SCOR Working Group Proposal

Microbial Community Responses to Ocean Deoxygenation

Summary: Water column oxygen (O_2) deficiency shapes food web structure by progressively directing nutrients and energy away from higher trophic levels and into microbial community metabolism. There is increasing evidence that ocean warming trends will decrease dissolved O_2 concentrations within the coastal and interior regions of the ocean, resulting in oxygen minimum zone (OMZ) expansion. These processes will directly impact coastal benthic ecosystems and fisheries productivity due to habitat compression and changes in nutrient cycles with currently unconstrained feedbacks on the global ocean. Our SCOR working group will catalyze knowledge creation at the forefront of research on microbial community responses to changing levels of water column O_2-deficiency. We will unite oceanographers, microbial ecologists and biogeochemists to define model ecosystems, new standards of practice, and economies of scale needed for effective comparative analyses and enhanced forecasts of ocean deoxygenation. Our deliverables will include one field experience, two program meetings, a white paper on best practices, and a peer-reviewed monograph.

Objectives and timeliness: Direct quantitative comparisons of microbial community structure and function in O_2-deficient marine waters are currently stymied by a lack of standards for process rate and molecular data collection. This deficiency prevents cross-scale analysis linking the genotypic properties of microbial communities to higher order biogeochemical cycles and impedes synergistic scientific collaborations. Moreover, we need to formally define model ecosystems and concerted community initiatives to address fundamental questions and take advantage of appropriate economies of scale for transformative knowledge creation and translation. Our working group proposal was inspired by a recent exploratory workshop sponsored by the Moore Foundation and the Agouron Institute in Santa Cruz, Chile, which focused on identifying opportunities and bottlenecks for collaborative research in O_2-deficient marine waters. This workshop identified cross-scale comparisons and standardized measurements as a key bottleneck and an urgent opportunity for transformative science. Here we propose the establishment of a working group that networks the intellectual power of oceanographers, microbial ecologists and biogeochemists to build on the momentum of the Chilean workshop based on the following program objectives:

1) Identify model ecosystems manifesting ecological and biogeochemical phenotypes across a range of water column O_2-deficiency states
2) Develop community standards of data collection for both process rate and molecular measurements enabling cross-scale comparisons
3) Establish core metrics for modeling microbial community responses to changing levels of O_2-deficiency.
4) Disseminate standards, data sets and comparative analysis to the wider oceanographic and Earth system science communities and the public.

Terms of Reference: Our working group will catalyze research network formation and collaborative scientific practices over a four-year time frame that progressively transforms participants into a more focused and effective research community.

1. In year 1 of the working group we will convene a practical workshop in Saanich Inlet, a seasonally anoxic fjord off the coast of Vancouver Island British Columbia, Canada, to

ground truth common standards for process rate and molecular measurements and identify model ecosystems for future cross-scale comparative analyses.

2. In year 2, we will convene a meeting at the Leibniz Institute for Baltic Sea Research in Warnemünde, Germany to codify standards of best practice, identify leveraged funding opportunities and economies of scale, and compose a white paper describing said standards and opportunities.
3. In year 3, we will sponsor a topical session at an international conference such as ASLO, ISME, or ASM to highlight research findings informed by the best practices described in the white paper.
4. In year 4, we will convene a meeting at the National Institute of Oceanography in Goa, India to compile a peer-reviewed monograph, which we tentatively plan to publish as an electronic book in the Frontiers or PLoS open access journals to ensure both visibility and long-term access.

Scientific background and rationale: Ocean deoxygenation directly impacts marine ecosystem functions and services through changes in food web structure and biodiversity [1]. Climate change induced water column stratification and anthropogenic discharges are enhancing deoxygenation throughout the modern ocean [2,3,4,5,6]. As oxygen levels decline, energy is increasingly diverted away from higher trophic levels into microbial community metabolism resulting in significant environmental changes including fixed nitrogen loss, possible accumulation of hydrogen sulfide, and the production of climate active trace gases. Current research efforts are defining the interaction networks underlying microbial community metabolism in O_2-deficient waters and are rapidly generating new insights into coupled biogeochemical processes in the ocean[7,8]. However, many open questions remain regarding the commonalities and differences among and between locales, sensitivities to climate forcing, underlying regulatory mechanisms, and biotic interactions that modulate microbial community metabolism including grazing and viral infection. Moreover, we are presently unable to accurately forecast biogeochemical dynamics associated with changing levels of water column O_2-deficiency due, in part, to the limited integration of process rate and microbial community structure and function information between locales. Thus, the inevitable impacts of deoxygenation on ocean ecosystems, climate and human society remain uncertain. Technological innovations from high throughput sequencing to in situ monitoring and paired isotope labeling methods have increased our analytical capacity to probe the mechanisms underlying microbial community responses to ocean deoxygenation [8,9,10,11,12,13,14]. These technical innovations have yet to be standardized and applied in a cross-scale collaborative scientific endeavor to integrate process rate and microbial community structure and function information. A SCOR working group is needed to overcome existing activation barriers and achieve such cross-scale syntheses.

