

SCOR Working Group Proposal

NEw physiological Metrics for Oceanography from 'Omics (NEMOO)

Summary/Abstract

The need to understand how ocean global change affects marine life has exposed gaps in our knowledge of fundamental principles. Although molecular biological techniques, particularly 'omics (genomics to proteomics), now dominate research in biological oceanography, physiological research has stagnated, leading to the assumption that physiology is outmoded. However, biological rates and biogeochemical fluxes remain the main currencies in biogeochemistry (BGC) models in which microbes play a central role. The question we aim to address – with a focus on marine microbes – is how to translate 'omics-based information on physiological potential into quantifiable physiological rates, and ultimately into BGC processes that can be represented in Earth system models.

While 'omics has revealed patterns in marine microbial diversity and metabolic pathways, it largely provides only static snapshots of physiological potential. Studies that weave 'omics and physiological rates together provide greater insights and improved mechanistic understanding. But despite these advances, there is widespread frustration about the paucity of physiological metrics, as most of these metrics were devised before the molecular biology revolution. To improve our understanding of the roles of marine microbes in biogeochemical cycles, we need better tools to quantify physiological activity. Physiological rates quantify the integrated activity of proteins that drive marine BGC cycles and can bridge the gap between 'omics and biogeochemistry. We propose the development of a community and framework for co-designing physiological metrics as currency converters to link 'omics datasets and BGC models, a central aim of the international BioGeoSCAPES program.

Scientific Background and Rationale

The necessity to understand the influence of ocean global change on biota has exposed wide-ranging gaps in our knowledge of the fundamental principles that underpin marine life (Cooley et al., 2022). Concurrently, physiological research has stagnated, in part driven by the advent and subsequent rapid evolution of molecular biological techniques (i.e., 'omics), such that they now influence all lines of enquiry in biological oceanography (Melzner et al., 2022). This dominance has led to an implicit assumption that physiology is outmoded, and that ecological and BGC models can be directly informed by 'omics (Oremland et al., 2005). However, the main modeling currencies are biological rates and BGC fluxes. We propose, in this working group, to address the question: *how do we translate the wealth of information on physiological potential and function from 'omics-based studies to quantifiable physiological rates and, ultimately, to BGC processes and their representation in Earth system models?*

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In marine science, over the last two decades, 'omics has clearly demonstrated large-scale patterns in microbial diversity across oceanic provinces and provided insights into which metabolic pathways are active. The history of marine nitrogen fixation research reveals the benefits and limitations of physiological rate measurements, and also points to how these measurements can be complemented by more recent 'omics approaches (Zehr and Capone, 2020). But, 'omics-based approaches provide static 'snap-shots' of physiological potential, and we need to improve our quantitative, process-level understanding of the roles of marine microbes in biogeochemical cycles. Indeed, it is physiological activity—as modified by biological species differences, environmental drivers, and the interactions between the two—that ultimately drives biogeochemical cycles (Falkowski et al., 2008).

