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

Sam Dupont is a new co-chair. Stephanie Dutkiewicz, Miriam Seifert and Cristian Vargas joined as new members. COBS is built around five cross-linked teams. Each team developed a position analysis that was discussed at the AGM in spring 2023.

Team 1. Identifying priorities for multiple driver / stressor research (Renaud, Vargas, Belgrano (IMBeR)).

This team focuses on collaborating with social scientists, and highlighting how this could improve solutions for research and wider education. Renaud has coordinated a collaboration with IMBeR, and Andrea Belgrano attended our annual meeting in March 2023. A manuscript is being prepared with the IMBeR IC4 co-champions and fellows, which will be the basis for joint synergies (e.g. joint theme session for the Future Ocean IMBeR meeting in 2024).

Vargas is working with social scientists (Stefan Gelcich, Chile) on multiple drivers on single stressors trends (e.g. eutrophication, pollution, water quality and land uses on decadal trends of seawater pH) in coastal areas, and how global actions for minimizing and addressing the impacts of ocean acidification in the coastal zone requires multiple actions across sustainable development goals. This also promotes the priority for recommendations on best locations for long-term ocean acidification monitoring (target 14.3 from IOC-UNESCO).

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

We continue to promote MEDDLE resources through in-person and online workshops. Two MEDDLE workshops took place in 2022 and early 2023 (International Symposium on the Ocean in a High-CO2 World 2022, Workshop for Shellfish Researchers NZ 2023). MEDDLE is being updated to include a more rigorous approach to experimental design (McGraw, Thomas, Collins, see Team 4), and a “train the trainers” workshop is being developed with the National Advocates (Cornwall). Cornwall has led expanding the National Advocate network from 6 to 24 advocates (see below). Advocates discuss ideas and take a leadership role in disseminating information.

National Advocates

Country	Name
Argentina	Bettina Lomovasky
Australia	Damon Britton
China	Peng Jin
Columbia	Susana Simancas
Finland	Christian Pansch
France	Steeve Comeau
Hong Kong	Juan-Diego Gaitan-Espitia
Israel	Gil Rilov
Israel	Yeala Shaked
Israel	Guy Haim
Japan	Ben Harvey
Mexico	Salvador Emilio Lluch Cota
Netherlands	Verena Schoepf
New Caledonia	Riccardo Rodolfo-Metalpa
Peru	Natalie Bravo
Samoa	Luia Taise
Saudi Arabia	Maggie Johnson
Saudi Arabia	Erik Krieger
Spain	Maria Segovia
UK	Bayden Russell
USA	Hollie Putnam
USA	Sophie McCoy

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. A 6-week Ocean Acidification in the Pacific Islands online training course attracted 248 Pacific Islanders. The course was jointly organized by SPC, USP, NOAA, IOC-UNESCO, University of Otago, NIWA, and University of Hawaii (21 February – 10 April).

Dupont has worked with IAEA as they re-evaluate their capacity development programme, and encouraged a shift in focus from single drivers to multiple drivers. These provide new opportunities to reach researchers from developing countries.

We have produced a "Multiple Drivers Talking Points" resource for people engaging with policy makers, as well as a guide for policy makers. Multiple Ocean Stressors: A Scientific Summary for Policy Makers, Arthur Beusen, Philip W Boyd, Denise Breitburg, Steeve Comeau, Sam Dupont, Per Juel Hansen, Kirsten Isensee, Raphael M Kudela, Nina Lundholm, Saskia Otto, Franklin Schwing, Bronte Tilbrook, UNESCO-IOC (2022).

Cornwall has approached three coral reef researchers to develop a paper on experimental design. The paper will build on Cornwall et al 2022 (Emerging Top Life Sci 6(1):1-9). A sub-group of the national advocates are working on guidelines for marine heatwave experiments in the context of multiple drivers.

Team 3. Model evaluation (Dutkiewicz,Seifert,Gehlen)

In spring 2023, the group conducted an informal survey of CO2 dependencies and multiple drivers in models to evaluate what models can currently do, and what is needed. They outlined three areas of interest. 1: moving from populations to plankton functional types; 2: CO2 dependencies in CMIP models and 3: Driver interdependencies in ocean-only and CMIP models. They evaluated the state of the art, research questions, previous and ongoing work, testable hypotheses, and what the COBS contribution to this might be. Two manuscripts were proposed, and are under discussion.

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

This group has focused on understanding biological responses to compound extremes. This has taken the form of a submitted paper (Thomas and collaborator Ranjan - see outputs), which builds on the Boyd et al 2018 COBS working group paper, and extends it by exploring uncommon designs for experiments, adding simulations to illustrate how these designs explore interaction surfaces, and exploring a leverage metric that may provide an automated way to choose treatment levels under some circumstances. This is useful to senior scientists and in major projects, and is the basis for updating MEDDLE and associated materials (see Team 2).

Team 5. Mechanistic understanding (Hutchins, Hall-Spencer, Leung)

Key areas were identified and discussed at the COBS AGM. These are: new publishing models; increasing emphasis on training and hypothesis driven studies, linked with MEDDLE (Team 2); improving uses of gradients of stress and real-world analogues; including in socioeconomic responses to changes in marine ecosystem services (Team 1); improving the appreciation of biological complexity in ocean change research; developing research priorities for understanding biological underpinning, including organismal interactions; exploring new conceptual thinking about mechanisms of global change responses, for example using physiological groupings and universal reaction norms (see also Teams 3 and 4). The team introduced MEDDLE into natural analogue discussions at a June 2023 workshop at the Ecosystem Studies of Subarctic and Arctic Systems annual science meeting entitled AnalogueART - Using natural analogues to investigate the effects of climate change on northern ecosystems https://essas.arc.hokudai.ac.jp/what_s_new/2023-essas-annual-science-meeting-in-bergen-norway/

SECTION 2. Documents published since 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 (ToRs are below - we can shorten them after we describe progress on each one)

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-based workshops continue to be delivered. To deliver these more widely, and to fit the training needs of specific local groups, C. Cornwall has expanded our network of National Advocates, which allows us to "train the trainer", and also acts as a network of ECRs interested in multiple driver research (see above). An update of MEDDLE learning resources and of the website are underway. Details of specific activities are above. There is good commitment and expertise for meeting this ToR, and integrating our resources into resources such as the Ocean Teacher Global Academy.

