2.0 WORKING GROUPS

2.1 Current Working Groups

The Executive Committee Reporter for each working group will present an update on working group activities and progress, and will make recommendations on actions to be taken. Working groups expire at each General Meeting, but can be renewed at the meeting and can be disbanded whenever appropriate.

2.2 Working Group Proposals

2.1 Current Working Groups

2.1.1 WG 142 on Quality Control Procedures for Oxygen and Other Biogeochemical Sensors on Floats and Gliders (2012) *Burkill*

Terms of Reference:

1. Summarize and assess the current status of biogeochemical sensor technology with particular emphasis on float-/glider-readiness (pressure and temperature dependence, long-term stability, calibration accuracy, measurements time constant, etc.).
2. Develop pre- and post-deployment quality control metrics and procedures for oxygen and other biogeochemical sensors deployed on floats and gliders providing a research-quality synthesis data product.
3. Collaborate with Argo and other data centers to implement these procedures in their standard routines.
4. Disseminate procedures widely to ensure rapid adoption in the community. Develop ideas for capacity building in this context.

Co-chairs: Arne Körtzinger (Germany) and Ken Johnson (USA)

Other Full Members: Herve Claustre (France), Denis Gilbert (Canada), Wajih Naqvi (India), Steven Riser (USA), Virginie Thierry (France), Bronte Tilbrook (Australia), Hiroshi Uchida (Japan), and Xiaogang Xing (China-Beijing)

Associate Members: Steve Emerson (USA), Katja Fennel (Canada), Hernan Garcia (USA), Nicolas Gruber (Switzerland), Dong-Jin Kang (Korea), Satya Prakash (India), and Osvaldo Ulloa (Chile)

Executive Committee Reporter: Peter Burkill

Final Report for SCOR Working Group 142

1. Name of group

SCOR WG 142:
Quality Control Procedures for Oxygen and Other Biogeochemical Sensors on Floats and Gliders

Chairs:
Arne Körtzinger (Germany) and Ken Johnson (USA)

Other Full Members:
Herve Claustre (France), Denis Gilbert (Canada), Wajih Naqvi (India), Steven Riser (USA), Virginie Thierry (France), Bronte Tilbrook (Australia), Hiroshi Uchida (Japan), and Xiaogang Xing (China-Beijing)

Associate Members:
Steve Emerson (USA), Katja Fennel (Canada), Hernan Garcia (USA), Nicolas Gruber (Switzerland), Dong-Jin Kang (Korea), Satya Prakash (India), and Osvaldo Ulloa (Chile)

2. Major Activities of SCOR WG 142

SCOR WG 142 held the following three in-person meetings of the full group:
(1) 1 March 2014, Honolulu, Hawaii, USA.
(2) 16-17 March 2015, Brest, France
(3) 27 February 2016, New Orleans, Louisiana, USA

In addition, a large number of e-mails discussions as well as in-person meetings of sub-groups or individual group members on the topic of SCOR WG 142 took place.

Furthermore, the WG initiated and lead a round-robin-style experiment on calibration and stability issues of the Aanderaa oxygen optode as the most prominent oxygen sensor that meets are recommendations of SCOR WG 142. This very successful experiment lead to major insight into this matter which was published in the peer reviewed literature.

Finally, through their memberships and various roles in other programs, projects and committees (e.g. Argo, Euro-Argo, SOCCOM, remOCEAN etc.), SCOR WG 142 members were able to provide a vivid interface between operational float programs or large projects and SCOR WG 142. One the one hand, this assured the WG to stay up-to-date with ongoing float-related research and operations. On the other hand, this assured that SCOR WG 142 best practice recommendations were quickly taken up at program level and included in cookbooks and other important documents.

3. Documents published by SCOR WG 142 (in chronological order)

The following publications are direct outcomes of SCOR WG 142:

Bittig, H., A. Körtzinger, K. Johnson, H. Claustre, S. Emerson, K. Fennel, H. Garcia, D. Gilbert, N. Gruber, D.-J. Kang, W. Naqvi, S. Prakash, S. Riser, V. Thierry, B. Tilbrook, H. Uchida, O. Ulloa, and X. Xing (2015). SCOR WG 142: Quality Control Procedures for Oxygen and Other Biogeochemical Sensors on Floats and Gliders. Recommendation for oxygen measurements from Argo floats, implementation of in-air-measurement routine to assure highest long-term accuracy, doi: https://doi.org/10.13155/45917

Bittig, H., Körtzinger, A., Johnson, K., Claustre, H., Emerson, S., Fennel K., Garcia H., Gilbert, D., Gruber, N., Kang, D-J., Naqvi, W., Prakash, S., Riser, S., Thierry, V., Tilbrook, B., Uchida, H., Ulloa, O., Xing, X. (2018). SCOR WG 142: Quality Control Procedures for Oxygen and Other Biogeochemical Sensors on Floats and Gliders. Recommendation for oxygen measurements from Argo floats, implementation of in-air-measurement routine to assure highest long-term accuracy. Version 1.1. Plouzane, France, Ifremer, doi: http://dx.doi.org/10.25607/OBP-10.

Johnson, K.S., and H. Claustre (2016). Bringing biogeochemistry into the Argo age. Eos, 97, doi: https://doi.org/10.1029/2016EO062427.

Bittig, H.C., A. Körtzinger, C. Neill, E. van Ooijen, J.N. Plant, J. Hahn, K.S. Johnson, B. Yang, and S.R. Emerson (2018). Oxygen Optode Sensors: Principle, Characterization, Calibration and Application in the Ocean. Front. Mar. Sci. 4, 429, doi: 10.3389/fmars.2017.00429.

In addition to this, the following BGC-Argo cookbooks and best practice documents were developed under lead or with participation of SCOR WG 142 members:

Bittig Henry C., Schmechtig Catherine, Rannou Jean-Philippe, Poteau Antoine (2017). Processing Argo measurement timing information at the DAC level. Argo data management, doi: https://doi.org/10.13155/47998

Johnson Kenneth S., Plant Joshua N., Maurer Tanya L. (2018). Processing BGC-Argo pH data at the DAC level. Argo data management, doi: https://doi.org/10.13155/57195

Johnson Kenneth S., Pasqueron De Fommervault Orens, Serra Romain, D'Ortenzio Fabrizio, Schmechtig Catherine, Claustre Hervé, Poteau Antoine (2018). Processing Bio-Argo nitrate concentration at the DAC Level. Argo data management, doi: https://doi.org/10.13155/46121.

Schmechtig Catherine, Poteau Antoine, Claustre Hervé, D'Ortenzio Fabrizio, Boss Emmanuel (2015). Processing bio-Argo chlorophyll-A concentration at the DAC level. Argo data management, doi: https://doi.org/10.13155/39468

Schmechtig Catherine, Thierry Virginie, The Bio Argo Team (2016). Argo quality control manual for biogeochemical data, doi: https://doi.org/10.13155/40879

Schmechtig Catherine, Poteau Antoine, Claustre Herve, D'ortenzio Fabrizio (2017). Processing BGC-Argo Radiometric data at the DAC level, doi: https://doi.org/10.13155/51541.

Schmechtig Catherine, Organelli Emanuele, Poteau Antoine, Claustre Hervé, D'Ortenzio Fabrizio (2017). Processing BGC-Argo CDOM concentration at the DAC level. Argo data management, doi: https://doi.org/10.13155/54541.

Schmechtig Catherine, Claustre Herve, Poteau Antoine, D'Ortenzio Fabrizio (2018). Bio-Argo quality control manual for the Chlorophyll-A concentration, doi: https://doi.org/10.13155/35385

Schmechtig Catherine, Poteau Antoine, Claustre Hervé, D'Ortenzio Fabrizio, Dall'Olmo Giorgio, Boss Emmanuel (2018). Processing Bio-Argo particle backscattering at the DAC level. Argo data management, doi: https://doi.org/10.13155/39459.