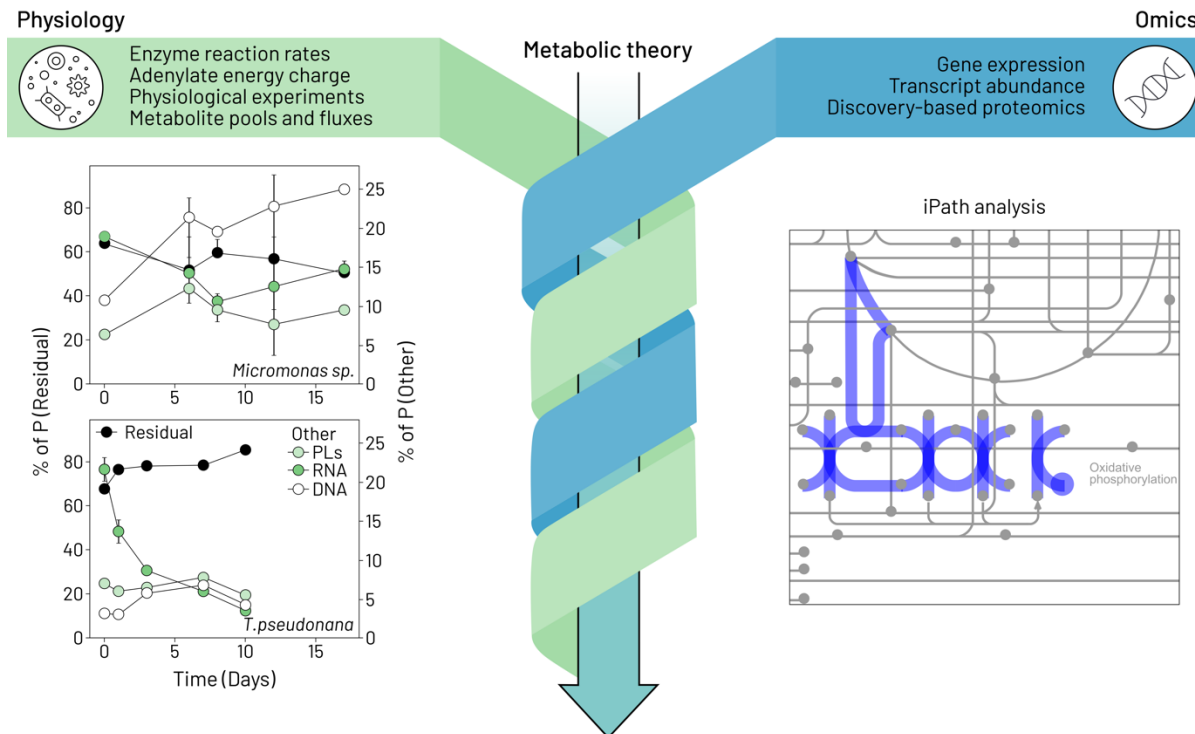
In contrast to the rapid evolution of 'omics techniques, the physiological metrics used to quantify biological rates that are the cornerstones of BGC and Earth system models, such as primary productivity, have not fundamentally changed in decades (*c.f.* Boyd et al., 2022). 'Omics provides a surfeit of data with immense potential to enhance our understanding, but at a level of detail that is often difficult to relate to the information provided by physiological rate measurements and the current need to better parameterize Earth system models (Meiler et al., 2022). This growing mismatch between the currencies of global-scale models (rates and fluxes) and the aspirations of omics (coupling cellular potential via 'omics to Earth system model projections) must be addressed urgently if we are to understand the fundamental principles driving marine life and BGC cycles (Strzepek et al., 2022).

Although our current choice of physiological metrics needs urgent scrutiny, there is compelling evidence of the utility of long-established (and overlooked) assays when interfaced with innovative phytoplankton cellular models (Inomura et al., 2020). But can we also be inventive and use 'omics to interpret physiology in a more holistic way? Physiology can provide valuable insights into metabolism, even when considering only a few cellular processes. Imagine the progress in our fundamental understanding of the microbial 'rules of life' if we developed better metrics jointly with 'omics.

Biogeochemical Currency Conversion

We propose that physiological rate measurements can bridge BGC and 'omics. Physiological rates quantify the integrated activity of proteins that drive marine BGC cycles in units that modelers can use. Looking at more advanced fields than oceanography, such as systems biology or biomedicine, 'rates from 'omics' is unlikely in the next decade. On the other hand, research into the ocean's BGC cycles reveals the potential of using the joint expertise of the physiology and 'omics communities (*i.e.*, co-design) to guide future research (Figure 1; Strzepek et al., 2022). We can extend this complementary approach to use 'omics datasets to develop new targeted physiological metrics that improve the parameterization of BGC processes. We propose to develop a community and framework for co-design of physiological metrics that may act as 'currency converters' to link 'omics datasets and BGC models, a central aim of the nascent (launch proposed for 2026) international BioGeoSCAPES program (www.biogeoscapes.org).

New physiological Metrics for Oceanography from 'Omics (NEMOO)



Co-design of new high-throughput metrics

Figure 1. The potential of reverse-engineering a new suite of physiological metrics to provide better linkages with molecular tools, as exemplified by phosphorus. Potential physiological approaches (top left green box of illustrative examples) applicable to the proposed WG include re-evaluation of long-established metrics, developing a framework for quantitative high throughput enzyme assays, clever experimental design (Bell, 2019), quantifying adenylate energy charge (Karl, 1980) and tracking metabolite pools / fluxes (Moran et al., 2022). Top right panel is a KEGG map from iPath, a web-based tool to visualize cellular pathways from 'omics (e.g., Nunn et al., 2013). Combining approaches—denoted by the green and blue intersecting arrows—will improve underpinning biochemical (e.g., metabolic, resource allocation) theory and identify candidate pathways for the co-design of new physiological assays.

Rationale. Why a SCOR working group now?