Why a SCOR Working Group?: Contemporary international collaborations can be effective in charting the microbial ecology and biogeochemistry of O_2-deficient waters. However these collaborations are almost exclusively compartmentalized into groups focused on specific biogeochemical processes in disparate oceanic locales. A SCOR working group would provide the opportunity to fuse these disparate efforts into a *bona fide* scientific network enabling synergistic cross-scale studies between locales that address long-term goals. Our working group focused on microbial controls on biogeochemical transformation and ecosystem stability in O_2-deficient marine waters is both timely and pressing as it directly addresses the ecological

implications associated with current global warming trends and OMZ expansion. Our working group will promote idea exchange, community engagement and transformative collaborative research projects on a global-scale by uniting oceanographers, microbial ecologists and biogeochemists across geopolitical and traditional disciplinary boundaries. The resulting network will build capacity in developing nations (India, Chile) and promote best practices at the epicenter of a pivotal issue in marine and climate science. We expect that our working group will inspire national agencies and international organizations to support operational components of our combined research programs, promote economies of scale that leverage matching funds between stakeholders including national and regional funding agencies and the private sector.

Relevance to other SCOR activities: Our proposed working group synergies with existing SCOR working groups including WG5 "The International Indian Ocean Expedition", WG128 "Natural and Human-Induced Hypoxia and Consequences for Coastal Areas", WG134 "Microbial Carbon pump in the Ocean" and WG137 "Patterns of Phytoplankton Dynamics in Coastal Systems". SCOR has a record of sustained interest in water column O_2-deficiency with a regional focus. Here we seek to develop an integrated science program that builds on previous working group successes on a global scale. Indeed a number of our members have participated in prior working groups bringing continuity and historical perspective to our new initiative. For example, between 2006-2010 associate members Daniel Conley, Nancy Rabalais, and SWA Naqvi participated in Working Group 128 focused on spatio-temporal variability, anthropogenic causes, ecological and biogeochemical impacts and ecosystem responses to coastal O_2-deficiency at a time when molecular methods for charting microbial community structure and function were still emerging. Our working group is differentiated from WG128 in its emphasis on cross-scale comparative analyses and standardization of process rate and molecular measurements. Our initiative is a direct and pressing response to recent scientific discoveries including the discovery of a cryptic sulfur cycle in the Eastern Tropical South Pacific OMZ[8] and the recent expansion of high throughput sequencing technologies opening a functional genomic window into microbial community metabolic potential and phenotypic expression. The monograph that we produce will integrate new data collected with best practices in working group defined model ecosystems to provide direct insight into the paradoxical role of microbial communities in biogeochemical transformation and ecosystem stability in O_2-deficient marine waters.

Composition of the group: Our working group management structure will be dynamic with leadership rotating between chairs each year. Bess Ward will serve as the leadership coordinator, working closely with the rotating chairs to ensure that working group objectives are met in accordance with the terms of reference. Sean Crowe and Steven Hallam will co-chair the field experience in year 1, Klaus Jurgens will chair the standards meeting in year 2, Virginia Edgcomb and Veronique Garcon will co-chair the session searches in year 3 and Nagappa Ramaiah will chair the synthesis meeting in year 4. All full members are committed to participating in working group activities and will engage associate members in collaborative scientific endeavors. Sean Crowe and Steven Hallam will edit the monograph.. Associate members augment the experience and expertise of the working group and in several cases provide an intellectual bridge to prior SCOR working groups.

Full Members

Name	Expertise/System Focus	Institution	Email
Bess Ward	Biogeochemistry	Princeton University,	bbw@princeton.edu

	Open Ocean	USA	
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Matt Sullivan	Viral Ecology Open Ocean	University of Arizona, USA	mbsulli@email.arizona.edu

Bess Ward is the William J. Sinclair Professor of Geosciences and the Chair of the Department of Geosciences at Princeton University. She has pioneered nitrogen cycle process rate measurements in O_2-deficient coastal and open ocean waters helping to elucidate the distributed nature of nitrogen transformations within microbial communities. Her research focuses on the marine and global nitrogen cycle, using molecular biological investigations of marine bacteria and bacterial processes. A major and continuing theme in her work is nitrification and denitrification. She is a Fellow of the American Academy of Microbiology, the American Geophysical Union and the American Academy of Arts and Sciences. She has received numerous awards including the G. Evelyn Hutchinson Medal from the American Society of Limnology and Oceanography making her the first women and the youngest person ever to receive such an award.