4. Progress toward achieving group's terms of reference.

(1) Summarize and assess the current status of biogeochemical sensor technology with particular emphasis on float-/glider-readiness (pressure and temperature dependence, long-term stability, calibration accuracy, measurements time constant, etc.).

Through publications fostered and headed by members of SCOR WG 142, our common knowledge about the current status of biogeochemical sensors for BGC-Argo core parameters (oxygen, pH, nitrate, chlorophyll, backscatter, and irradiance) has been advanced very significantly – for some of the parameters are at (or very close to) full operationality. Hereby, a clear focus was placed on the float platform but the results are to a large extent also applicable to the glider platform. In several instants, aspects of glider-based applications were addressed specifically in publications.

(2) Develop pre- and post-deployment quality control metrics and procedures for oxygen and other biogeochemical sensors deployed on floats and gliders providing a research-quality synthesis data product.

SCOR WG 142 group members developed (or contributed significantly to the development of) pre- and post-deployment procedures and metrics to assure research-quality data of the emerging BGC- Argo program that were documented for widespread information of and use by the scientific community.

(3) Collaborate with Argo and other data centers to implement these procedures in their standard routines.

Through personal involvement and functions of SCOR WG 142 members in float programs and committees, a seamless flow on information was assured. Results and recommendations of SCOR WG 142 were taken up in the cookbooks and best practices manuals for sensor treatment, data processing and quality control. These are being implemented at DAC level.

(4) Disseminate procedures widely to ensure rapid adoption in the community. Develop ideas for capacity building in this context.

SCOR WG 142 communicated results in various forms and on a multitude of occasions. These range from an EOS article for a wider audience to specific presentations at meetings of the Argo Data Management Team. The preferred dissemination pathway chosen by SCOR WG 142 is through technical documentation that is available freely via the Argo reference documentation portal: http://www.argodatamgt.org/Documentation

5. Comments to SCOR

WG 142 acknowledges the support provided by SCOR which allowed us to focus as a group on important sensor-related issues of the new BGC-Argo program and interact in various contexts with relevant programs and project to assure rapid dissemination and use of novel knowledge achieved within SCOR WG 142.

2.1.2 WG 143 on Dissolved N_2O and CH_4 measurements: Working towards a global network of ocean time series measurements of N_2O and CH_4 ***Urban*** (2013)

Terms of Reference:

1. Establish the analytical reporting procedures to be used for N_2O and CH_4
2. Adopt an appropriate standard to be used by the scientific community
3. Conduct an intercalibration exercise between the time series programs
4. Host at least two international meetings
5. Establish framework for an N_2O/CH_4 ocean time series network
6. Write a global oceanic N_2O/CH_4 summary paper for publication in *Annual Review of Marine Science* or an equivalent journal.

Co-chairs: Herman Bange (Germany) and Sam Wilson (USA)

Other Full Members: Mercedes de la Paz Arándiga (Spain), Laura Farias (Chile), Cliff Law (New Zealand), Wajih Naqvi (India), Gregor Rehder (Germany), Philippe Tortell (Canada), Rob Upstill-Goddard (UK), and Guiling Zhang (China-Beijing)

Associate Members: John Bullister (USA), Jan Kaiser (UK), Annette Kock (Germany), Sunyoung Park (Korea), Andy Rees (UK), and Alyson Santoro (USA)

Executive Committee Reporter: John Turner

1. Name of group

SCOR Working Group #143: Oceanic methane and nitrous oxide

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

In October 2018, we organized a three-day workshop in Lake Arrowhead, California to discuss current and future measurements of greenhouse gases (methane and nitrous oxide). With respect to the lifetime of the SCOR Working Group #143, this was an opportunity to disseminate the results from the SCOR Working Group to a larger group of trace gas analysts. All fifteen of the laboratories that participated in the intercomparison of methane and nitrous oxide (one of the main activities of the WG#143) were present, with the exception of Cliff Law and Alberto Borges. The workshop was funded by the OCB program and SCOR. The OCB program continues to host the website that provides information about the workshop and its intended outcomes. The workshop was well-received by the 60 participants as it offered the opportunity to evaluate the status of trace gas research and great networking opportunities.

3. 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 WG activities and which acknowledge SCOR support

Bange, H.W., M. de la Paz, L. Farías, J. Kaiser, A. Kock, C.S. Law, A.P. Rees, G. Rehder, P. Tortell, R.C. Upstill-Goddard and S.T. Wilson (2019) A harmonized nitrous oxide ocean observation network for the 21st century. *Front. Mar. Sci.* 6:157. doi: 10.3389/fmars.2019.00157

Wilson, S.T., H.W. Bange, J. Barnes, A. Borges, I. Brown, J. Bullister, M. Burgos, D.W. Capelle, M. Casso, M. de la Paz, L. Farías, L. Fenwick, S. Ferrón, G. Garcia, M. Glockzin, D.M. Karl, A. Kock, S. Laperriere., C.S. Law, C.C. Manning, A. Marriner, J.-P. Myllykangas, J.W. Pohlman, A.P. Rees, A. Santoro, P. Tortell, D. Wisegarver, R.C. Upstill-Goddard, G.L. Zhang, G. Rehder (2018) An intercomparison of oceanic methane and nitrous oxide measurements. *Biogeosciences* 15:5891–5907, doi: 10.5194/bg-15-5891-2018.

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

1. Conduct an intercalibration exercise between the time series programs (for methane and nitrous oxide)

This is completed and published (Wilson et al., 2018).

2. Establish the appropriate standards to be used by the scientific community
This is completed and the Technical Report has been published on the SCOR website (Bullister, J.L., D.P. Wisegarver and S.T. Wilson (2016) Technical Report: The production of

methane and nitrous oxide gas standards for Scientific Committee on Ocean Research (SCOR) Working Group #143. pp 1-9) See http://dspace.udel.edu/handle/19716/23288.

3. Recommend the analytical reporting procedures to be used for N_2O and CH_4
All members of SCOR WG#143 publish their own research on methane and nitrous oxide, and are therefore very familiar with their own analytical procedures. However, as a community of trace gas analysts, there is no published consensus about the most appropriate methods and we have not yet agreed on the reporting procedures. In response to this, we are currently writing the Standard Operating Protocols (SOPs) for methane and nitrous oxide. This was agreed by the workshop participants as essential to improving the inter-comparability of the methane and nitrous oxide measurements. There are 9 chapters, which cover all aspects of the measurements from sampling, analysis, and data reporting. These are being written at the moment by members of the SCOR Working Group and the workshop participants. Once we have full drafts we will post them on the workshop website for the broader community to comment and contribute if they wish. They will then be collated and published as a single document, potentially using *Frontiers* as the host publisher.

4. Establish framework for an N_2O/CH_4 ocean time series network and write a global oceanic N_2O/CH_4 summary paper for publication in an open access journal.

This is completed and published (Bange et al., 2019).

There are different components to this Terms of Reference
1. The production and distribution of common gas standards will benefit the framework for methane and nitrous oxide measurements. This has been completed.
2. The intercomparison work identified several key steps to methane and nitrous oxide analyses that need to be taken into consideration when conducting the measurements. This forms part of the forthcoming *Biogeosciences* manuscript.
3. There was an OCB workshop at Lake Arrowhead Conference Center in October 2018. This workshop specifically asked the question '*Where are the critical locations in the global oceans to measure dissolved methane and nitrous oxide in order to document long-term changes to the oceans as a source of these greenhouse gases?*' Therefore, in addition to existing measurements, where should new or increased measurements be located? This information will comprise the workshop report and will become part of any open-access peer reviewed publication that is produced following the event.
4. The GEOMAR group (H. Bange, A. Kock, D. Arevalo) will take the lead writing a manuscript about the MEMENTO database for submission to *Earth System Science Data*. The MEMENTO database is the current data portal for the methane and nitrous oxide measurements.