Humanity needs us to be able to make accurate predictions about the current and future states of marine biogeochemical cycles now. Marine microbes drive most of the key marine biogeochemical cycles (Falkowski et al., 2008). Yet, our ability to predict the responses of marine microbes to complex climate change is currently limited, in part, by our inability to translate the ever-growing wealth of information we now have on physiological potential, gained from 'omics, into an understanding of their activity. We need to capitalize on what we have already learned from the rare studies that have considered 'omics and physiology jointly (e.g., Walworth et al., 2016). We are now at cross-roads – if we don't address the imbalance between the paucity of physiological metrics and their limited applicability to 'omics urgently we may soon be at an impasse for the improved parameterization of ocean scale models needed to project the responses of microbes to complex climate change. The recent

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debate between the DARWIN modeling group from MIT (Meiler et al., 2022, 2023) and marine nitrogen fixation genomicists (Zehr and Riemann, 2023) reveals some of the emerging challenges in converting between 'omics and modeling currencies that will become exacerbated if not addressed in a timely way. The need is clear, and the opportunity is now, but we have been hindered by disciplinary silos and language barriers between physiologists, molecular biologists, and modelers. This working group will serve the crucial role of getting these communities in the same room, organized around the common aim of connecting this great need to this great opportunity. The multi-disciplinary and international work we propose would be impossible to support from national or regional funding.

This WG's goals are to:

1. Identify what physiological processes we should be paying attention to. Many physiological approaches were developed before the 'omics revolution. Are we still measuring the best currencies? If so, can we measure them more efficiently? Can we currently leverage 'omic measurements to estimate rates effectively?
2. Develop a framework and toolset for discovering proxies of physiological processes that can bridge 'omics and models, leveraging expertise from physiologists, 'omics researchers as well as cell and BGC modelers.

The overarching aim of the WG is to identify and set the stage for the development of a core suite of measurements that are harmonized, low-cost, easy to use, and high throughput to promote co-measurement of 'omics, rates, and BGC. Some of these will be new physiological measurements and some of these will be new ways to combine 'omic measurements and cellular modeling approaches to understand physiology and improve the parametrization of larger scale models. The measure of success for this WG would be to bring co-design to fruition and establish a framework for the creation of physiological metrics that when implemented at scale and at low cost are broadly accessible.

Terms of Reference

ToR1

Review current physiological metrics, **identify the key gaps** in our understanding of marine microbial metabolism as revealed by 'omics that are candidates for the co-design of new physiological assays, and **rank** these candidate assays according to their likely success for development and their biogeochemical importance.

ToR2

Identify the physiological metrics of marine microbial metabolism best suited to **convert between the currencies** of 'omics datasets and models, from cellular (fine scale) to BGC (coarse scale) models, using the WG's combined expertise in 'omics, physiology and modeling, and the knowledge gained from ToR 1.

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ToR3

Determine the pathways to implementation with respect to assay development (learning the design process from systems biology, ecotoxicology, and biomedical sciences), and in doing so **develop a framework and toolset** for discovering proxies of marine microbial physiological processes that can bridge 'omics and models.

ToR4

As a proof of concept, **identify a flagship physiological metric to develop**, using the roadmap designed in ToR 3, and assess whether this can be made **high throughput and integrated with new observational platforms to stimulate the co-measurement** of marine microbe 'omics, physiology, and the BGC processes.

Working plan and Timeline

To address ToR 1, we will undertake 3 activities.

1.1: **review the literature for existing physiological metrics**, including those from other relevant research fields (e.g., freshwater science, ecotoxicology, gut microbiome) and from other SCOR WGs (e.g., 156, 165, 166). This review will cover **classic** physiological **metrics** routinely used in biological oceanography, as well as **novel metrics** that are being developed to determine physiological rates at a cellular and community level (e.g., click chemistry, nano-SIMS and SIP, quantitative metaproteomics).

1.2: **identify knowledge gaps of key metabolic pathways, as revealed by the global 'omics datasets**, due to the lack of physiological measurements.

1.3: combine the outcomes from Activities 1.1 and 1.2 to **create a ranked list of the key metabolic pathways to focus on**. Activity 1.3 will include a detailed assessment of i) the **best approach** for each physiological process (e.g., targeted assays vs. measuring substrates), ii) our **ability to design such metrics**, and iii) their **highest-value insight into marine microbial dynamics** and biogeochemical cycling.

To address ToR 2, we will undertake 2 activities that build on the ToR 1 deliverables.

