

Annual SCOR Project Reports to SCOR Changing Oceans Biological Systems (COBS)

Summary (200-300 words)

The Changing Oceans Biological Systems project focuses on improving our understanding of how multiple drivers impact biological responses in marine systems. Activities in 2021/2022 focused on three key areas. First, our activities facilitated discussions within the scientific community on multiple driver research by organizing a session at the Ocean Sciences 2022 conference, as well as by building a collaboration with IMBeR to examine the socio-economic aspects of multi-driver change in ocean systems. Second, we developed new or improved training materials and opportunities around our online bank of resources (meddle-scor149.org), including developing slide decks for educators, and offering online in an in-person workshops. Finally, COBS members played pivotal roles in preparing high-level documents informing policy, such as the [Multiple Ocean Stressors: A Scientific Summary for Policy Makers](#) (UNESCO-IOC (2022)) and the chapter section on multiple stressors in the 2022 IPCC WG2 AR6 Chapter 3 on ocean systems.

In the coming year, we will continue to offer workshops aimed at Early Career Researchers (ECRs), and expand this focus to better reach scientists from developing countries by expanding our national advocate network, and improving the coordination and crosstalk within this network. We will also coordinate with members of research-active communities (such as coral reef researchers) to discuss multiple driver experimental design in the context of these specific systems. We will strengthen the collaboration between COBS and IMBeR on multiple drivers and changing socio-economic systems. Potential for shared activities include publications, workshops within the IMBeR summer school or open sciences meeting, or a jointly-run seminar with the IMBeR ECR network. Finally, we will re-invigorate several projects on surveys and high level peer reviewed publications that were put on hold during the pandemic.

Current composition and affiliation/country of Scientific Steering Committee or Steering Group members

Co-Chairs: Sinéad Collins (University of Edinburgh), Philip Boyd (University of Tasmania)

Full members: Aurea Ciotti (Brazil), Kunshan Gao (China-Beijing), Marion Gehlen (France), Jason Hall-Spencer (UK, Japan), David Hutchins (USA), Christina McGraw (New Zealand), Mridul Thomas (Switzerland), Paul Renaud (Norway)

Associate members: Haimanti Biswas (India), Christopher Cornwall (New Zealand), Sam Dupont (Sweden), Jonathan Havenhand (Sweden), Haruko Kurihawa (Japan), Uta Passow (Canada), Hans-Otto Pörtner (Germany), Marcello Vichi (Italy, South Africa)

Project goals – overall

The overall goals of the COBS project is to evaluate current approaches to studying organismal responses to multiple drivers in the ocean, and to advocate for the improvement of multiple

driver experiments. We aim to reach early-career and established researchers, policy makers, and funding agencies. We do this by developing educational materials and workshops to facilitate improving multiple driver experiments, building collaborations with other scientists (e.g. IMBeR), publishing high-level, peer reviewed papers, and participating in high-level policy and summary documents aimed at policy makers.

Activities since previous report to SCOR (e.g., virtual or in-person meetings, email discussions, special sessions).

COBS is built around five cross-linked teams. Each team has developed a 2-3 page position analysis, which will be discussed at the AGM in early 2023 (moved from summer 2022 due to GRC cancellation). Revised versions of these will go to the Advisory panel, made up of SCOR WG149 ex-members (Gattuso, Riebesell, Fabricius and Navarro).

Team 1. Identifying priorities for multiple driver / stressor research (Havenhand, Collins).

Goals: Bottom-up evaluation - formulate key scientific questions to advance this topic (scientists within COBS). Top-down evaluation - Identify available and tractable solutions to reduce the cumulative pressure on marine life from multiple stressors and constraints on implementing them (policy/innovation discussions with UN Decade of Ocean Science, IMBeR)

Deliverables: Recommendations on what science is needed to develop/implement solutions in ocean global change research. Collins and Thomas published an opinion paper in 2022 (Collins et al. *Current Opinion in Microbiology* 68 (2022): 102151) identifying a research gap where full factorial experiments are rarely done, even in cases where they are possible (mainly for phytoplankton). Closing this gap will improve projections of phytoplankton population growth rates, and more generally identify inflection points (tipping points) in multidriver responses for primary producers. Draft of broader position piece on what (Collins, Havenhand, Dupont, Hutchins) was paused during pandemic, as both Collins and Havenhand were both moved into new, high-workload directorships at their institutions at or near the beginning of the pandemic.

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

Goals: Engage all stakeholders on this topic (communication). Teaching and promotion of best practices in experimental design. Increase engagement with researchers from developing countries.

Deliverables: Delivery of in-person and virtual trainings. Expansion of slide decks and other educator resources. Improved communication and recruitment of national advocates for ongoing education and engagement. See specific activities for details.