5. WG activities planned for the coming year. Limit 500 words

This is the last year of WG#143. We have accomplished our objectives and come a long way in the last 5 years. However, there is still more to be done. The two outcomes that we would

like to achieve in the remainder of 2019 are completion of the SOPs and the publication of a perspective article based on the discussions and recommendations of the OCB workshop. The driving motivation behind these two activities is that they will be used in support of coordinated research activity.

There are 2 activities in 2019 which SCOR WG#143 will be attending:

1. At Ocean Observation '19 (being held in Honolulu, Hawaii in September 2019) we will be advocating for increased measurements of methane and nitrous oxide and push for increased inter-comparabilities.
2. There will be an OCB workshop in October 1-3 that will discuss potential activities of U.S. scientists relevant to the Surface Ocean - Lower Atmosphere Study (SOLAS) program. The workshop is being led by Rachel Stanley from Wesley College. Sam Wilson has applied to attend this workshop and will report on the outcomes of the SCOR WG#143 and the 2018 workshop.

6. Is the group 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

No difficulties to report

7. Any special comments or requests to SCOR. Limit 100 words.

None at this time. Thank you to Ed Urban and SCOR for supporting the activity of WG#143 during the past four years. It has been extremely helpful to the progress of methane and nitrous oxide measurements in the ocean.

Additional information can be submitted and will be included in the background book for the SCOR meeting at the discretion of the SCOR Executive Committee Reporter for the WG and the SCOR Secretariat.

2.1.3 WG 145 on Chemical Speciation Modelling in Seawater to Meet 21st Century Needs (MARCHEMSPEC) (2014) *Sicre*

Terms of Reference:

1. To document the current status, and basis in laboratory measurements, of Pitzer models of seawater and estuarine water focusing on the chemistry of ocean acidification and micronutrient trace metals (including, but not limited to, Fe, Cu, Cd, Co, Mn, and Zn). Current capabilities and limitations for oceanographic and biogeochemical calculations will be defined, and future needs established. Important gaps in knowledge, which should have high priority for new measurements, will be identified. The components to be covered will include the seawater electrolytes, the selected trace metals, and buffer solutions and key organic ligands such as those used in CLE-CSV titrations.
2. To publish the results of the first term of reference in the refereed scientific literature, and to introduce the conclusions and recommendations to the oceanographic community at a "town hall" event or special session at an international ocean sciences meeting.
3. To specify the functions and capability for a web-based modelling tool that will make chemical speciation calculations easily accessible for a wide range of applications in oceanography research and teaching, and thus improve understanding and spread best practice in modelling.
4. To implement the web-based tool for chemical speciation calculations, based upon the specification developed in the third term of reference which will also be used to obtain external funding to develop the programs, documentation, and site.

Chair: David Turner (Sweden)

Vice-Chairs: Simon Clegg (UK) and Sylvia Sander (New Zealand)

Other Full Members: Heather Benway (USA), Arthur Chen (China-Taipei), Andrew Dickson (USA), Vanessa Hatje (Brazil), Maite Maldonado (Canada), Alessandro Tagliabue (UK), and Rodrigo Torres (Chile)

Associate Members: Eric Achterberg (Germany), Yuri Artioli (UK), Parthasarathi Chakraborty (India), Peter Croot (Ireland), Martha Gledhill (Germany), Giles Marion (USA), Peter May (Australia), Frank Millero (USA), Ivanka Pizeta (Croatia), Darren Rowland (Australia), Pavel Tishchenko (Russia), Stan van den Berg (UK), Wolfgang Voigt (Germany), Christoph Völker (Germany), Feiyue Wang (Canada), and Mona Wells (China)

Executive Committee Reporter: Marie-Alexandrine Sicre

1. Name of group

WG145: Chemical Speciation Modelling in Seawater to meet 21st Century Needs

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

NERC/NSF project

This project (PI's Clegg, Dickson and Benway) was initiated to support the WG aims.

- Simon Clegg has almost completed the coding of the speciation model that will form the core of the modelling tools that are one of the goals of this project. Matthew Humphreys has made substantial progress in adding uncertainty calculations to it, so that we are able to estimate individual contributions of all "interactions" in the model to the final calculated result (pH for example). The interaction parameters in the Miami models of the Millero group are our starting point.

Experimental measurements

- A major effort has been made to identify the limitations of Harned cell measurements through an intercalibration exercise between Dickson's laboratory and the national standards laboratories in France, Germany, Japan and USA. Measurements at high chloride concentration (5 molal) lead to electrode degradation. At lower chloride concentrations, agreement between laboratories at the level of 0.2 mV is considered to be achievable, an uncertainty level that is acceptable for model development.
- Pablo Lodeiro, working in Achterberg's laboratory at GEOMAR has completed an extensive series of measurements of TRIS in NaCl solutions, and of NaCl in TRIS solutions (over 700 measurements over the temperature range 5 - 45°C and full concentration ranges). The data are now being analysed to provide Pitzer coefficients for the interactions between Na, Cl and TRIS, and also the TRIS self-interaction coefficients. This will provide essential information for the improved Pitzer model of the TRIS-artificial seawater buffers used for calibration of seawater pH measurements. The raw data have been added to the WG145 database.
- Simon Clegg visited Andrew Dickson's laboratory to discuss plans for Harned Cell measurements of H+ and Cl- activities in seawater-related media that will be carried out by the new postdoctoral researcher (Ellen Briggs) that Andrew appointed in early 2019.

New collaborations

- SCOR/IAPSO/ICPWS Joint Committee on the Properties of Seawater: Simon Clegg is now a member of this committee, recognising the value of WG145 activities in advancing our ability to model pH, and speciation generally, in natural waters.

Conference presentations

- David Turner presented the WG's work at the COST workshop on Technology Critical Elements (Bialystock, Poland, January 2019).
- Simon Clegg gave a presentation about the work of WG145, and what has been achieved in his project, in one of the BIPM/IAPWS Seawater Workshops (pH) at the International Conference on the Properties of Water and Steam, held in Prague in (Sept. 2018).
- Matthew Humphreys gave an oral presentation, describing the modelling work at UEA and its contribution to WG activities, at the Challenger Conference 2018 in Newcastle (UK).

3. 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 WG activities and which acknowledge SCOR support

No new publications in this period

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

1) *To document the current status, and basis in laboratory measurements, of Pitzer models of seawater and estuarine water focusing on the chemistry of ocean acidification and micronutrient trace metals (including, but not limited to, Fe, Cu, Mn, Cd, and Zn). Current capabilities and limitations for oceanographic and biogeochemical calculations will be defined, and future needs established. Important gaps in knowledge, which should have high priority for new measurements, will be identified. The components to be covered will include the seawater electrolytes, the selected trace metals, and buffer solutions and key organic ligands such as those used in CLE-CSV titrations.*

A second WG paper setting out the chosen modelling approach (Pitzer equations) is being developed (see also section 5).

2) *To publish the results of the first term of reference in the refereed scientific literature, and to introduce the conclusions and recommendations to the oceanographic community at a "town hall" event or special session at an international ocean sciences meeting.*

The WG's progress is reported as updates to the website **marchemspec.org**

3) *To specify the functions and capability for a web-based modelling tool that will make chemical speciation calculations easily accessible for a wide range of applications in oceanography research and teaching, and thus improve understanding and spread best practice in modelling.*

The results of the web survey described in the previous report, will be described in the *Frontiers* paper in preparation (see section 5 below).