2.1: identify **improvements needed in our ability to couple 'omics to physiological rate proxies**. This will enhance the skill of cellular-scale models that predict physiological rates, perhaps through the leveraging of 'omics data directly (e.g., McCain et al., 2021). This work will focus on physiological rate proxies that are relevant to, and can be easily incorporated into, ocean scale models (e.g., nutrient uptake, organic carbon production). WG member Levine will lead this effort, as their group develops innovative, interdisciplinary numerical models that provide insight into how cell dynamics impact large-scale processes (e.g., rates of global carbon cycling). The WG will discuss how to best link observations and laboratory data to coarser grained biogeochemical models (e.g., NPZD or trait-based models), exploring the use of proteome allocation, quota, and metabolic models. We will also work to **identify the best ways to leverage output from cell-scale models into ocean scale models** (e.g., DARWIN).

2.2: **collaborate with ocean scale modelers (see NEMOO net, described below)** to identify critical physiological proxies to parameterize in their models. For the desired proxies, we can then determine the candidate assays we need to quantify to target those proxies. In this way, we propose to **'reverse engineer' physiological metrics from 'omics with input from modelers**. Ultimately, Activity 2.1 and 2.2 will allow us to create a **ranked list of the priority co-designed physiological proxies to target for method development**.

To address ToR 3, we will develop a framework and toolset to design and implement the physiological proxies identified in ToR 2. WG members with expertise in novel physiological techniques (e.g., nano-SIMS and SIP, quantitative metaproteomics) will lead the effort. We will draw on our WG members' knowledge of isotope and tracer labeling (e.g., Maldonado), *in situ* stable isotope probing techniques to tease apart individual contributions of different taxa to community physiological rates (e.g., Wilkin), and novel methods' development for physiological rate determinations in marine phytoplankton (e.g., Behrendt), as well as insights from researchers in other disciplines (e.g., systems biology, ecotoxicology, and biomedical sciences) that our WG members collaborate with.

To address ToR 4, we will undertake 2 activities.

4.1: **identify a flagship physiological metric to develop**, using the roadmap designed in activity 3.1. This WG has the capability to conduct concomitant *in situ* community-based rate measurements, single-cell physiological rate determinations, and 'omics research. Furthermore, WG and NEMOO net members (e.g., Bertrand, Crowe and Maldonado) have developed a novel autonomous submersible profiling and incubation system (BioApnea) to investigate *in situ* microbial activity and function. This system can i) collect samples for microbial 'omics studies, and for dissolved and particulate trace metal and nutrient analyses, and ii) determine *in situ* metabolic rates with minimal perturbation and high temporal and spatial resolution. These combined multi-disciplinary approaches will be used to **validate this flagship physiological metric as a proxy bridging 'omics and models**.

4.2: explore whether our flagship physiological metric can be made **high-throughput and scalable**. Can this assay be conducted using existing, **low-cost** instruments and accessible reagents? Such efforts would enable unprecedented spatial and temporal resolution and accessibility to research communities lacking complex instrumentation. Such accessibility could provide inspiration for our research community in future assay co-design efforts.

Timeline

Month 1: First online working group meeting, focused on planning and identification of leadership and sub-groups for each of the ToRs.

Months 1-12: Meet virtually each month to guide the literature review, build the online databases, and conduct the gap analysis (ToR 1); implement **a mentorship program** (see below) to facilitate mentee participation in the first annual in-person meeting, scheduled to occur in conjunction with the Marine Microbes Gordon Research Conference in Switzerland, June 2024 (co-chaired by Levine).

Months 12-24: Identify and rank the physiological metrics best suited as 'currency converters' between 'omics and models; engage with ocean scale modelers (NEMOO net, see below) to identify the desired

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physiological proxies to parameterize in their models; virtual second annual meeting, commence work on a Perspective paper focused on 'currency conversion' between 'omics and modeling.

Months 20-36: Develop an assay creation framework (ToR 3); hold a third annual in-person meeting and host a town hall at the Ocean Sciences Meeting 2026 to present our new metric and our assay development tool; continued work on ToR 2 deliverable.

Months 30-42: develop and validate the flagship physiological metric (ToR 4); ongoing mentorship exchanges; commence work on web-based marine microbial **assay workflow optimization tool**.

