

# Methane Production in Oxic Environments

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DOI: 10.5185/vpoam.2021.02118

## Abstract

Active methane production in oxygenated environments challenges the long-standing paradigm that microbial methane production occurs only under anoxic conditions and forces us to rethink the ecology and environmental dynamics of this powerful greenhouse gas. Methane production, e.g., in the upper oxic water layers, places the methane source closer to the air–water interface, where convective mixing and microbubble detrainment can lead to a methane efflux higher than that previously assumed. Microorganisms may produce methane in oxic environments by being equipped with enzymes to counteract the effects of molecular oxygen during methanogenesis or using alternative pathways that do not involve oxygen-sensitive enzymes.

I demonstrate that cyanobacteria living in marine, freshwater, and terrestrial environments produce methane at substantial rates under light, dark, oxic, and anoxic conditions, linking methane production with light-driven primary productivity in a globally relevant and ancient group of photoautotrophs. Methane production, attributed to cyanobacteria using stable isotope labeling techniques, was enhanced during oxygenic photosynthesis. I suggest that the formation of methane by cyanobacteria contributes to methane accumulation in oxygen-saturated marine and limnic surface waters. In these environments, frequent cyanobacterial blooms are predicted to further increase because of global warming potentially having a direct positive feedback on climate change. I conclude that this newly identified source contributes to the current natural methane budget and most likely has been producing methane since cyanobacteria first evolved on Earth.

## Biography of Presenting Author



### Education / Employments:

**1984:** School leaving examination (Naturwissenschaftliches Gymnasium Sobernheim)

**1991:** Diploma thesis (University of Constance, Limnology)

**1995:** Dissertation (University of Constance, Limnology, *summa cum laude* "Occurrence, formation, and microbial processes on macroscopic organic aggregates (lake snow) in Lake Constance" (the thesis was part of the **SFB 248:** "Stoffhaushalt des Bodensees", funded by the German Science (DFG) foundation.

**1992-95:** Interdisciplinary collaboration in the **SFB 248:** "Stoffhaushalt des Bodensees", funded by the German Science foundation (DFG).

**1995:** Postdoctoral student of Prof. Dr. T. Berman at the Yigal Allon **Kinneret Limnological Laboratory**, Tiberias, Israel. Scholarship of the „Förderkreises der deutsch-israelischen Zusammenarbeit, Konstanz“.

**1996-98:** Postdoctoral student of Prof. F. Azam at the **Scripps Institution of Oceanography** in La Jolla, USA. Research scholarship of the German Science Foundation (DFG, Gr 1540/11): "Formation of marine snow and the role of populations of attached heterotrophic bacteria".

**1998-2002:** Assistant professor at the **University of Oldenburg** (Institute for Chemistry and Biology of the Sea, ICBM) in the lab of Prof. Dr. Meinhard Simon: "Biology of biogeological processes". My main task was the quantification and characterisation of biogeological processes and the role of heterotrophic bacteria in aquatic systems, e.g.. German Wadden Sea, Red Sea, Lakes Kinneret and Constance.

**2002-present:** Head of the "Aquatic microbial ecology group" at the **Institute of Freshwater Ecology and Inland Fisheries (IGB)**. My main interest is to characterizing community structures of aquatic microorganisms, e.g. in various lakes of the Mecklenburg Lake District, Northeastern Germany, and in the Baltic Sea, and to elucidating their role in energy and nutrient cycles. The primary goal of my research is to combine fundamental and applied research to better exploit the present knowledge in aquatic microbial ecology for specific applications in industry, e.g. secondary metabolites including antibiotics, microbial processes of Poly-P storage and release, role of fungi in degradation of polymeric substances, aggregation processes and biofilm formation etc. My lab is well equipped to perform the most recent molecular techniques

(Real time PCR, PCR, DGGE, Sequencing, Transcriptomic), primary and secondary production measurements, as well as analytical methods (HPLC, TOC analyser etc.).

**2004: Habilitation** at the University of Oldenburg. “Role of heterotrophic bacteria in aquatic nutrient and energy cycles”.