4) *To implement the web-based tool for chemical speciation calculations, based upon the specification developed in the third term of reference which will also be used to obtain external funding to develop the programs, documentation, and site.*

Coding of the calculation engine is near completion, and the associated code to estimate uncertainties is underway.

5. WG activities planned for the coming year. Limit 500 words

<u>Ocean Sciences 2020</u>

The following activities are planned in conjunction with this meeting:

- Final WG meeting in person, probably on the Sunday before the conference opens
- A proposal has been submitted for a session entitled "Chemical speciation in seawater: Measurements, modelling and uncertainties".
- A proposal has been submitted for a tutorial presentation entitled "Chemical Speciation Modelling in Seawater to meet 21st Century Needs".

- SCOR have agreed to provide space in their exhibition booth for OSM participants to get hands-on experience of the draft software. This will be advertised at the proposed tutorial, and also through relevant mailing lists.

Publications

- A paper is being prepared for the *Frontiers in Marine Science* Special Topic "Best Practices in Ocean Observing". This paper will both present the case for the use of Pitzer equations rather than stoichiometric constants in speciation modelling, and describe the design of the software user interface based on the WG's earlier web survey.
- A paper on the completed TRIS-NaCl solubility work will be submitted to an appropriate journal.

Collaboration

- The potential for collaboration with the University of Belgrade, who have the capacity to contribute new isopiestic measurements, is being investigated.

Experimental measurements

- The coordinated programme of new experimental measurements in the NERC/NSF project and collaborating laboratories will continue.

Model development

- The potential for including natural organic matter in the speciation model will be explored in collaboration between David Turner and Martha Gledhill (Associate Member), who has been awarded a grant from DFG in Germany for new experimental studies (project start January 2019).

6. Is the group 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

The timetable for the WG has been dependent on securing research funding, which was successful through the NERC/NSF project that will run from November 2017 – October 2020. Complementing this project, collaborating laboratories are contributing new experimental data from their own funding. Given the timing of the NERC/NSF project, we anticipate that we will be able to fulfil the terms of reference by the end of 2020. However, there may be a delay at UEA in early 2020, due to a change in personnel (a new postdoctoral researcher will be needed). Experimental work in Andrew Dickson's laboratory, that contributes to model development, is likely to continue beyond 12/2020 (due to a late start). We would like to keep the WG active until the project activities are complete so that the software package can be released as a SCOR product. We would like to use the limited funding remaining for this WG to finance (in part) a final WG meeting at the 2020 Ocean Sciences meeting in San Diego, where we plan to highlight the WG's work through a session on speciation, and also present the software's capabilities (see section 5).

7. Any special comments or requests to SCOR. Limit 100 words.

We apply to use the remaining funds allocated to this WG to support the final WG meeting in San Diego on 16 February 2020.

2.1.4 WG 147: Towards comparability of global oceanic nutrient data (COMPONUT) (2014) *Aoyama, Sicre*

Terms of Reference

1. To establish mechanisms to ensure comparability of oceanic nutrient data in collaboration with International organisations such as ICES and PICES.
2. To assess the homogeneity and stability of currently available RMs/CRMs: The group needs to determine whether the current producers are achieving a level of precision within and between laboratories which is comparable to or better than 1 %.
3. To develop standardized data-handling procedures with common data vocabularies and formats, across producers and users, and will include the future linking of national and international data archives. The group will seek to involve international data center representatives to contribute to and lead this task.
4. To promote the wider global use of RM's by arranging workshops to actively encourage their use, and to provide training in analytical protocols and best practices, including sample preservation protocols, particularly targeted towards developing countries.
5. To continue regular global inter-comparison studies, following on from the previous exercises in 2003, 2006, 2008 and 2012, with collaboration of IOCCP-SSG and RCGC-JAMSTEC.
6. To update the GO-SHIP nutrient measurement manual, which was originally a product of the IOC-ICES SGONS, (Study Group on Nutrient Standards).
7. To publish reports on this WG's activities and workshops.

Co-chairs: Michio Aoyama (Japan) and E. Malcolm S. Woodward (UK)

Other Full Members: Susan Becker (USA), Karin Bjorkman (USA), Anne Daniel (France), Claire Mahaffey (UK), Hema Naik (India), Raymond Roman (South Africa), Bernadette Sloyan (Australia), and Toste Tanhua (Germany)

Associate Members: Karel Bakker (Netherlands), Minhan Dai (China-Beijing), Andrew Dickson (USA), Akiharu Hioki (Japan), Alex Kozyr (USA), Akihiko Murata (Japan), TaeKeun Rho (Korea), Sophie Seeyave (UK), Jonathan Sharp (USA), Winnie van Vark (Netherlands), and Takeshi Yoshimura (Japan)

Executive Committee Reporter: Marie-Alexandrine Sicre

Annual SCOR Working Group Reports to SCOR
By Malcolm Woodward and Michio Aoyama, July 2019.

1. Name of group

SCOR WG#147 “Towards comparability of global oceanic nutrient data”

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

The standard 3 years of SCOR funding for this working group essentially ended in 2018, but we requested an extension of one year’s funding at last years’ SCOR Annual Meeting in order to complete a couple of important tasks that will finalise the outputs of this group.

There was no official annual meeting this year, but following discussions, there was organised a writing workshop in order to complete and finally edit the GO-SHIP repeat hydrography nutrient manual.

The draft version of the manual was submitted at the end of 2018 to the *Frontiers of Marine Science* journal and to Ocean Best Practices and left there for a couple months to invite comment from the global community. We also made the draft manual widely available to the community for comment through emailing the community and also on the IOCCP website via Aoyama. All of the comments received were collated by Woodward and Becker, who was the lead author for the new manual. Many emails and phone calls occurred between the writing team of authors over the year to bring this all together.

A writing workshop was then convened at Scripps Institution of Oceanography between the 5th and 10th of July, 2019. All 7 of the authors of the manual were invited to attend the writing workshop. but due to other conflicting commitments only 4 were able to attend, those being Woodward, Aoyama (co-chairs), Becker (first author) and Bakker. This turned out to be a very productive and active session of writing and we completed the task of editing. All the comments we had been sent by the community for improvements to the manuscript were considered, discussed, and incorporated, where appropriate.

The final version of the manual has been sent to GO-SHIP for incorporating on their website and to update the previous nutrient manual of 2010. It will also be incorporated on the IOCCP website.

The final manual will also be sent for publication and to obtain a publication doi from the *Frontiers of Marine Science*, plus it will be sent and published on the Ocean Best Practices website so as to be even more widely globally available.

The Community White Paper to the OceanObs’19 meeting entitled: “The importance of high quality inorganic macro-nutrient data and how to get them” by SCOR WG#147 was sent to IOCCP as part of the overall IOCCP submission to the OceanObs’19 meeting, however, IOCCP failed to submit the white paper before the submission deadline. Both Becker and

Woodward will attend OceanObs'19 in September to represent the Working Group and its aims.

The 5 differing batches of the SCOR-JAMSTEC CRMs are now fully available for purchase through JAMSTEC: one low-level surface water and then a Medium and Deep concentration sample for both the Atlantic and Pacific 0ceans. These are readily available to the global community at a competitive price, and it is hoped that the community continues to use these on a regular basis to help improve quality nutrient data across the world.

The most recent IOCCP-JAMSTEC International Intercalibration exercise was carried out over the winter of 2017/2018. The Working Group members agreed that that this exercise should be continued every 2 years into the future, if possible.

The results have already published with ISBN and available at IOCCP web site, http://www.ioccp.org/images/06Nutrients/IOCCP_JAMSTEC_IC2018report180903protected.pdf, and also available at the OceanBestPractices web site at https://www.oceanbestpractices.net/handle/11329/883.