Months 38-48: launch the assay workflow optimization tool (ToR 4); summarizes the outcomes and recommendations of the WG in a synthesis paper; final meeting, and **hybrid training course** for ECRs and researchers from developing countries, in UAE, 2025 (hosted by Amin, NYU Abu Dhabi); meeting will focus on community outreach and seeking other fora to further capitalize on the synergies and stronger collaborations emerging from the WG.

Deliverables

The WG deliverables are designed to build capacity for the co-measurement of 'omics, rates, and BGC processes (Fig. 2).

The deliverables for ToR 1 are: an online database of current and desired physiological metrics, highlighting metabolic processes revealed by 'omics that are critical for quantifying marine microbial metabolism, but that we do not currently have assays for (**D1**), and an "ocean metabolism by the numbers" database which lists and describes key physiological parameters and how they are known to be linked to BGC processes (**D2**). Both D1 and D2 will be available on a freely accessible web portal. Social media will be used to publicize these open access tools (e.g., [@biogeoscapes](#)).

The deliverable for ToR 2 is an open-access Perspective paper focused on 'currency conversion' between 'omics and modeling (**D3**).

The deliverables for ToR 3 and 4 are a **high-throughput flagship assay protocol and companion paper (D4)**, which will serve as an exemplar for a freely accessible web-based marine microbial **assay workflow optimization tool (D5)**, with video tutorials and a training workshop to facilitate capacity development in implementing D4 and D5 (**D6**). An overarching deliverable is an open-access synthesis paper describing our co-design approach and assay workflow optimization tool (**D7**).

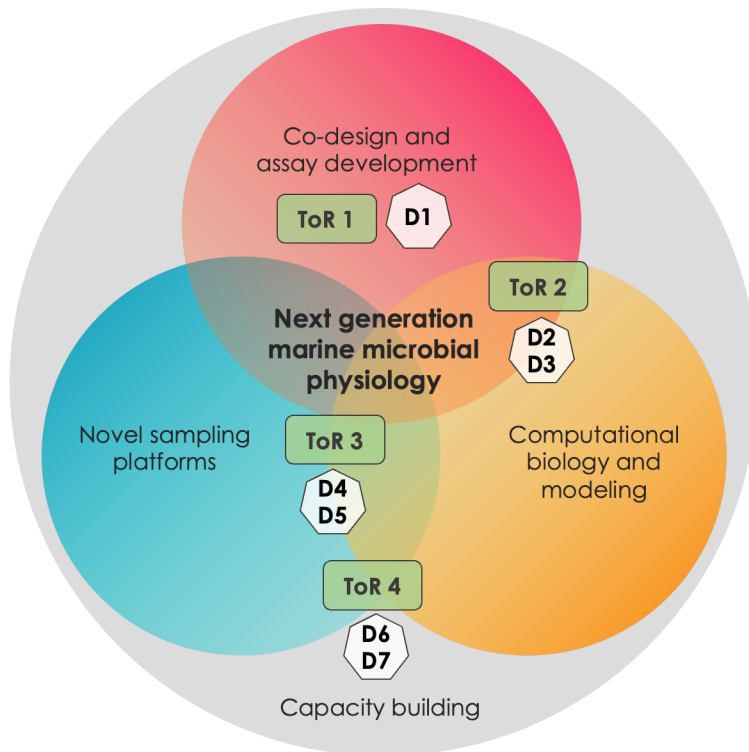


Figure 2. The WGs tripartite approach to setting the stage for the development of a core suite of marine microbial physiological measurements that are harmonized, low-cost, easy to use, and high throughput to promote co-measurement of 'omics, rates, and BGC., annotated with Terms of Reference (ToRs 1-4) and deliverables (D1-7).

Capacity Building

At the heart of our working group aims is building a community of researchers poised to ensure microbial physiology is embedded in the next great wave of ocean discoveries. This will only be possible through extensive capacity building across the globe and, in particular, in developing nations and indigenous communities.

Currently, much of the work done to glean physiological information from ocean 'omics data and to advance microbial physiology approaches in the marine sciences appears to be coming from groups based in the US, Japan, Europe and Canada. The historical expense of generating 'omics data and the specialized instrumentation required for making many of the required measurements appear to be, in part, causative. Our approach to address this and center Capacity Building in our activities is three-pronged. First, we will maintain focus on developing assays that can be implemented at scale and at low cost, increasing their accessibility. Second, we will ensure that there are extensive opportunities for early career researchers, indigenous youth and researchers from developing nations to engage with and benefit from our WG progress and activities, and third, we will ensure that our products are freely available, accessible and usable. Our deliverables were designed with these aims in mind.