**2008:** Head of the “**Programmbereich: Aquatic Biodiversity**” at the IGB.

**2009:** Call for W2-professorship, Microbiology (University of Dresden)

**2010-currently:** W2-professorship for Biodiversity and Microbial Ecology at University of Potsdam

### **Honors:**

**1983:** Laureate of the nation wide scientific contest: “Jugend forscht”.

**1995:** Second prize for specific ecological studies: 1500 DM, funded by Landesbausparkasse (LBS) for my PhD thesis.

**1997:** DIALOG II Symposium of the American Society of Limnology and Oceanography on Bermuda, Biological Station for Research, 12 to 17 October 1997.

Invited speaker on the spring meeting of the American Society for Limnology and Oceanography (ASLO), Santa Fe, 10 to 14 February 1997: “Lake Snow Aggregates: Centres of microbial activity?”

**1998:** Invited Speaker on the Kinneret Symposium. “Limnology and Lake Management 2000+”, August: “Bacterial motility and its implications for nutrient cycling”.

**2000:** Invited speaker of the CIESM Workshop: “Investigating marine microbial loops: new tools and perspectives”: ”Bacterial motility and its implications for nutrient cycling”, Zichron Yaakov, Israel, May 5 -8, 2000.

Position 25 in publication ranking from 1977-99 in ecology. Laborjournal 05/2000.

Position 27 in publication ranking from 1977-99 in marine and limnetic research. Laborjournal 10/2000.

**2002:** Invited Chair of the session:” Viruses and Prokaryotes in Aquatic Systems I + II”, AGU Meeting, Hawaii, February 11-15, 2001.

Invited speaker, Gordon-Conference, Biogeochemistry, Oxford, August 11-16, 2002.

**2003:** Invited speaker, FEMS-workshop: “Assessing the Variability in Aquatic Microbial Populations: Facts and Fiction”, Mondsee, 16-20 February 2003.

**2004:** Invited speaker, ASLO 2004 Ocean Sciences Meeting: “Bacterial dynamics on particles: colonization, interactions, and growth”, Hawaii, USA, February 15-20, 2004.

DGL- poster price for Glöß, S., M. Hupfer, **H.P. Grossart** 2004. “Untersuchung von Polyphosphat-speichernden Bakterien in Gewässersedimenten und Sinkstoffen”. DGL- annual meeting, September 20-24, 2004, Potsdam, Germany.

Invited speaker for the Minerva (Israeli-German) School 2004 funded by the BMBF, KLL, Tiberias, October 4, 2004.

**2005:** DAAD-short-term lectureship: Fluorescence In Situ Hybridisation (FISH) in collaboration with Dr. W. Reichardt, Marine Science Institute of the University of the Philippines, Bolinao, Philippines, May 9- June 2, 2005.

Invited speaker, seminar at the MSI, University of the Philippines (Diliman): Molecular methods in aquatic microbial ecology and their potential for marine resources management. May 31, 2005.

**2006:** Invited lecturer: Marine Microbiology class of the University Osnabrück in Eilat (February 5-19, 2006, Prof. Dr. K.-H. Altendorf).

Participation at the NSF funded workshop: “Microbial Ecology” held at the Mathematical Biosciences Institute, Ohio State University, Orlando, May 15-19, 2006.

DAAD-short-term lectureship: “Molecular methods in microbiology”, University of Kalmar, Sweden, in cooperation with L. Riemann, November 5-11, 2006.

**2007:** DGL-poster price for Koppe, C., L. Krienitz, **H.P. Grossart** 2007. “Mikrobielle Charakterisierung von Interaktionen zwischen heterotrophen Bakterien und Phytoplankton”. DGL- annual meeting, September 24-28, Münster, Germany

**Grossart, H.-P.,** F. Levold, M. Allgaier, M. Simon, and T. Brinkhoff. 2005. Marine diatom species harbour distinct bacterial communities. *Environ. Microbiol.* 7: 860-873. Paper among the top 25 cited papers in *Environ. Microbiol.*

**2008:** Our review paper: Simon, M., **Grossart, H.P.,** Schweitzer, B., Ploug, H. 2002. Microbial Ecology of Organic Aggregates in Aquatic Ecosystems. *Aquat. Microb. Ecol.* 28:175-211. was ranked the second most cited review paper in aquatic sciences (Germany, Austria and Switzerland, Laborjournal)

Invited speaker, Gordon Research Conference: Marine Microbes. Il Ciocco, Lucca, Italy, July 13-18, 2008

**2009:** Outstanding L&O reviewer. *ASLO bulletins*, June issue.

Invited plenary speaker, SAME 11th Symposium on Aquatic Microbial Ecology, Prian, Slovenia, 30th August to 4th September 2009.