3. 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 WG activities and which acknowledge SCOR support

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

ToR 1: To establish mechanisms to ensure comparability of oceanic nutrient data in collaboration with International organisations such as ICES and PICES.

The SCOR WG#147 in collaboration with JAMSTEC, Japan, is now providing SI traceable Nutrient CRMs for the global community. There are a series of concentration seawater solutions available for both the Pacific and Atlantic Oceans.

ToR 2: To assess the homogeneity and stability of currently available RMs/CRMs: The group needs to determine whether the current producers are achieving a level of precision within and between laboratories which is comparable to or better than 1%.

In the IOCCP-JAMSTEC Inter-laboratory calibration exercise of CRM/RMNS in 2017/18, SCOR-JAMSTEC CRM, KANSO CRM and KIOST RM were used. By the producers of SCOR-JASMTEC CRM and KANSO CRM, the uncertainty (2k) for nitrate, phosphate and silicate were better than 1 % at high concentration levels, e.g. 19-43 µmol kg^{-1} for nitrate, 14-160 µmol kg^{-1} for silicate and 1.4-3.0 µmol kg^{-1} for phosphate. Consensus standard deviation of the reported values from the participants for nitrate were similar with uncertainty for nitrate which confirmed better homogeneity of CRMs and good comparability among participants. However, consensus standard deviation for phosphate and silicate were larger than

uncertainties of certified concentration for phosphate and silicate. For KIOST RM, the standard deviation (k=1) for nitrate, phosphate and silicate were around 1.5 – 3.3 % at concentration levels of 8-23 μmol kg^{-1} for nitrate, 16-40 μmol kg^{-1} for silicate and 0.6-1.7 μmol kg^{-1} for phosphate.

ToR 3: To develop standardized data-handling procedures with common data vocabularies and formats, across producers and users, and will include the future linking of national and international data archives. The group will seek to involve international data center representatives to contribute to and lead this task.

A part of this ToR3 will be included in the updated GO-SHIP nutrients manual, discussed in ToR6.

ToR 4: To promote the wider global use of RM's by arranging workshops to actively encourage their use, and to provide training in analytical protocols and best practices, including sample preservation protocols, particularly targeted towards developing countries.

WG#147 organised the 'International training workshop on Nutrient analysis', which was held at the NIOZ laboratory in November 2017. This was co-organised by NIOZ and PML.

ToR 5: To continue regular global inter-comparison studies, following on from the previous exercises in 2003, 2006, 2008, 2012, 2015/16, and the recent one in 2017/18. This with the collaboration of IOCCP-SSG and RCGC-JAMSTEC.

WG#147 collaborated with IOCCP and JAMSTEC and helped to conduct the IOCCP-JAMSTEC Inter-laboratory calibration exercise of CRM/RMNS in 2017/18. It is hoped the next intercalibration exercise will take place in 2020/2021.

ToR 6: To update the GO-SHIP nutrient measurement manual, which was originally a product of the IOC-ICES SGONS, (Study Group on Nutrient Standards).

WG147 has completed the final version of the updated GO-SHIP nutrient manual, which was achieved following a writing workshop held at Scripps, in San Diego. This will now be published in a journal and on various global websites to ensure it is easily available to the global nutrient community.

ToR 7: To publish reports on this WG's activities and workshops.

Updates have been communicated to the other WG members and the GO-SHIP manual will soon be published.

5. WG activities planned for the coming year. Limit 500 words

Sadly this brings to an end the SCOR Working Group #147. Thanks to SCOR for funding the project and for encouraging the activities, and we are proud of the outcomes that have been achieved since we were formed. The collaborations and work to improve global nutrient quality will still continue into the future following on from the global links and communications built up by WG#147 during the last 4 years.

6. Is the group 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

7. Any special comments or requests to SCOR. Limit 100 words.

2.1.5 WG 148 on International Quality Controlled Ocean Database: Subsurface temperature profiles (IQuOD) *Myers* (2015)

Terms of Reference

1. To develop, implement and document algorithms for assignment of "intelligent" metadata – i.e. an informed guess as to likely values for missing information – for temperature profiles where crucial metadata is missing.
2. To evaluate and document the most effective combination of automated quality control (AutoQC) procedures for temperature profile observations. International collaboration will be required for the design and coordination of benchmarking experiments using high quality reference datasets.
3. To establish and implement a set of optimal automated quality control procedures, by reaching international community consensus and using the knowledge gained in the benchmarking tests from ToR-2 (above); to produce and publish a reference guide for best practices in automated quality control of ocean temperature profiles; and to develop and freely distribute an open-source quality control software toolkit to promote wide and rapid adoption of best practices by the oceanographic community.
4. To examine and document the feasibility of machine learning and other novel computational methods for enhanced quality control, to potentially minimize labor costs associated with human expert quality control procedures.
5. To develop, implement and document internationally agreed best practice methods for assignment of uncertainty estimates to each temperature observation.
6. To freely disseminate (interim) versions of the IQuOD global temperature profile database (and added value-products) as it evolves over the next 3 years, in user-friendly file formats.
7. To share knowledge and transfer skills in instrumentation, regional oceanography, quality control procedures and data stewardship with international scientists in both developed and developing nations.

Co-chairs: Catia Domingues (Australia) and Matt Palmer (UK)

Other Full Members: TVS Udaya Bhaskar (India), Tim Boyer (USA), Marcela Charo (Argentina), Christine Coatanoan (France), Viktor Gouretski (Germany), Shoichi Kizu (Japan), Alison Macdonald (USA), and Ann (Gronell) Thresher (Australia)

Associate Members: Lijing Cheng (China-Beijing), Mauro Cirano (Brazil), Rebecca Cowley (Australia), Sergey Gladyshev (Russia), Simon Good (UK), Francis Bringas Gutierrez (USA), Katherine Hutchinson (South Africa), Gabriel Jorda (Spain), Sergio Larios (Mexico), and Toru Suzuki (Japan)

Executive Committee Reporter: Paul Myers

1. Name of group

SCOR Working Group 148 (since April 2016)

International Quality Controlled Ocean Database: Subsurface temperature profiles (IQuOD)

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

- Virtual communication and task team updates/activities largely recorded via Slack Channels and GitHub (including code repository).
- Article published on the Ocean Challenge newsletter (2018, Vol. 23,1), the Challenger Society for Marine Science.
- Keynote talk at the International Conference on Marine Data and Information Systems (IMDIS) - A New World Ocean Temperature Profile Product (v0.1): The International Quality Controlled Ocean Database (IQuOD), Catia Domingues, on behalf of the IQuOD team. Session 4 - Data products, information and knowledge. IMDIS 2018 - Barcelona, 5-7 November 2018.
- Poster presentation at the IOC/IODE-XXV. Authors: T.P Boyer and T. Suzuki, on behalf of the IQuOD Project Team (including SCOR working group 148 and IOC/IODE SG-IQuOD). Tokyo, 19-22 February 2019.
- Abstract submission to OCEANOBS'19 (26 June 2019) for poster presentation.
- Invited US CLIVAR webinar, Simon Good on behalf of the IQuOD team: https://www.dropbox.com/s/gx57e2rtbz3w1h6/IQuOD_CLIVAR_webinar_20190711.pdf?dl=0
- IQuOD engagement with users through peer-reviewed community white papers (OCEANOBS'19)