To ensure access and engagement in our working group process from early career researchers and researchers from developing nations, we will implement **a mentorship program** where each of our members is paired with a mentee from one of those two groups, with a preference for early career researchers from developing nations. This mentorship will begin in the first 12 months of the working group and will last for its lifetime. We will work to raise funds, through our universities- many of which

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have already expressed interest in sponsoring this approach, and other avenues, to facilitate mentee participation in scientific meetings (e.g. Marine Microbes Gordon Research Conference 2024) at which we hold our annual working group meetings and at the Ocean Sciences 2026 Town Hall we will host. Other avenues for supporting focused mentorship opportunities with our working group include the Swedish [STINT](#) program and the Canadian [MITACS](#) program which financially support research exchanges with developing nations

We will ensure **free and open dissemination of all our deliverables**. Specifically, our Perspective paper, our comprehensive review, and our manuscript describing our co-designed assay will be published in open access journals. Additionally, we will build a video tutorial as a how-to guide to implementing this co-designed assay, for example in the Journal of Visualized Experiments (www.jove.com) that has an open access option. A centerpiece of our Working Group, our assay development tool, will be created collaboratively with [lonata](#), a digital agency based in Hobart, Tasmania that designed the web interface for the [MEDDLE](#) best practice guide developed by SCOR WG 149, and hosting will be initially supported financially by the University of Tasmania (host institute of co-chair Strzepek). The burgeoning BioGeoSCAPES program (www.biogeoscapes.org) is a viable entity that could maintain this development tool on the web beyond the lifetime of this working group, which will be imperative for its continued utility to the community and its continued contribution to capacity building.

We will also **host a hybrid training course in the United Arab Emirates**, building on our video tutorials, for early career researchers and those from developing nations to receive tailored training in our assay implementation and our development tool. This training course will contribute to focused capacity building in the Persian Gulf, the hottest body of water on Earth and arguably the least studied (6 research cruises in total since the 1960s; last one in 2001). This region hosts a new environmental center ([ACCESS](#)) to build infrastructure for data collection, which lacks qualified personnel for accomplishing microbial rate measurements but has funds to support hosting this training course.

While developing nations around the world currently lack capacity for participating in this work, indigenous communities within developed nations also lack this capacity in a profound way. The lack of participation of indigenous peoples in the natural sciences has many varied and complex causes, and there are growing calls for natural scientists to actively work against this. In an important 2020 paper, Wong et al. lay out “10 Calls to Action to natural scientists working in Canada” to work towards reconciliation with indigenous communities. While focused on Canada, we believe this offers valuable perspectives for all. Their Call 5: “We call upon natural scientists to provide meaningful opportunities for Indigenous community members, particularly youth, to experience and participate in science” resonates with this working group. We propose to **hire indigenous youth as field technicians** in three countries to implement our flagship assay in coastal regions of their territory. We will use these data and their work in our manuscript and video tutorials describing these assays, allowing these youth to engage in many aspects of the scientific process and making the contributions of indigenous youth visible for all who engage with our work. We have already received positive feedback from our universities regarding offering funding for this purpose.

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NEMOO net: Experienced researchers, in addition to those who are members of our working group, have expressed enthusiasm for contributing to our working group activities. These include Alessandro Tagliabue (University of Liverpool), Philip Boyd (University of Tasmania), Mick Follows (Massachusetts Institute of Technology), Stephanie Dutkiewicz (Massachusetts Institute of Technology), Julie LaRoche (Dalhousie University), Zoe Finkel (Dalhousie University), Mak Saito (Woods Hole Oceanographic Institute), Sean Crowe (University of British Columbia), Brook Nunn (University of Washington), Tatiana Rynearson (University of Rhode Island), C. Mark Moore (University of Southampton), Sinead Collins (University of Edinburgh), and Emilio Marañón (University of Vigo). This consortium, along with our WG, trainees and mentees form NEMOO net, which will enable us to provide high quality training and development opportunities and benefit from extensive collaborative interactions.

Working Group composition

NEMOO includes 10 Full Members with the range of expertise needed to address the Terms of Reference, including microbial physiology and ecology, molecular biology, biogeochemistry, and numerical modeling, as well as experience in method development, public engagement, and capacity building. The Full Members represent a broad geographic spread from Europe, Australia, Africa, North America, Asia, and the Middle East. The gender balance is 5:5 female:male with two early career researchers (ECR).