DGL-poster price for Roskosch, A., Dziallas, C., **Grossart, H.-P.,** Hupfer, M., Lewandowski, J. Die Auswirkung von Bioirrigation auf mikrobielle Gemeinschaften und Prozesse in limnischen Sedimenten. DGL/SIL-annual meeting, Oldenburg, 28th September to 2d September 2009 (*Poster*).

Invited plenary speaker, the Symposium of the International Society of Limnology (SIL) 2009, Theme: Global Change and Freshwater Environments, October 24 – 27, 2009, Nanjing, China.

**2010:** Invited Lecturer: Linking bacteria-zooplankton interactions with aggregate dynamics in aquatic systems. Marine Biogeochemistry of Persian Gulf, Qeshm Island, Iran, October 24-27

**2011:** EU-Fellowship for my PhD student Bizic for participating in the PhD school: “Next generation insights into geosciences and ecology” on 12-13.05.2011, Tartu, Estonia.

Organizing committee for ASLO Ocean Sciences 2013 meeting in New Orleans

Young Scientist Award from the German Limnological Society (DGL) for my PhD student Claudia Dziallas. (Plenary talk on the DGL-2011 meeting in Munich, 11<sup>th</sup>-16<sup>th</sup> Septmeber 2011).

DGL-poster price for Fiedler, D., **H.P. Grossart**, Zwirnmann, E., Köhler, J. 2011. “DON-The forgotten nitrogen source”. DGL- annual meeting, September 11-16, Munich, Germany

**2012:** Young scientist award of the Leibniz foundation for Claudia Dziallas „Microbial interactions with cyanobacteria and zooplankton“, 28 November 2012, Berlin (3000 €)

First Northern German Science award (50,000 €) for the DFG funded “Forschergruppe Watt” in which I was PI and responsible for the the PhD programme. The prize was donated to all members of the research consortium.

**2013:** VAAM Poster Price 2013: Störkel, K., Gläser, S.P., Leunert, F., **Grossart, H.P.**, Salka, I., Gläser, J. (2013) Diurnal pattern of bacterial activity and growth in a humic lake. Annual meeting of the VAAM 2013, 10.-13. March, Bremen (Poster)

Young scientist award for Katrin Attermeyer (1<sup>st</sup> DGL young scientist presentation). Alles Gute kommt von Oben: Eintrag von terrigenem organischem Material. DGL-GfÖ annual meeting 2013: Sept. 9-13, Potsdam-Griebnitzsee

Young scientist award for Falk Eigemann (2<sup>nd</sup> DGL young scientist presentation). Allelopathische Eigenschaften aquatischer makrophyten. DGL-GfÖ annual meeting 2013: Sept. 9-13, Potsdam-Griebnitzsee

**2015:** “Friedrich Wilhelm Bessel-Forschungspreis” from the Humboldt society for Beatrice Beisner: Global change effects on limnic food webs: a mesocosm study.

Humboldt fellowship for Takeshi Miki: Linking bacterial community structure and functionality. 12 month stay in my lab.

SAME 14: poster price for Sarahi Garcia: The power of mixed cultures as model communities: Metabolic cooperation and genetic structure in freshwater. SAME 2014 meeting, Aug. 23-28, Uppsala, Sweden.

**2016:** Human Frontiers Science Program (HFSP), Award of HFSP research grant (RGP0020/2016): ”Interactions among marine microbes as they grow and die: linking experiments and genome-scale models” (ranked 14<sup>th</sup> of 672 initial applications), Strasbourg, 18. March 2016.

**2016 class of ASLO Fellow** honors ASLO members who have advanced the aquatic sciences via their exceptional contributions to the benefit of the society and its publications, meetings, and other activities.

**2017:** The review article: “Methane Production in Oxic Lake Waters Potentially Increases Aquatic Methane Flux to Air” was selected as one of the four best ones published in the reknown journal Environmental Science and Technology (ES&T) in 2016.

