Changing Ocean Biological Systems
2024 Annual Report to SCOR

SECTION 1. Activities since the previous report to SCOR (e.g., virtual or in-person meetings, email discussions, special sessions). Limit 1000 words

This year, COBS has focused mainly on first, establishing involvement with a recurring conference where ocean multiple driver biology researchers can network and exchange ideas regularly. We have identified the "Ocean in a High CO_2 world symposium" as a possible option (see below), and established ties with the BioGeoScapes programme. Second, we have improved the interface and statistical support associated with MEDDLE, our suite of resources for designing multiple driver experiments, as well as improved the structure and support for our National Advocated network, a group of ECRs who disseminate MEDDLE resources globally. Finally, we continue to produce outputs aimed at researchers in the form of peer reviewed papers and conference presentations.

Since its first inception at the UNESCO Headquarters in Paris in 2004, the "Ocean in a High CO_2 world" symposium was held every 4 years with a main focus on ocean acidification. The fifth edition was held in Lima, Peru in September 2022 gathering hundreds of scientists. SCOR was instrumental in the initiation and support of these events in collaboration with UNESCO, SOLAS, IMBER, the IAEA and many other international organizations. The need for a new edition was discussed at the last meeting in Peru. A survey was conducted, and the community advocated for expanding the central theme from ocean acidification to multiple stressors. A collaboration is now initiated between COBS, the SOLAS-IMBER ocean acidification working group (SIOA) and the Ocean Acidification International Coordination Center (OA-ICC) of the International Atomic Energy Agency (IAEA) to co-organize the next edition in 2026. Hong Kong University has expressed interest in hosting such an event.

Team 1. Identifying priorities for multiple driver / stressor research (Renaud, Vargas, Belgrano, IMBeR). During 2024, Vargas worked with social scientists, including Dr. Stefan Gelcich (Chile), and both published an article in *Communications Earth & Environment* highlighting the importance of recognizing the role of multiple drivers of changing coastal pH on the decadal trends of coastal acidification. This analysis emphasizes the importance of addressing coastal acidification through a suite of linked Sustainable Development Goals (SDGs) related to different pH drivers (e.g., eutrophication, pollution, changing land uses, climate change, among others), as it may help avoid inaction at local scale by connecting global phenomena such as ocean acidification with local impacts and drivers. The article also promotes the prioritization of recommendations for the best locations for long-term ocean acidification monitoring (target 14.3 from IOC-UNESCO) (see: Vargas & Gelcich 2024, https://doi.org/10.1038/s43247-024-01485-6). This type of article highlights the need for holistic and integrative perspectives to analyze how multiple stressors operate in the ocean. This is especially important in coastal areas, where it is necessary to develop and implement methodologies to prioritize some of these stressors.

Team 2. Promoting action on multiple driver / stressor research (McGraw, Dupont, Cornwall)

Team 2 has hosted workshops on experimental design aimed primarily at ECRs and those from developing countries, and is improving resources for workshops and support based both on feedback, and on advances in best practices. The most common request from ECRs is for more extensive resources around statistics. To meet this, Dillingham, McGraw, Collins, Thomas and guest Comeau met in Kristeneberg, Sweden 22nd July to 26th July 2024 and developed 6 vignettes walking through analysis strategies and R code for common multidriver experiments. They are also facilitating efforts by other communities to do the same. For example, they facilitated a workshop for researchers working on heatwaves in warm water corals to organize distributed experiments (Gothenburg, Sweden. 19th to 21st July 2024). This will be moved forwards by the coral group itself, with COBS providing support where appropriate.