Ocean data

- Goni, Gustavo J., Janet Sprintall, Francis Bringas, Lijing Cheng, Mauro Cirano, Shenfu Dong, Ricardo Domingues, Marlos Goes, Hosmay Lopez, Rosemary Morrow, Ulises Rivero, Thomas Rossby, Robert E. Todd, Joaquin A. Trinanes, Nathalie Zilberman, Molly Baringer, Timothy Boyer, Rebecca Cowley, Catia Domingues, Katherine Hutchinson, Martin Kramp, Mauricio Mata, Franco Reseghetti, Charles Sun, Udaya Bhaskar TVS, Denis Volkov, 2019. More than 50 years of successful continuous temperature section measurements by the Global Expendable Bathythermograph Network, its integrability, societal benefits, and future. Frontiers in Marine Science 6:437, section Ocean Observation. Review. DOI=10.3389/fmars.2019.00452. Manuscript ID: 433073. https://www.frontiersin.org/articles/10.3389/fmars.2019.00452/full

Ocean reanalyses

- Storto, Andrea, Aida Alvera-Azcárate, Magdalena Alonso Balmaseda, Alexander Barth, Matthieu Chevallier, Francois Counillon, Catia M. Domingues, Marie Drévillon, Yann Drillet, Gaël Forget, Gilles Garric, Keith Haines, Fabrice Hernandez, Doroteaciro

Iovino, Laura C. Jackson, Jean-Michel Lellouche, Simona Masina, Michael Mayer, Peter Robin Oke, Stephen G. Penny, Andrew K. Peterson, Chunxue Yang, Hao Zuo, 2019. Ocean reanalyses: Recent advances and unsolved challenges. Frontiers in Marine Science, section Ocean Observation. Mini Review. Manuscript ID: 433756. https://www.frontiersin.org/articles/10.3389/fmars.2019.00418/full

- Penny, Stephen G., Santha Akella, Magdalena A. Balmaseda, Philip Browne, James A. Carton, Matthieu Chevallier, Francois Counillon, Catia Domingues et al., 2019. Observational Needs for Improving Ocean and Coupled Reanalysis, S2S Prediction, and Decadal Prediction. Front. Mar. Sci. 6:391. doi: 10.3389/fmars.2019.00391. https://www.frontiersin.org/articles/10.3389/fmars.2019.00391/full

Earth, ocean climate and sea level

- Meyssignac B., Boyer T., Zhao Z., Hakuba M.Z., Landerer F., Stammer D., Köhl A., Kato S. 7, L'Ecuyer T., Ablain M., Abraham J.P., Blazquez A., Cazenave A., Church J., Cowley R., Cheng L.J., Domingues C., et al., 2019 (accepted). Measuring Global Ocean Heat Content to estimate the Earth Energy Imbalance. Frontiers in Marine Science, section Ocean Observation. Mini Review. Manuscript ID: 435756. https://www.frontiersin.org/articles/10.3389/fmars.2019.00432/full
- Ponte Rui M., Carson Mark, Cirano Mauro, Domingues Catia M., Jevrejeva Svetlana, Marcos Marta, Mitchum Gary, van de Wal R. S. W., Woodworth Philip L., Ablain Michaël, Ardhuin Fabrice, Ballu Valérie, Becker Mélanie, Benveniste Jérôme, Birol Florence, Bradshaw Elizabeth, Cazenave Anny, De Mey-Frémaux P., Durand Fabien, Ezer Tal, Fu Lee-Lueng, Fukumori Ichiro, Gordon Kathy, Gravelle Médéric, Griffies Stephen M., Han Weiqing, Hibbert Angela, Hughes Chris W., Idier Déborah, Kourafalou Villy H., Little Christopher M., Matthews Andrew, Melet Angélique, Merrifield Mark, Meyssignac Benoit, Minobe Shoshiro, Penduff Thierry, Picot Nicolas, Piecuch Christopher, Ray Richard D., Rickards Lesley, Santamaría-Gómez Alvaro, Stammer Detlef, Staneva Joanna, Testut Laurent, Thompson Keith, Thompson Philip, Vignudelli Stefano, Williams Joanne, Williams Simon D. P., Wöppelmann Guy, Zanna Laure, Zhang Xuebin, 2019. Towards Comprehensive Observing and Modeling Systems for Monitoring and Predicting Regional to Coastal Sea Level. Front. Mar. Sci. 6: 437. DOI=10.3389/fmars.2019.00437 https://www.frontiersin.org/articles/10.3389/fmars.2019.00437/full

3. 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 WG activities and which acknowledge SCOR support

- Leahy, Thomas P, Francesc Pons Llopis, Matthew D Palmer, Niall H Robinson, 2018. Using Neural Networks to Correct Historical Climate Observations. Journal of Atmospheric and Oceanic Technology, 35, 10, 2053-2059. https://doi.org/10.1175/JTECH-D-18-0012.1.
- Updates to code repository on the AutoQC GitHub webpage: https://github.com/IQuOD/AutoQC
- Goni et al., 2019. More than 50 years of successful continuous temperature section measurements by the Global Expendable Bathythermograph Network, its integrability, societal benefits, and future. Frontiers in Marine Science 6:437, section Ocean Observation. Review. DOI=10.3389/fmars.2019.00452. Manuscript ID: 433073. https://www.frontiersin.org/articles/10.3389/fmars.2019.00452/full.

- Storto et al., 2019 Ocean reanalyses: Recent advances and unsolved challenges. Frontiers in Marine Science, section Ocean Observation. Mini Review. Manuscript ID: 433756. https://www.frontiersin.org/articles/10.3389/fmars.2019.00418/full.

- Ponte et al., 2019. Towards Comprehensive Observing and Modeling Systems for Monitoring and Predicting Regional to Coastal Sea Level. Front. Mar. Sci. 6: 437. DOI=10.3389/fmars.2019.00437 https://www.frontiersin.org/articles/10.3389/fmars.2019.00437/full

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

SCOR WG 148 proposal: Copy

1. **To develop, implement and document algorithms for assignment of "intelligent" metadata – i.e. an informed guess as to likely values for missing information – for temperature profiles where crucial metadata is missing.**

I-metadata classification underpinned by neural networks (Leahy et al., 2018) and ensemble machine learning approaches (in progress).

Palmer et al (2018) paper describing the IQuOD v0.1 intelligent metadata algorithm has been published in Journal of Atmospheric and Oceanic Technology. These metadata assignments have been included in the v0.1 IQuOD database (published March 2018).

2. To evaluate and document the most effective combination of automated quality control (AutoQC) procedures for temperature profile observations. International collaboration will be required for the design and coordination of benchmarking experiments using high quality reference datasets.

3. To establish and implement a set of optimal automated quality control procedures, by reaching international community consensus and using the knowledge gained in the benchmarking tests from ToR-2 (above); to produce and publish a reference guide for best practices in automated quality control of ocean temperature profiles; and to develop and freely distribute an open-source quality control software toolkit to promote wide and rapid adoption of best practices by the oceanographic community.

Combined response for ToRs 2 and 3:

57 AutoQC tests from six different institutions have been implemented and are freely available from the GitHub respository: https://github.com/IQuOD/AutoQC

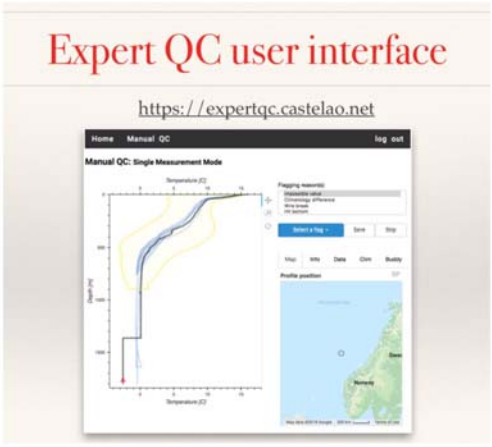
Progress has been made improving the software infrastructure and code to assess the performance of AutoQC combinations to yield best combination of tests for a given false positive rate. A first assessment of best combinations has been carried out on the QuOTA dataset (Gronnel and Wijffels, 2016, https://journals.ametsoc.org/doi/full/10.1175/JTECHO539.1). Quality control checks and benchmarking metrics code were written in Python and are available from our Github. Can be used by anyone. Python reader for World Ocean Database ASCII data also available. All code continues to be made available in real-time via the GitHub repository. Analysis of AutoQC tests has begun and will form the basis of a scientific paper.