Team 3. Model evaluation (Gehlen, Vichi)

Goal: Scrutinizing model projections and parameterisations - are they fit for purpose in the context of multiple drivers and their influence on ocean processes?

Deliverables: scientific papers, workshops within the modelling communities. Initial paper drafts are in progress. We do not anticipate these being finished in 2022, as significant data gathering and analysis needs to be done.

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

Goal: To expand suites of observations to provide a biological context of when detrimental thresholds are crossed.

Deliverables: Use GOA-ON (Global Ocean Acidification Network) as a test bed for developing and testing new tools (such as seawater omega sensor), (scientific articles, position analysis).

Boyd has been co-ordinating with international members of the Biogeosciences (biogeosciences.org) community in North America and Europe in discussions around how to best sample for biological processes and omics to ensure intercomparability of data from planned research voyages to multiple oceanic provinces. He has also been exploring how to add a multiple stressors dimension to this fledgling international programme.

Paper by Boyd's lab on the need for new metrics for physiological rates that are codesigned by the omics community (Strzepek et al. 2022, Journal of Plankton Research). This approach also has widespread applications of multiple driver / stressor research.

Team 5. Mechanistic understanding (Hutchins, Passow, Ciotti)

Goal: Improved mechanistic understanding of biological responses to multiple drivers.

Deliverables: developing our mechanistic understanding beyond two drivers, exploring compound extremes (concurrent warming acidification and hypoxia) as test beds for better conceptual understanding (scientific articles (Gruber et al., 2021 Nature), position analysis)

Specific activities

- A. *Facilitating discussions within the scientific community on multiple driver research:* COBS proposed and chaired a session at Ocean Sciences in February 2022 (OC08 Multiple Stressors: from ocean physics to ecosystem function).

We have continued to work towards integrating social scientists into our activities. The task team led by Paul Renaud continues to discuss with IMBeR representative Carol Robinson and with Mike Drexler from the Ocean Conservancy on how to best move forward (see future plans).

- B. *Continued development of training materials and opportunities in improving the design of multiple driver experiments.*

Publications by project members provide high-level, peer-reviewed publications on marine multiple driver experiments and their design (see Documents published)

We continue to improve and expand our in-person, virtual workshops that use our online resources of introductory text and videos, as well as our experimental simulator (meddlescor149.org). In 2021 and 2022, McGraw and Dupont led the production of stand-alone tools and slide decks for workshops that are freely available to educators. Collins and Renaud offered an online training to the Marine Alliance for Science and Technology Scotland doctoral training programme in 2021 online. Several workshops and trainings are planned for 2022/2023 (see planned activities).

The activities of individual SCOR members also supports the activities of the group. For example, a grant submission to NERC UK (Collins) in winter 2022 includes the development of a multiple drivers workshop/best practices guide funded by the IAEA (Monaco) for producing 3-driver interaction surfaces for phytoplankton (Collins, Dupont, Thomas, with collaborator Ward (Southampton, UK) and Rost (AWI, Germany)). Decision on grant application expected in summer/autumn 2022.

C. *Activities focused on informing policy*

Our members (Boyd, Dupont) have participated in producing a summary for policy makers as requested by the UN Decade of ocean science for a sustainable ocean. This also provides “talking points” for policy makers.

Boyd and Dupont led the chapter section on multiple stressors in the IPCC WG2 AR6 Chapter 3 on ocean systems. This included a new hierarchical approach to categorizing advances in our understanding on biological responses to multiple stressors and also included a cross reference to how far our understanding has advances since the 2014 IPCC WG2 AR5 report. Note that the IPCC has strict rules on acknowledgments.

Documents published since previous report to SCOR (e.g., peer-reviewed journal articles, reports, Web pages). Those listed are publications that resulted directly from project activities and which acknowledge SCOR and/or NSF support (COBS members are underlined in the following publications).

Note that significant effort from COBS members has gone into preparing the 2022 IPCC AR6 Working Group 2 Chapter 3 but this report does not permit recognizing affiliations (such as the NSF support for COBS) beyond one’s institution, so this substantive publication is not eligible for inclusion in the publication record for COBS even though it has an emphasis on multiple drivers/stressors that was driven by COBS members and informed by our project activities.

Cooley, S., D. Schoeman, L. Bopp, P. Boyd, S. Donner, D.Y. Ghebrehiwet, S.-I. Ito, W. Kiessling, P. Martinetto, E. Ojea, M.-F. Racault, B. Rost, and M. Skern-Mauritzen, 2022: Ocean and Coastal Ecosystems and their Services. In: *Climate Change 2022: Impacts, Adaptation, and Vulnerability*. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. In Press.