Name	Gender	Place of work	Expertise relevant to proposal
Erin Bertrand (co-chair; ECR)	F	Dalhousie University, Canada	marine microbial physiology and biogeochemistry, proteomics, metabolomics
Robert Strzepek (co-chair)	M	University of Tasmania, Australia	physiological ecology of marine phytoplankton, biogeochemical cycles of bioactive metals
Shady Amin	M	NYU Abu Dabi, UAE	microbial biogeochemical cycles, symbiotic interactions between phytoplankton and bacteria, multi-omics techniques
Federico Baltar	M	University of Vienna, Austria	role of fungi and prokaryotes in marine elemental cycles, genomics, transcriptomics, proteomics
Rachel Foster	F	University of Stockholm, Sweden	interactions between prokaryotes and photosynthetic eukaryotic hosts, single cell microbial physiology

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Naomi Levine	F	University of Southern California, USA	single cell models of microbial biogeochemical cycles
Aditee Mitra	F	Cardiff University, UK	system dynamics modeling, plankton food web models
Thomas Ryan-Keogh (ECR)	M	Southern Ocean Carbon and Climate Observatory, South Africa	microbial physiology and primary production, algorithms on bio-optical data, seasonal variability in microbial dynamics
Koji Suzuki	M	Hokkaido University, Japan	interaction between phytoplankton and diazotrophs, metabarcoding, metatranscriptomics, stable isotope labeling
Susanne Wilkin	F	University of Amsterdam, Netherlands	role of mixotrophic protists in primary production and bacterivory, stable isotope probing, physiological assays, transcriptomics

Associate Member

The Associate Members provide additional expertise and experience in microbial physiology and ecology and modeling. The Associate Members represent a broad geographic spread from Europe, North America, Asia, and the Middle East. The gender balance is 4:6 female:male with two ECR.

Name	Gender	Place of work	Expertise relevant to proposal
Kai Ziervogel	M	University of New Hampshire, USA	bacterial metabolic rates, secondary production and respiration, microbial elemental cycles
Maite Maldonado	F	University of British Columbia, Canada	phytoplankton physiology, trace metal acquisition by marine phytoplankton
Lars Behrendt (ECR)	M	Uppsala University, Sweden	microbial ecology (single cell and community level), microbial community structure and function
Tom Bibby	M	University of Southampton, UK	photophysiology of phytoplankton, links between physiology and -omics
Chuan Ku (ECR)	M	National Taiwan University, Taiwan	alga-microbial interactions (symbioses and viral infections), multi-omics approaches

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Jana Milucka	F	Max Planck Institute for Marine Microbiology, Germany	microbial physiology and metabolic rates (single cell and community level), metagenomics and metatranscriptomics
Yeala Shaked	F	The Hebrew University of Jerusalem, Israel	microbial ecology, nutrient and trace metal uptake, -omics, molecular fingerprinting
Dalin Shi	M	Guangxi University, China	phytoplankton ecophysiology, physiological and biogeochemical measurements coupled with -omics
Taichi Yokokawa	M	Japan Agency for Marine-Earth Science and Technology, Japan	marine microbial activity (heterotrophic and autotrophic), large scale microbial community distribution and biogeochemical modeling
Patrizia Ziveri	F	Autonomous University of Barcelona, Spain	marine pelagic ecosystem diversity and evolution, marine food web interactions

Working Group contributions

Erin Bertrand applies proteomic and metabolomic approaches in the field and the lab to understand marine microbial physiology and biogeochemistry. She has experience using cellular models and proteomics to estimate rates from omic data and is currently working to identify physiological rates that can be estimated directly from quantitative proteomic measurements.

Robert Strzepak combines classic physiological tools and (meta-)proteomics in the laboratory and field to better understand the physiological ecology of marine phytoplankton and the impact they have on marine biogeochemical cycles, particularly of bioactive metals.

Shady Amin uses multi-omics techniques to study the role microbes play in global biogeochemical cycles with a strong emphasis on symbiotic interactions between phytoplankton and bacteria at the microscale and how they influence large-scale phenomena. He is currently developing techniques in metagenomics and metabolomics at the single-cell level to understand these relationships in the ocean.

Federiko Baltar studies the role of microbes (fungi and prokaryotes) on marine elemental cycles, the influence of mesoscale features on microbial functioning and diversity, and the anthropogenic impact on marine microbes and organic matter cycling. He combines physiological rate measurements and molecular tools with modern -omics approaches on natural communities and cultured isolates.