Team 3. Model evaluation (Dutkiewicz, Seifert, Gehlen, Thomas)
Team 3 is identifying ways to enhance collaboration between modellers and experimentalists, with a focus on improving the parameterization of phytoplankton growth in models. The objective is to more effectively communicate relevant concepts to experimentalists who measure growth rates in the laboratory. To better understand the range of current model parameterizations, they have created a survey (https://forms.gle/aX2FL47Eiy4H4XYp7) that queries how modelled growth rates are influenced by temperature, light, and nutrients, the perceived limitations of current parameterizations, potential improvements, and the requirements from experimentalists to enhance these parameterizations. They currently have 7 models represented in the survey and anticipate 3 more models to be included. The survey reveals that all models use a multiplicative function to account for nutrient and temperature limitations. This approach does not optimally capture the complex combined effects of these two environmental variables – a point that most survey participants noted as a next step requirement. The subgroup is developing an article that clarifies why these simplifications are currently used, and helps experimentalists understand the necessary steps to improve parameterizations.

Team 4. From ocean observations to biological thresholds (Thomas, Boyd, Collins)

COBS has been forging linkages with the emerging international programme “Biogeoscapes” (https://biogeoscapes.org/) whose aim is to study “Ocean metabolism and nutrient cycles on a changing planet”, as captured on their website:

“Despite over a century observing Earth’s biogeochemical cycles, we still lack fundamental knowledge about the *environmental and microbial controls* on these essential biogeochemical cycles. This knowledge is necessary for understanding the response of the Earth system to human perturbations.”Thus, there is mutual benefit to cross-linking the aims of team 4 with some of the planned products from this decade-long programme such as “BioGeoSCAPES would

create the first global scale microbial maps revealing the distribution of microbes and their genes in every ocean basin."

To facilitate this development, Boyd is part of the Science plan writing team for Biogeoscapes and a member of the international implementation plan. He has been an advocate for voyages to collect microbes for lab culture, to provide a linkage between microbial ocean provinces, environmental data on multiple stressors, and lab based experiments into biological thresholds.

Team 5. Mechanistic understanding (Hutchins, Hall-Spencer, Leung) . This team has focused on peer-reviewed outputs this year (see outputs table).

SECTION 2. Documents published since the previous report to SCOR (e.g., peer-reviewed journal articles, reports, Web pages) and should be limited to publications that resulted directly from project activities and which acknowledge SCOR support.

See output table

SECTION 3. Progress toward achieving project's terms of reference. List each term of reference separately and describe progress on each one. Limit 1000 words

ToR1. Develop open-access teaching and learning resources for educators and researchers based on the Best Practice Guide (https://eprints.utas.edu.au/29392/) and MEDDLE (https://meddle-scor149.org/). These resources will be used to train scientists in multiple driver research in coordination with existing programs, e.g. MSc programmes, summer schools and conference-affiliated training sessions. An online-only program will also be developed.

The MEDDLE website (https://meddle-scor149.org/) has been improved based on user and expert feedback, to make it more accessible to users who have not attended MEDDLE workshops. The landing page now has three main links, with a clear path for users to follow (Design your experiment -> MEDDLE simulator -> Additional Resources). The primary page (*Design your experiment*) has been updated with clearer guidance and material based on MEDDLE workshops, and working through the material has been streamlined . Background and supporting material is consolidated in the *Additional resources* page. Notable workshops facilitated this year were: The 10th International Conference on Marine Pollution and Ecotoxicology, Hong Kong, China. 3rd to 6th January 2024 and a MEDDLE training workshop. Asian Pacific Phycological Forum. Sapporo, Japan. 18th April 2024.

ToR2. Advocate coordination and harmonisation of experimental approaches by providing data-based guidance through existing structures on how to maximise overlap between different experimental approaches and analysis to allow tighter intercomparison.

Several of our actions are aimed at harmonizing or improving experimental approaches. The resources associated with MEDDLE and the National Advocates network have been improved, as has training and guidance for the National Advocates.