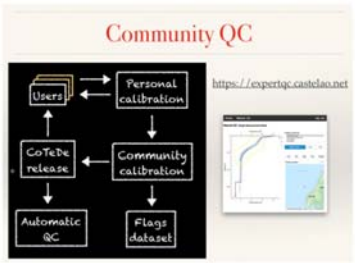
Benchmarking results and validation tests for the AutoQC tests from different institutions were produced and briefly presented in a U.S. CLIVAR webinar by Simon Good. Further evaluations and larger IQuOD discussion are planned during our next SCOR-IODE IQuOD workshop (IFREMER, October 2019). Next step will be to agree on the optimal set of Auto QC tests to be used for the quality flags for the next IQuOD interim data product release.

4. To examine and document the feasibility of machine learning and other novel computational methods for enhanced quality control, to potentially minimize labor costs associated with human expert quality control procedures.

Machine learning approaches are being used as part of the AutoQC benchmarking exercise (e.g., the CoTeDe “fuzzy logic” test). Machine learning approaches are also being investigated for future assignment of XBT intelligent metadata (iMeta). A paper on applying a neural network approach to iMeta has been published in Journal of Atmospheric and Oceanic Technology (Leahy et al., 2018) with a more comprehensive intercomparison of various Machine Learning approaches underway at the UK Met Office.

Initial evaluation of a GUI tool from Guilherme Castelão (see diagram below) through performing the QC of the profiles and feedback for improving the interface. QC of certain number of profiles each day manually, so that the data will be cleaned and be available for the IQuOD data product release.





5. To develop, implement and document internationally agreed best practice methods for assignment of uncertainty estimates to each temperature observation.

A first approach to assignment of uncertainty to each temperature observation was incorporated into the IQuOD v0.1 dataset. We now aim to devise further refinements for the next dataset version.

6. To freely disseminate (interim) versions of the IQuOD global temperature profile database (and added value-products) as it evolves over the next 3 years, in user-friendly file formats.

Release of the next interim IQuOD dataset version will include refinements to both uncertainty assignment and i-metadata. Major advance will be inclusion of quality flags based on the agreed optimal AutoQC procedures. File format will follow previous version (based upon the widely used Argo

NetCDF format). Next IQuOD dataset version will be available from various mirror-sites (UK, USA, China, Japan, Australia, etc).

7. To share knowledge and transfer skills in instrumentation, regional oceanography, quality control procedures and data stewardship with international scientists in both developed and developing nations.

Knowledge transfer activities are reflected by involvement of IQuOD members in a range of OCEANOBS'19 white papers from different user communities (e.g., observations, reanalyses, climate science) as well as through dissemination/discussions via relevant meetings (e.g., keynote and poster presentations) and via Slack/GitHub (task team activities and code repository) in addition to annual SCOR/IODE workshops.

5. WG activities planned for the coming year. Limit 500 words

- Annual SCOR/IODE IQuOD workshop planned for 28 October - 1 November 2019, IFREMER, Brest, France. Host: Loic PETIT DE LA VILLEON Loic.Petit.De.La.Villeon@ifremer.fr
- Optimal AutoQC software and preparation of a related peer-reviewed paper.
- Progressing machine learning based community expert quality control via a cloud-based user interface https://expertqc.castelao.net
- Release next interim IQuOD dataset, with refined uncertainties, i-metadata and quality flags based on optimal AutoQC.

6. Is the group 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

- In general, there has been a delay in the original time schedule by some months to accommodate higher than normal working schedules in 2018/19 and a long-term service leave.

7. Any special comments or requests to SCOR. Limit 100 words.

Although we were planning to submit a 4-year IQuOD-related project proposal for the Australian Research Council – Linkage Projects in December 2018. We were unable to match the overall required cash contributions (despite SCOR support). New avenues will continue to be explored. Technical focus will be on data rescue and Expert Quality Control activities.

Additional information can be submitted and will be included in the background book for the SCOR meeting at the discretion of the SCOR Executive Committee Reporter for the WG and the SCOR Secretariat.

2.1.6 WG 150: Translation of Optical Measurements into particle Content, Aggregation and Transfer (TOMCAT) (2015) *Burkill*

Chair: Sari Giering (UK)

Other Full Members[1]: Klas Ove Möller (Germany), Sünnje Basedow (Norway), Lionel Guidi (France), Morten Iversen (Germany), Andrew McDonnell (USA), Adrian Burd (USA), Catarina Marcolin (Brazil), Sandy Thomalla (South Africa), and Tom Trull (Australia)

Associate Members: Emma Cavan (UK), Uta Passow (USA), George Jackson (USA), Nathan Briggs (France), Dhugal Lindsay (Japan), and Lou Darroch (UK)

Terms of Reference[2]

1. Compare current devices that optically measure particles and document the advantages and disadvantages of each device.
2. Inter-calibrate the outputs of different devices and/or highlight calibration difficulties.
3. Define key parameters to use for interpretation of the optical information and decide which measurements are most important for characterizing particle export.
4. Improve techniques/algorithms for the conversion of optical observation into fluxes.
5. Decide on how to best analyse the increasingly larger data sets.
6. Develop software examples and codes, placed on a public repository.
7. Deposit optical particle data in an internationally recognised database that can be actively added to as new data is collected (to allow for large scale analysis and future data exchange)
8. Advise on future methods to maximize data collection and interpretation

Executive Committee Reporter: Peter Burkill

[1] SCOR has asked the group to add another Full Member from a developing country and move one of the following Full Members to Associate Member status.
[2] SCOR has asked that the group streamline its terms of reference.

2.1.7 WG 151: Iron Model Intercomparison Project (FeMIP) (2016) *Casacuberta Arola*

Co-chairs: Alessandro Tagliabue (UK) and Stephanie Dutkiewicz (USA)

Other Full Members: Tatiana Ilyina (Germany), Kazuhiro Misumi (Japan), Fanny Monteiro (UK), J. Keith Moore (USA), Yeala Shaked (Israel), Marcello Vichi (South Africa), Christoph Völker (Germany), Mustafa Yücel (Turkey)

Associate Members: Olivier Aumont (France), Alex Baker (UK), Philip Boyd (Australia), Fei Chai (China-Beijing), Peter Croot (Ireland), Christel Hassler (Switzerland), Eun Young Kwon (Korea), Jun Nishioka (Japan), Maite Maldonado (Canada), Mark Moore (UK), Andy Ridgwell (USA), Benjamin Twining (USA)

Terms of Reference

- To identify best practices for minimum complexity representations of the iron cycle in models, with options given for more advanced aspects, and publish the guidance in a peer-reviewed paper.
- To develop tools for a wide variety of platforms to validate global model results in a standardised way and make these available via a peer-reviewed publication and a website.
- To facilitate a focussed intercomparison of iron models to constrain the impact of varying residence times and a consensus dust deposition scheme and publish the results in a peer-reviewed journal.
- To review how to represent biological interactions in the iron cycle, the linkages to key phytoplankton species and the interactions with zooplankton and bacteria, as well as broader connections with other biogeochemical cycles and publish the results in a peer-reviewed journal.

Executive Committee Reporter: Nuria Casacuberta Arola

1. Name of group

Iron Model intercomparison project (FeMIP), SCOR WG 151

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

Correspondences via Slack on working group activities.

Review activities for objective 1 have been completed and material for the review paper has been gathered.