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Rachel Foster holds expertise in microbial oceanography with an emphasis on microbial interactions between nitrogen fixing microbes and photosynthetic eukaryotic hosts (e.g., symbioses, consortia). She works in the development of single cell methodologies that couple physiology with rate measurements (e.g. Mass Spectrometry Imaging), microscopy, genome content, and gene expression, so that phenotype and activity can be matched to specific cells.

Naomi Levine is developing interdisciplinary numerical models that allow us to understand how dynamics occurring at the scale of individual microbes impact large-scale ecosystem processes such as rates of global carbon cycling. Ultimately, these models seek to incorporate -omic information and trade-offs that individual cells make to predict large-scale biogeochemical rates.

Aditee Mitra holds expertise in system dynamics modeling to integrate eco-physiological data into plankton food-web models for *in silico* investigations. Over the last few years, her research has focused primarily on the mixoplankton paradigm.

Thomas Ryan-Keogh works on the development and application of physiological and primary production algorithms on bio-optical data collected in the Southern Ocean to understand seasonal variability and long-term changes. His more recent projects include the applications of these algorithms on a global scale.

Koji Suzuki studies phytoplankton and diazotrophs in the North Pacific through GEOTRACES-relevant field campaigns and ship-of-opportunity observations between Japan and North America using metabarcoding, metatranscriptome, UHPLC algal pigment, and stable isotope (^{13}C and ^{15}N) labeling techniques.

Susanne Wilkin focuses on mixotrophic protists to assess their quantitative contribution to ecosystem processes including primary production and bacterivory, as well as the balance of auto- versus heterotrophy in individual lineages. She uses stable isotope probing approaches (RNA-SIP) in the field, physiological assays and transcriptomics in the lab, and is planning to combine those with meta-omics in the future.

Relationship to other international programs and SCOR Working groups

This WG links to SCOR activity “Changing Ocean Biological Systems (COBS): how will biota respond to a changing ocean?” (formerly WG 149) by developing new methods to quantify this change. It will contribute to WG 166 (DMS-PRO) by working to improve the accurate rate measurements of the biotic processes involved in the cycling of sulfur compounds in the ocean; WG 165 (MixONET) by contributing to the development of new methods and simple protocols to better quantify mixoplankton physiological activities; WG 156 (Active Chlorophyll fluorescence) by assessing alternatives to the methods currently used to quantify marine primary productivity; and WG 161 (Respiration in the Mesopelagic Ocean) by developing a link between microbial rate measurements including respiration,

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and BGC models.

This WG has direct bearing on the science plan being developed for [BioGeoSCAPES](#), which is an international and interdisciplinary microbial biogeochemistry program to improve our understanding of ocean metabolism. The ToRs of this WG will contribute towards the main goal of BioGeoSCAPES to combine 'omics and biogeochemical rate measurements on a global scale. The work within NEMOO will also be of relevance to other international project and networks including [SOLAS](#) (Surface Ocean Lower Atmosphere Study; Core Theme 3: Atmospheric deposition and ocean biogeochemistry; Core Theme 5: Ocean biogeochemical control of atmospheric chemistry) and [GEOTRACES](#) (Marine Biogeochemical Cycles of Trace Elements and Isotopes; Theme 2: Internal cycling).

This WG also addresses several of the [UN Decade of Ocean Science for Sustainable Development Priority Challenges](#), helping to align their goals towards the realization of a healthy ocean future. Specifically, Challenge 2 (Protect and restore ecosystems and biodiversity): Understand the effects of multiple stressors on ocean ecosystems, and develop solutions to monitor, protect, manage, and restore ecosystems and their biodiversity under changing environmental, social and climate conditions. Challenge 5 (Unlock ocean-based solutions to climate change): Enhance understanding of the ocean-climate nexus and generate knowledge and solutions to mitigate, adapt and build resilience to the effects of climate change across all geographies and at all scales, and to improve services including predictions for the ocean, climate and weather, Challenge 7 (Expand the Global Ocean Observing System): Ensure a sustainable ocean observing system across all ocean basins that delivers accessible, timely, and actionable data and information to all users, and Challenge 9 (Skills, knowledge and technology for all): Ensure comprehensive capacity development and equitable access to data, information, knowledge and technology across all aspects of ocean science and for all stakeholders.

Key References

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Appendix: Five key publications for each full member

Erin Bertrand (Co-Chair)

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Robert Strzepek (Co-Chair)

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