Peer-reviewed publications:

Collins, S., H. Whittaker, and M.K. Thomas. "The need for unrealistic experiments in global change biology." *Current Opinion in Microbiology* 68 (2022): 102151.

IOC-UNESCO (2022) Multiple Ocean Stressors: A Scientific Summary for Policy Makers, (eds P.W. Boyd, S. Dupont and K. Isensee). Paris, France, UNESCO, 20pp. (IOC Information Series, 1404). DOI: <http://dx.doi.org/10.25607/OBP-1724>

Gruber, N, P.W. Boyd, T.L Frölicher and M. Vogt (2021). Biogeochemical extremes and compound events in the ocean. December 2021, Nature 600 :395-407. DOI:10.1038/s41586-021-03981-7

Workshop materials: Teaching slide decks for one day workshops or a series of 1-2 hour tutorials available at <https://meddle-scor149.org/teaching-resources/>

Progress toward achieving project's goals.

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 be developed to reach researchers who cannot attend in-person training.*

MEDDLE resources include a best practice guide, tutorial texts and videos, and experimental design simulator, and slide decks for workshops (<https://meddle-scor149.org/teaching-resources/>), in addition to trainings that we deliver. Improvement of resources to include monitoring (see planned activities) is in progress. Widdicombe et al. (*Unifying biological field observations to detect and compare ocean acidification impacts across marine species and ecosystems*) is currently in Review in *Global Change Biology*. This will be adapted to a short addition to the Handbook or website by December 2022.

In MEDDLE workshops, we have seen that many ECRs believe that they can answer challenging multiple driver questions with a single study. Although the MEDDLE training resources state that experiments should be designed as part of a *strategy*, this needs to be clearer. This has become a stronger focus of the workshops, and Dupont's interactive talks, and the Havenhand paper. However, when the Handbook is updated, this message will be emphasised.

It has been difficult to reach established researchers who are in fields that are self-perceived as more contained (eg. Coral reef community). To address this, we will develop short papers targeted at specific fields. Cornwall has approached three coral reef researchers who are interested in working together to develop a short paper that addresses shortcomings in some long-standing experimental practices, e.g., definitions of marine heat waves. By working with established researchers in the field this paper may hold more weight than a paper written by people outside of the field. The proposed paper would build on Cornwall et al.'s recently published paper: *Impacts of ocean warming and acidification on calcifying coral reef taxa: mechanisms responsible and adaptive capacity* (*Emerg Top Life Sci* (2022) 6 (1): 1–9).

ToR2. *Advocate coordination and harmonisation of experimental approaches by providing data-based guidance through existing structures such as the GRC (ocean Global Change Biology workshop), IOC (UN Decade of Ocean Science) on how to maximise overlap between different experimental approaches and analysis to allow tighter intercomparison.*

Communicating multiple driver research to established researchers can hit roadblocks due to differences in terminology. To address this, we propose a series of interactive talks at local and international conferences. Dupont has developed an engaging webinar (*Do you (really) know your multiple stressors?*) which he has presented as a 2021 [GOA-ON webinar](#) and as a presentation at the 2021 New Zealand Ocean Acidification Conference. Initial responses (approximately 150 respondents) indicate a surprisingly high number of misconceptions about stressors and their impacts. For example, on average, the ~100 participants in Dupont's [GOA-ON webinar](#), answered only 28% of multiple-choice answers correctly. Data collection will continue through 2022 as opportunities arise. Data will be used for a short conceptual paper revising the key concepts in late 2022.

We can increase engagement with researchers from developing countries by applying lessons learned from the last two years (2020 – 2022) of on-line learning. Dupont is coordinating the activity for the OA-ICC. New training opportunities will be organized in late 2022 in Monaco (in collaboration with the Foundation Prince Albert II) and will include multiple stressors.

We have also integrated our workshops with other platforms. McGraw and Dupont prepared OA lectures for [IOC UNESCO's Ocean Teacher Global Academy](#). McGraw and Dupont also led two modules of the course's first training. This 6-week [Ocean Acidification in the Pacific Islands](#) online training course attracted 248 Pacific Islanders who came together virtually to learn more about OA impacts, research, and monitoring. The course was jointly organised by SPC, USP, NOAA, IOC-UNESCO, University of Otago, NIWA, and University of Hawaii (21 February – 10 April).

COBS members have published peer-reviewed scientific papers that outline the logic behind using specific experimental designs (e.g. full factorial) to develop generalizable theoretical underpinnings for phytoplankton responses to 2 or more drivers, or which examine rate measurements in the context of biogeochemistry. See Collins et al. 2022 paper in outputs, and Strzepek et al 2022 (<https://doi.org/10.1093/plankt/fbac026>) (co-authored by Boyd, but does not formally acknowledge SCOR).