Over the past 2 years, Cornwall and McGraw have identified research communities who are not reached by existing resources. One such community are researchers on warm-water corals. To facilitate coordinated multidriver experiments in the coral community, COBS facilitated a two day working group on “Coordinating Coral Heatwave Experiments” in Gothenburg, Sweden in July 2024. The meeting was facilitated by Collins and Dupont. Cornwall is conducting a meta-analysis of coral heatwave experiments, and also coordinates COBs National Advocate Network; he is also an active researcher in understanding bleaching and heatwave response in warm water corals. The meeting assembled early and mid-career researchers who currently carry out heatwave/bleaching experiments in corals, and produced a framework and plan for coordinated coral heatwave experiments, as well as a way to open up this network to the wider community. Attendees at the meeting were Verena Schoepf (Amsterdam), Maggie Johnson (KAUST), Heidi Burdett (Umeå), Christopher Cornwall (Wellington), Erik Krieger (KAUST), Nick Kamenos (Umeå) , Steeve Comeau (Villefranche), Marlene Wall (Geomar), Sebastian Hennige (Edinburgh). The format of a small and focused working group as a first step in this project has worked well, with very high engagement, and a clear plan for expanding membership in the coordinated experiment, as well as a path for producing guidelines and data curation.

ToR3. Progress the science towards a more holistic approach to address how multiple drivers will reshuffle marine ecosystems at a decadal scale. To do this, we will develop a strong conceptual framework around a subset of key questions that will be determined by surveying the ocean global change biology community as broadly as possible. This will allow us to bridge disjoints between models, experiments and observations. This framework will be published as a high-profile publication, and survey results will be made available on our website and publicized at meetings.

This ToR is advanced by the ongoing work led by Boyd - BIOGEOSCAPES - see Team 3 and 4 update above.

ToR4. Publish a series of short articles in both the scientific media and with scientific journalists to disseminate the challenges and opportunities surrounding multiple drivers and ecosystems.

Paul Renaud and colleagues have had a manuscript accepted in *Limnology and Oceanography Letters* entitled *Multiple climatic drivers increase pace and consequences of ecosystem change in the Arctic Coastal Ocean.* This article suggests the open-ocean perspective on Arctic change has largely neglected the coastal regions where the diversity and magnitude of changes in the marine system are generally higher and are amplified by changes occurring on land. Further, many of the ecological impacts of changes in multiple coastal drivers are poorly quantified and have more direct implications for human communities. Priorities for addressing these issues are outlined.

Sejr, M.K., A. Poste, P.E. Renaud. 2024. Multiple climatic drivers increase pace and consequences of ecosystem change in the Arctic Coastal Ocean. *Limnology and Oceanography Letters*. in press

ToR5. Link to societal questions, such as food security, by expanding multiple driver research to include higher trophic levels. This will be done, in part, by engaging with IOC-endorsed and other initiatives to promote an interdisciplinary process-based approach linking observations, models, and experiments within the UN Decade of Ocean Science for Sustainable Development.

P. Renaud has coordinated a collaboration with IMBeR and Andrea Belgrano attended our annual meeting in March 2023. Based on this, a joint manuscript has been submitted with the IMBeR IC4 co-champions and fellows. This manuscript identifies some of the main challenges in combining ecological and social science perspectives in addressing transdisciplinary issues and cites examples of capacity development to meet these challenges. We hope this work and a planned joint session at the Future Ocean IMBeR meeting in 2024, will create synergies for solving the complex problems created by changing oceans.

The sixth edition of the International Workshop "*Bridging the Gap between Ocean Acidification Impacts and Economic Valuation*" will be held the 9-11 October 2024 in Monaco. This edition focuses on multi-disciplinary approach to address multiple ocean stressors. Six members of COBS will be present as experts (Collins, Hall-Spencer, Renaud), chairs and/or keynote speakers (Boyd, Dupont). This was made possible through the collaboration and in-kind contribution (travel, local costs) of the IAEA and the Prince Albert the Second Foundation (PFA2). Several deliverables are expected including scientific publications centered on case studies (e.g. combined effect of ocean acidification and local drivers) as well as a high-level summary for policy makers endorsed by his highness the Prince Albert of Monaco.