routes for aerobic biodegradation of dimethylsulfoniopropionate. *Appl Environ Microbiol* 57: 3581-3584
- Taylor BF, Visscher PT (1996) Metabolic pathways involved in DMSP degradation. In: Kiene RP, Visscher PT, Keller MD, Kirst GO (eds) Biological and environmental chemistry of DMSP and related sulfonium compounds. Plenum Press, New York, p 265-276
- Townsend DW, Keller MD (1996) Dimethylsulfide (DMS) and dimethylsulfoniopropionate (DMSP) in relation to phytoplankton in the Gulf of Maine. *Mar Ecol Prog Ser* 137: 229-241
- Trossat C, Rathinabapathi B, Weretilnyk EA, Shen TL, Huang ZH, Gage DA, Hanson AD (1998) Salinity promotes accumulation of 3-dimethylsulfoniopropionate and its precursor S-methylmethionine in chloroplasts. *Plant Physiol* 116: 165-171
- Tuchman NC (1996) The role of heterotrophy in algae. In: Stevenson RJ, Bothwell MI, Lowe RL (eds) *Algal Ecology*. Academic Press, San Diego, p 299-319
- Turner SM, Malin G, Liss PS, Harbour DS, Holligan PM (1988) The seasonal variation of dimethyl sulfide and dimethylsulfoniopropionate concentrations in nearshore waters. *Limnol Oceanogr* 33: 364-375
- Uchida A, Ooguri T, Ishida T, Kitaguchi H, Ishida Y (1996) Biosynthesis of dimethylsulfoniopropionate in *Cryptocodinium cohnii* (Dinophyceae). In: Kiene RP, Visscher PT, Keller MD, Kirst GO (eds) Biological and environmental chemistry of DMSP and related sulfonium compounds. Plenum Press, New York, p 97-107
- Underwood GJC, Phillips J, Saunders K (1998) Distribution of estuarine benthic diatom species along salinity and nutrient gradients. *Eur J Phycol* 33: 173-183
- Vairavamurthy A, Andreae MO, Iverson RL (1985) Biosynthesis of dimethylsulfide and dimethylpropiothetin by *Hymenomonas carterae* in relation to sulfur source and salinity variations. *Limnol Oceanogr* 30: 59-70
- Van Bergeijk SA, Stal LJ (1996) The role of oxygenic phototrophic microorganisms in production and conversion of dimethylsulfoniopropionate and dimethylsulfide in microbial mats. In: Kiene RP, Visscher PT, Keller MD, Kirst GO (eds) Biological and environmental chemistry of DMSP and related sulfonium compounds. Plenum Press, New York, p 369-379

- Van den Berg AJ, S.M. T, F.C. VD, P. R (1996) Model structure and analysis of dimethylsulphide (DMS) production in the southern North Sea, considering phytoplankton dimethylsulphoniopropionate- (DMSP) lyase and eutrophication effects. *Mar Ecol Prog Ser* 145: 233-244
- Van den Berg HA, Jonkers HM, Van Bergeijk SA, Kooijman SALM (1998) Dimethyl sulfide emissions from a sedimental microbial ecosystem subject to diel variations of oxic and anoxic conditions: a simple mathematical model. *FEMS Microbiol Ecol* 26: 1-16
- Van den Ende FP, Meier J, Van Gernerden H (1997) Syntrophic growth of sulfate-reducing bacteria and colorless sulfur bacteria during oxygen limitation. *FEMS Microbiol Ecol* 23: 65-80
- Van den Ende FP, Van Gernerden H (1994) Relationships between functional groups of organisms in microbial mats. In: Stal LJ, Caumette P (eds) *Microbial Mats. Structure, development and environmental significance*. Springer Verlag, Heidelberg, p 339-352
- Van der Maarel MJEC (1993) Anaerobic degradation of dimethylsulfoniopropionate to 3-S-methylmercaptopropionate by a marine *Desulfobacterium* strain. *Archives of Microbiology* 160: 411-412
- Van der Maarel MJEC, Jansen M, Hansen TA (1995) Methanogenic conversion of 3-S-methylmercaptopropionate to 3-mercaptopropionate. *Appl Environ Microbiol* 61: 48-51
- Van der Maarel MJEC, Hansen TA (1996) Anaerobic microorganisms involved in the degradation of DMS(P). In: Kiene RP, Visscher PT, Keller MD, Kirst GO (eds) *Biological and environmental chemistry of DMSP and related sulfonium compounds*. Plenum Press, New York, p 351-360
- Van der Maarel MJEC, Jansen M, Haanstra R, Meijer WG, Hansen TA (1996a) Demethylation of dimethylsulfoniopropionate to 3-S-methylmercaptopropionate by marine sulfate-reducing bacteria. *Appl Environ Microbiol* 62: 3978-3984
- Van der Maarel MJEC, Van Bergeijk S, Van Werkhoven AF, Laverman AM, Meijer WG, Stam WT, Hansen TH (1996b) Cleavage of dimethylsulfoniopropionate and reduction of acrylate by *Desulfovibrio acrylicus* sp. nov. *Archives of Microbiology* 166: 109-115
- Van der Maarel MJEC, Aukema W, Hansen TA (1996c) Purification and characterization of a dimethylsulfoniopropionate cleaving enzyme from *Desulfovibrio acrylicus*. *FEMS Microbiol Lett* 143: 241-245
- Van Duyl FC, Gieskes WWC, Kop AJ, Lewis WE (1998) Biological control of short-term variations in the concentration of DMSP and DMS during a *Phaeocystis* spring bloom. *J Sea Res* 40: 221-231
- Van Gernerden H (1993) Microbial mats: a joint venture. *Mar Geol* 113: 3-25
- Vetter Y, Sharp JH (1993) The influence of light intensity on dimethylsulfide production by a marine diatom. *Limnol Oceanogr* 38: 419-425
- Visscher PT (1992) Microbial sulfur cycling in laminated ecosystems. PhD thesis, University of Groningen, Groningen
- Visscher PT, Kiene RP, Taylor BF (1994) Demethylation and cleavage of dimethylsulfoniopropionate in marine intertidal sediments. *FEMS Microbiol Ecol* 14: 179-190
- Visscher PT, Quist P, Van Gernerden H (1991) Methylated sulfur compounds in microbial mats: in situ concentrations and metabolism by a colorless sulfur bacterium. *Appl Environ Microbiol* 57: 1758-1763