**ISME young scientist award** for my postdoc Luca Zoccarato on the SAME 15, Zagreb meeting for his talk: Zoccarato, L., Sher, D., Grossart, H.P. (2017) Searching for genomic signatures for

functional traits in marine bacteria by whole-genome comparative analysis. Symposium on Aquatic Microbial Ecology, SAME 15, Zagreb, Croatia, 3-8 Sep 2017.

**2018:** Our paper: “Freshwater copepod carcasses as pelagic microsites of dissimilatory nitrate reduction to ammonium” by Peter Stief, Ann Sofie Birch Lundgaard, Alexander H Treusch, Bo Thamdrup, Hans-Peter Grossart and Ronnie N Glud has been featured as the editor’s choice for issue 94-10 of FEMS Microbiology Ecology.

**2019:** Guest professorship at the Mediterranean Institute of Oceanography, Marseille

**2020:** 4 weeks of research stay on the Argentinian Carlini Station, King George Island, Antarctica

### Co-Organisation of Workshops:

**2013: ASLO 2013 Aquatic Sciences Meeting:** Learning for the Future, 17-22 February 2013, Ernest N. Morial Convention Center, New Orleans, Louisiana, USA (ca. 2500 participants)

**2013: Annual Meeting 2013 German Limnological Society and German Society for Ecology** on the Campus Griebnitzsee Potsdam 9.-13. September 2013 (ca. 1000 participants).

**2015: Biodiversity Workshop Programmbereich I:** The next generation of biodiversity research: theory, traits and methods. Biodiversity workshop at the Leibniz-Institute of Freshwater Ecology and Inland Fisheries (IGB) Berlin, 7-9 October 2015 (ca. 50 participants).

**2016: International Workshop: Dry Limit of Life,** 19.-21. October 2016, IGB, Lake Stechlin, Neuglobsow, 28 participants, co-organized with Dirk Schulze-Makuch und Mark Gessner

**2016: International HFSP Kick-Off Workshop: Microbial Interactions.** 20.-23. November 2016, IGB, Lake Stechlin, Neuglobsow, 15 participants

**2018: MANTEL Workshop.** 21.-25. February, IGB, Lake Stechlin, Neuglobsow, 30 participants

**2019:** Leibniz Forschungsverbund **Infections’21 Meeting**, IGB, Berlin, Germany 20-22 May 2019, ca. 50 people

**2019: 16<sup>th</sup> Symposium of Aquatic Microbial Ecology (SAME),** Potsdam, Germany, 1<sup>st</sup>-6<sup>th</sup> September 2019, ca. 250 people

### Editorial Board:

Fundamental and Applied Limnology (Editorial Board),

The Scientific World (Editorial Board),

Aquatic Microbial Ecology (Reviewing Editor),

Frontiers in Aquatic Microbiology

## **Reviewer of:**

### Journals:

Nature, Nature-Geosciences, Proc. Nat. Amer. Soc. (PNAS), Limnology and Oceanography, Marine Ecology Progress Series, Journal of Plankton Research, Journal of Phycology, Archiv für Hydrobiologie, Limnologica, International Review of Hydrology, Estuaries, Estuarine Coastal and Shelf Science, Helgoland Marine Res., FEMS Microbiology Ecology, Polar Scientific Publications, Microbial Ecology, BMC Ecology, International Microbiology, FEMS Microbiology Letters, Freshwater Biology, CSIRO Publishing, ISME Journal, Biogosciences, Organic Geochemistry, Marine Chemistry, Journal of Marine Systems, Journal of Applied Phycology, Phycology, Marine Environmental Research etc.

### Funding Agencies:

National Science Foundation (NSF, USA), Deutsche Forschungsgemeinschaft (DFG), Israelian Society of Science, Natural Environment Research Council (NERC, England), French National Science Foundation, Czech National Science Foundation, Finnish Academy of Science, Humboldt, BMBF, DBU, DAAD...

## **Member of the following organisations:**

Vereinigung für Allgemeine und Angewandte Mikrobiologie (VAAM), American Society of Limnology and Oceanography (ASLO), Deutsche Gesellschaft für Limnologie (DGL), Institute of Coral Reef Studies (ICRS), Polichia (Pfälzer Naturkundeverein), The Scientific World (Online Publisher), International Society for Microbial Ecology (ISME)

## **Citation of Video Article**

Vid. Proc. Adv. Mater., Volume 2, Article ID 2102118 (2021)

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