From our experience teaching MEDDLE workshops, we have seen that many ECRs believe that they can answer a challenging multiple driver question with only a single study. Although the MEDDLE training resources state that an experiment should be designed as part of a *strategy*, this needs to be made clearer. In progress: This has become a stronger focus of the workshops, and is being emphasized in the updated materials.

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.

As indicated above, several of our actions are aimed at harmonizing or improving experimental approaches by using existing structures or resources, particularly through IOC UNESCO's Ocean Teacher Global Academy. We are applying to have MEDDLE endorsed as part of the UN Ocean decade.

COBS members have published peer-reviewed scientific papers that explore the logic behind using specific experimental designs (eg. full factorial) to develop generalizable theoretical

underpinnings for phytoplankton responses to 2 or more drivers, to explore the statistical power of different multidriver experimental designs. See attached outputs record.

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; subsequent discussion at the 2023 AGM and with collaborators (IMBeR) on ToR5 have convinced us that a broad survey is not the best way to meet this goal. However, with the new members who have joined the modeling team (Dutkiewicz, Seifert) we will address the disjoints between models, experiments and observations in a publication on challenges and utility of model parameterization, as well as incorporate these insights into our training materials and wider outreach talks.

This ToR is also advanced by the ongoing work led by Boyd and Thomas on understanding compound extremes in biotic responses to multiple drivers, and individual publications (Litchman and Thomas 2022) on the generality of responses to key drivers across taxonomic levels.

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 focused on the Summary for Policy Makers and IPCC chapters in 2022. The summary was an excellent opportunity to link with other programmes such as GOA-ON (Tillbrook) and GO2NE (Breitbart). Following these two major undertakings, SCOR members have focused on papers on experimental design (e.g. Collins, Thomas) or are undertaking exercises that reach out to specific communities by either bringing together ECRs in multidriver research, or reaching out to self-contained communities such as coral reef researchers (Cornwall).

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 is being prepared with the IMBeR IC4 co-champions and fellows, which will be the basis for joint synergies (e.g. joint theme session for the Future Ocean IMBeR meeting in 2024).

SECTION 4. Project activities planned for the coming year. Limit 500 words

With our new co-chair team, our activities are focused on resources and advocacy for multiple driver experiments. This has two main components. The first is an ongoing assessment, synopsis and improvement of the necessary knowledge base for multiple driver experiments, and these activities primarily produce academic papers or facilitate collaborations between scientists (teams 1 and 5). The second branch produces materials aimed at improving the design of multidriver experiments by scientists, and advocating at a high level for the valuing and funding of these experiments. For scientists, MEDDLE resources and the National Advocates network provide materials, and these will be overhauled and updated in 2023/24 to reflect advances in best practices. For others, Collins and Dupont aim to draw on the outputs of COBS so far to produce a range of materials for high level institutions (universities or research centres), funding bodies, and policy makers on why multiple driver ocean change matters, over the coming 2 years.

1. Confirmed workshops and trainings using MEDDLE resources. Six workshops are confirmed over the next year; more are being planned but are not yet confirmed.

2.Improvement of MEDDLE resources. Specific plans for improvement to site navigation and to make the site more self contained and simplify the simulator. We will also update much of the text, including adding a discussion about what is gained in using different experimental designs, and removing outdated suggestions. Thomas, McGraw, Cornwall and Collins have assembled a document outlining specific tasks to this update which will be carried out over the next year. A request for resources from SCOR to pay for implementing changes to the MEDDLE website and simulator have been submitted and approved in June 2023.

3.Collaboration between COBS and IMBeR. Renaud and Belgrano are preparing a joint manuscript on links between social sciences and hard science in ocean change biology, and developing options for future synergies between COBS and IMBeR

4.Replacement of the function of the GRC on Ocean Global Change Biology. Until 2018, 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 canceled with one month notice in 2022 due to low participant registration. COBS co-chairs will meet with ERCs who were organizing the associated GRS in late summer/early autumn 2023 to discuss how best to replace the function of the GRC. Considerations include that the conference

roster is quite full, with many researchers being at the edge of the time and money that can be devoted to conferences, fatigue for online meetings, and the desire of COBS to have an inclusive meeting that is small enough for continued discussion to take place.

5. Development and trial dissemination (initially through existing networks in Sweden and Scotland) of new resources (outlined above) led by Dupont and Collins.

6. Peer reviewed manuscripts within each working group
Several peer-reviewed manuscripts are planned, and are outlined with the relevant teams or ToRs above.

Is the project having difficulties expected in achieving terms of reference or meeting original time schedule? If so, why, and what is being done to address the difficulties Limit 200 words

COBS is more or less back on track following the setbacks associated with the pandemic. 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 canceled 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 happened in Monaco in spring 2023. We substantially refreshed our membership in 2023 in order to accommodate people's shifting time allocations since the pandemic; this is especially evident in teams 1 and 3). In 2023, the co-chairs, along with the COBS membership and the ECRs who organized the Ocean Global Change Biology GRS will discuss how to best replace the GRC that has been central to COBS meetings and science.