Nagappa Ramaiah is chief scientist at the National Institute of Oceanography in Goa, India. He is a biological oceanographer with a deep and abiding interest in microbial mediated biogeochemical cycles. He has extensive leadership experience and has participated in numerous international oceanographic initiatives including previous SCOR working groups.

Phyllis Lam is a Lecturer at the University of Southampton and National Oceanography Centre in Southampton, UK. She is a microbial ecologist and biogeochemist with expertise in coupled process rate and molecular analyses including functional genomics, gene expression and nanoSIMS. Phyllis has extensive expertise in describing nitrogen cycling in both coastal and open ocean OMZs with particular emphasis on microbial controls on anaerobic ammonia oxidation.

Sean Crowe is an Assistant professor and Canada Research Chair nominee cross-appointed to the departments of Microbiology & Immunology, and Earth, Ocean & Atmospheric Sciences at the University of British Columbia. His background is transdisciplinary spanning the fields of geology, geochemistry and environmental microbiology. His specific interests are in the coupled evolution of microorganisms and Earth surface chemistry over multiple scales of space and time.

Veronique Garcon is a CNRS senior scientist at the Laboratoire d'Etudes en Géophysique et Océanographie Spatiales where she develops coupled physical/biogeochemical models of marine ecosystem function. Her research interests include marine biogeochemistry and ecosystem dynamics, large-scale ocean circulation and tracers, global carbon and nitrogen cycles, physical-biological interactions, eastern boundary upwelling systems and biogeochemical climatic monitoring. She is

currently a steering committee member for SOLAS (Surface Ocean Lower Atmosphere Study) and has participated in numerous international collaborative initiatives.

Osvaldo Ulloa is Professor of Biological Oceanography at the University of Concepcion, in Concepcion, Chile. He is an international leader in the study of microbial community responses to marine O_2-deficiency with extensive biological oceanographic experience. He currently runs a time-series monitoring program in permanent and seasonal OMZs off the Chilean coast that has been the source of fundamental new insight into coupled biogeochemical cycling in the ocean.

Virginia Edgcomb is a Research Specialist in the department of Geology & Geophysics at the Woods Hole Oceanographic Institution. Her research focuses on the ecology and evolution of protists and their interactions with other microorganisms in marine micro-oxic and anoxic/sulfidic environments including coastal OMZs and semi-enclosed basins.

Steven Hallam is a Canada Research Chair in Environmental Genomics. He is an Associate Professor in the Department of Microbiology and Immunology and program faculty member in the bioinformatics training program at the University of British Columbia. His background is in the field of microbial ecological genomics and genetics with specific emphasis on the creation of computational tools and workflows for taxonomic and functional binning, population genome assembly, and comparative community analysis. He currently runs a time-series monitoring program in the northeast subarctic Pacific Ocean focused on microbial community structure and function in coastal and open ocean OMZs.

Klaus Jurgens is Professor of Biological Oceanography at the University of Rostock, Germany and the Deputy Head of Biological Oceanography at the Leibniz Institute for Baltic Sea Research in Warnemünde. He is international leader in the study of microbial community structure and function in O_2-deficient waters, with particular emphasis on chemolithoautotrophic prokaryotes and protist interactions in enclosed basins including the Baltic and Black Seas.

Matt Sullivan is an Assistant Professor in Ecology & Evolutionary Biology and a Joint Assistant Professor of Molecular & Cellular Biology at the University of Arizona. His research aims to elucidate the mechanisms of phage and host genome evolution, as well as to explore the roles of ocean viruses in global biogeochemical cycling. In 2013 he was awarded a Marine Microbiology Investigator Award from the Gordon and Betty Moore Foundation in recognition of his ground breaking contributions to the filed of viral ecology.

Associate Members

Konstantinos Kormas (University of Thessaly, Greece: Microbial Ecologist), Daniel Conley (Lund University, Sweden: Quaternary Sciences), Karen Casciotti (Stanford University, USA: Geochemistry), Nancy Rabalais (Louisiana Universities Marine Consortium, USA: Biological Oceanography), Raquel Vaquer-Sunyer (Lund University, Sweden: Biogeochemistry), Frank Stewart (Georgia Tech, USA: Microbial Ecology), Mark Altabet (University of Massachusetts, USA: Geochemistry), SWA Naqvi (National Institute of Oceanography, India), Jody Wright (University of British Columbia, Canada: Microbial Ecologist), David Karl (University of Hawaii, USA: Biological Oceanographer), Jon Kaye (Gordon and Betty Moore Foundation: Program manager), Robinson (Wally) Fulweiler (Boston University, USA: Biogeochemist) Annie Bourbonnais (University of Massachusetts, USA: Geochemistry), Mak Saito (Woods Hole, USA, geochemistry).

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