- Visscher PT, Taylor BF (1993a) Organic thiols as organolithotrophic substrates for growth of phototrophic bacteria. *Appl Environ Microbiol* 59: 93-96
- Visscher PT, Taylor BF (1993b) Aerobic and anaerobic degradation of a range of alkyl sulfides by a denitrifying marine bacterium. *Appl Environ Microbiol* 59: 4083-4089
- Visscher PT, Taylor BF (1994) Demethylation of dimethylsulfoniopropionate to 3-mercaptopropionate by an aerobic marine bacterium. *Appl Environ Microbiol* 60: 4617-4619
- Visscher PT, Taylor BF, Kiene RP (1995) Microbial consumption of dimethyl sulfide and methanethiol in coastal marine sediments. *FEMS Microbiol Ecol* 18: 145-154
- Visscher PT, Van den Ende FP (1994) Diel and spatial fluctuations of sulfur transformations. In: Stal LJ, Caumette P (eds) *Microbial Mats. Structure, development and environmental significance*. Springer Verlag, Heidelberg, p 353-359
- Visscher PT, Van Gernerden H (1991a) Production and consumption of dimethylsulfoniopropionate in marine microbial mats. *Appl Environ Microbiol* 57: 3237-3242
- Visscher PT, Van Gernerden H (1991b) Photoautotrophic growth of *Thiocapsa roseopersicina* on dimethyl sulfide. *FEMS Microbiol Lett* 81: 247-250
- Vogt C (1997) Untersuchungen zum Metabolismus von DMS und verwandter Verbindungen durch phototrophe Bakterien. PhD thesis, Universität Bremen, Bremen
- Vogt C, Rabenstein A, Rethmeier J, Fischer U (1998) Alkali-labile precursors of dimethyl sulfide in marine benthic cyanobacteria. *Arch Microbiol* 169: 263-266
- Wagner C, Stadtman ER (1962) Bacterial fermentation of dimethyl- β -propiothetin. *Arch Biochem Biophys* 98: 331-336
- Watermann F, Hillebrand H, Gerdes G, Krumbein WE, Sommer U (1999) Competition between benthic cyanobacteria and diatoms as influenced by different grain sizes and temperatures. *Mar Ecol Progr Ser* 187: 77-87
- Wetsteyn LPMJ, Kromkamp JC (1994) Turbidity, nutrients and phytoplankton primary production in the Oosterschelde (The Netherlands) before, during and after a large-scale coastal engineering project (1980-1990). *Hydrobiol* 282/283: 61-78
- White RH (1982) Analysis of dimethyl sulfonium compounds in marine algae. *J Mar Res* 40: 529-536
- Williams GR (1996) *The molecular biology of Gaia*. Columbia University Press, New York
- Wilson WH, Turner S, Mann NH (1998) Population dynamics of phytoplankton and viruses in a phosphate-limited mesocosm and their effect on DMSP and DMS production. *Estuar Coast Shelf Sci* 46: 49-59
- Wolfe GV (1996) Accumulation of dissolved DMSP by marine bacteria and its degradation via bacterivory. In: Kiene RP, Visscher PT, Keller MD, Kirst GO (eds) *Biological and environmental chemistry of DMSP and related sulfonium compounds*. Plenum Press, New York, p 277-291
- Wolfe GV, Sherr EB, Sherr BF (1994) Release and consumption of DMSP from *Emiliania huxleyi* during grazing by *Oxyrrhis marina*. *Mar Ecol Progr Ser* 111: 111-119
- Wolfe GV, Steinke M (1996) Grazing-activated production of dimethyl sulfide (DMS) by two clones of *Emiliania huxleyi*. *Limnol Oceanogr* 41: 1151-1160
- Wolfe GV, Steinke M, Kirst GO (1997) Grazing-activated chemical defence in a unicellular marine alga. *Nature* 387: 894-897

- Yoch DC, Ansede JH, Rabinowitz KS (1997) Evidence for intracellular and extracellular dimethylsulfoniopropionate (DMSP) lyases and DMSP uptake sites in two species of marine bacteria. *Appl Environ Microbiol* 63: 3182-3188
- Zeyer J, Eicher P, Wakeham SG, Schwarzenbach RP (1987) Oxidation of dimethyl sulfide by phototrophic purple bacteria. *Appl Environ Microbiol* 53: 2026-2032