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.

During the past two years, we have not been able to prioritize the planned survey; we will discuss how best to move forward with this at our next AGM. However, activities by Boyd and Dupont on the IPCC WG2 AR6 Chapter 3 on ocean systems and the Summary for Policy makers contribute to this ToR. Progress on this ToR was limited due to the difficulties engaging with our community without the connections provided by conferences, workshops, and other in-person events. Attendance at meetings such as the Royal Society Meeting on marine microbes in a

changing ocean in September 2022 will provide a springboard to reconnect with the community and resume activities on this ToR.

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. See publication list.*

The major efforts of SCOR members have been focused on the Summary for Policy Makers and IPCC chapters referenced above. The summary was an excellent opportunity to link with other programmes such as GOA-ON (Tilbrook) and GO₂NE (Breitbart).

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.*

Paul Renaud is leading an initiative to build a collaboration between COBS and IMBeR (SSC members Carol Robinson, Alistair Hobday, Alice Newton) on multiple drivers and changing socio-economic systems. The form and outputs for the collaboration are being discussed at the IMBeR SSC. Possibilities include a perspectives paper, participation in the IMBeR summer school or open sciences meeting, or a jointly-run seminar with the IMBeR ECR network.

Project activities planned for the coming year.

1 Confirmed workshops and trainings using the MEDDLE resources: Christina McGraw will offer a workshop at the [International Symposium on the Ocean in a High-CO₂ World](#) (September 2022). Sam Dupont is leading a 2-week training in Monaco (October 2022) that will incorporate MEDDLE; Chris Cornwall will participate in the section of the workshop that uses the MEDDLE resources. Chris Cornwall and Damon Britton (University of Tasmania) have proposed a one-day workshop at the [International Seaweed Symposium](#) (February 2023). McGraw and Cornwall plan to offer a workshop for the Pacific region later this year, building on related training in the region; this is still in the planning stages.

2. Improvement of MEDDLE workshops and resources: This includes expansion of MEDDLE resources (ie- handbook) to include monitoring/biological monitoring and producing new video for using MEDDLE simulator. It also involves redesigning the MEDDLE workshop to take advantage of on-line collaboration software (e.g. Miro), to develop engaging regional on-line workshops. These will take advantage of the lessons learned in online workshops in Scotland and Sweden. Using existing networks and groups (e.g. ApHRICA, SPREP, Pacific Island Ocean Acidification Centre), we can target the concerns and capacities of developing regions, while encouraging long-term collaborations.

Expanding the National Advocate programme for MEDDLE. Currently, we have six National Advocates who have agreed to share information about MEDDLE resources: Yeala Shaked (Israel), Maria Segovia (Spain), Christian Pansch-Hattich (Finland), Gareth Pearson (Portugal), Ester Serrão (Portugal), Salvador Emilio Lluch Cota (Mexico). The

engagement we have received from Advocates is variable, so Cornwall is developing a paired, ECR-based approach to create a platform where Advocates can discuss ideas and take a leadership role in disseminating information about multiple driver experiments.

3. Paul Renaud will continue to strengthen the collaboration between COBS and IMBeR (Carol Robinson, Alistair Hobday, Alice Newton) on multiple drivers and changing socio-economic systems. Possibilities for shared activities include publications, workshops within the IMBeR summer school or open sciences meeting, or a jointly-run seminar with the IMBeR ECR network.

4. Potential development of a best practice guide (Collins/Dupont/Thomas in collaboration w Rost) this output relies on a NERC (UK) grant application by Collins (decision pending) that includes an expert workshop on producing interaction surfaces for phytoplankton in collaboration with the IAEA (Monaco).

5. Peer reviewed manuscripts by each working group.

Additional sources of funding secured. In-kind contributions from IAEA through Sam Dupont for workshop development and promotion; travel funds for Christina McGraw for workshops through the University of Otago.

Any special comments or requests to SCOR. Continued difficulty meeting and scheduling around covid disruption, coupled with the sustained increase in teaching and administration workloads that many of our members experienced at the beginning of the pandemic, limit the bandwidth of members. However, we are making steady progress on our proposed actions.

In previous years, the COBS AGM has been held at Waterville Valley in the 2 days before the Ocean Global Change Biology Gordon Research Conference. The conference was deferred in 2020 to 2022, and cancelled with one month notice in 2022 due to low participant registration. It has been challenging to schedule a replacement in-person meeting on short notice; the COBS AGM will likely happen in early 2023.