Several emails have been exchanged on the model output needed for the activities of Objective 2.

Plans have been made for objective 3 model simulations

Several emails have also been exchanged and a table developed on the physiological components of interest in the iron cycle (Objective 4)

3. 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 WG activities and which acknowledge SCOR support

None yet

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

Objective 1: The working group has put together the materials and finalized a table on the complexity used in various models. An open-access article is being drafted by Tagliabue.

Objective 2: The working group is in process of obtaining the relevant model fields for model evaluation. We have targeted the specific models and types of fields (Fe, nutrients, oxygen, Chl-a, temperature and salinity for 10-year monthly climatologies) that will be most useful. Marcello Vichi has taken the lead of this objective.

Objective 3: Our plans are to use a single model (GENIE) with different assumptions on the solubility, natural versus anthropogenic, depth of deposition, and scavenging particles. These plans wait though on the availability of Andy Ridgwell to have the time to do these simulations.

Objective 4: Phil Boyd and Stephanie Dutkiewicz have started a table with the main physiological process that need to be captured in models that are important for iron cycling

5. WG activities planned for the coming year. Limit 500 words

We have submitted a proposal for a session at Ocean Sciences that relates the goals of this working group (Al Tagliabue and Andy Ridgwell)

We plan an internet meeting for each of the 4 objectives over the next few months to jumpstart the process of finishing these items.

We plan for a working meeting at the Ocean Sciences meeting of the WG members to serve as a catalyst for the completion of objectives 1 and 2, and to discuss initial results and finalise plans for objectives 3 and 4. We request funds to accommodate this meeting.

6. Is the group 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

Leads of the group have been over-committed over this time period, and have not provided sufficient energy to keep the group moving forward at the pace we had hoped. This has arisen largely due to the insertion of unforeseen and time-sensitive roles taking up significant co-chair time (e.g., Tagliabue as a lead author on IPCC special report on oceans and cryosphere in a changing climate chapter and summary for policy makers).

We plan to prioritize this SCOR WG more fully in the next year to fulfil the terms of reference

7. Any special comments or requests to SCOR. Limit 100 words.

We would like to request funds for a meeting to be held in conjunction Ocean Sciences 2020. The likely date for this meeting would be 16 February 2020.

Additional information can be submitted and will be included in the background book for the SCOR meeting at the discretion of the SCOR Executive Committee Reporter for the WG and the SCOR Secretariat.

2.1.8 WG 152: Measuring Essential Climate Variables in Sea Ice (ECV-Ice) (2016) *Nomura, McDougall*

Co-chairs: Daiki Nomura (Japan), François Fripiat (Belgium), and Brent Else (Canada)

Other Full Members: Bruno Delille (Belgium), Mar Fernandez-Méndez (Norway), Lisa Miller (Canada), Ilka Peeken (Germany), Janne Markus Rintala (Finland), Maria van Leeuwe (Netherlands), and Fan Zhang (China-Beijing)

Associate Members: Katarina Abrahamsson (Sweden), Jeff Bowman (USA), James France (UK), Agneta Fransson (Norway), Delphine Lannuzel (Australia), Brice Loose (USA), Klaus Meiners (Australia), Christopher J. Mundy (Canada), Hyoung Chul Shin (Korea), and Jean-Louis Tison (Belgium)

Terms of Reference

- Publish synthetic reviews compiled from measurements demonstrating large, unresolved discrepancies, with a special emphasis on primary production, gas concentrations and fluxes. These detailed reviews will draw on both the literature and unpublished studies to evaluate the strengths and weaknesses related to each methodology.
- Design and coordinate intercalibration experiments to evaluate different methods for key parameters. In addition to organizing field experiments, we will pursue use of ice tank facilities and stimulate and support applications for funding, at both national and international levels, to further facilite the experiments. If successful, manuscripts will be written and the outcomes will be presented in the guide of best practice to support the recommendations.
- Design intercomparison studies to facilitate validation and adoption of new technologies for assessing the complexity and heterogeneity of sea ice at various spatial and temporal scales.
- Create a guide of best practices for biological and biogeochemical studies in the sea-ice environment. This will be accomplished using a web-based forum for compiling and disseminating the outcomes of past and new intercomparison studies.

Executive Committee Reporter: John Turner

1. Name of group

Working Group 152, Measuring Essential Climate Variables in Sea Ice (ECV-Ice)

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

Virtual meeting #1: 11 Oct. 2018, ECV-Ice co-chair meeting, Present: Brent Else, Daiki Nomura, Francois Fripiat.

Virtual meeting #2: 25 Jan. 2019, CO_2 flux compilation meeting, Present: Daiki Nomura, Sebastien Moreau

Virtual meeting #3: 19 Apr. 2019, ECV-Ice co-chair meeting, Present: Daiki Nomura, Francois Fripiat.

In-person meeting #1: 17 Jun. 2018, BEPSII and ECV-Ice Meeting, Davos, Switzerland. 10 ECV-ice members: B. Delille, F. Fripiat, K. Meiners, L. Miller, J-L. Tison, M. van Leeuwe, D. Nomura, M. Vichi, J. Bowman, B. Else (Skype).

28 Other participants: S. Moreau, J-M. Rintala, J. Stefels, L. Tedesco, M. Chierici, E. Mortenson, P. Wongpan, G. Castellani, P. Duke, H. Kaartokallio, D. Konig, C. Hauri, M. Frey, I. Peeken, O. Crabeck, K. Campbell, K. Brown, A. Fong, E. Damm, E. Jones, M. Dall'Osto, A. van de Putte, P. Snoeijs, F. Deman, J. Janssens, C. Jacques, F. van der Linden, M. Kotovich

In-person meeting #2: 18 Mar. 2019, CO_2 flux compilation meeting at Alfred Wegener Institute, Germany, Present: Daiki Nomura, Bruno Delille

Intercomparison Experiment #1: 23-28 Feb. 2019, Sea ice intercomparion experiment for light measurement in Saroma-ko Lagoon, Hokkaido Japan. Present: D. Nomura, P. Wongpan, T. Toyota, T. Tanikawa, Y. Kawaguchi, T. Ono, T. Ishino, M. Tozawa, T. P. Tamura, I. Yabe, E. Y. Son, F. Vivier, A. Lourenco, M. Lebrun, Y. Nosaka, and M. Vancoppenolle

3. 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 WG activities and which acknowledge SCOR support

Peer-reviewed journal article #1: Butterworth, B.J, and Else, B.G.T. 2018.Dried, closed-path eddy covariance method for measuring carbon dioxide flux over sea ice, *Atmos. Meas. Tech*. 11:6075-6090, https://doi.org/10.5194/amt-11-6075-2018.

Peer-reviewed journal article #2: Meiners, K.M., Vancoppenolle M., et al. 2018. Chlorophyll-a in Antarctic land-fast sea ice: a synthesis of historical ice-core data. *Geophysical Research: Oceans* 123:8444-8459, https://doi.org/10.1029/2018JC014245.

Peer-reviewed journal article #3: Roukaerts, A, Nomura, D, Deman, F, Hattori, H, Dehairs, F, and Fripiat, F. 2019. The effect of melting treatments on the assessment of biomass and nutrients in sea ice (Saroma-ko lagoon, Hokkaido, Japan). *Polar Biology* 42:347–356.

Peer-reviewed journal article #4: Campbell, K, Mundy, C.J, Juhl, A.R, Dalman, L.A, Michel C, Galley R. J, Else B. E, Geilfus N. X and Rysgaard S. Melt Procedure Affects the Photosynthetic Response of Sea Ice Algae. *Front. Earth Sci*. 7:21. doi: 10.3389/feart.2019.00021, 2019.

Web pages: Updated by Daiki Nomura (https://sites.google.com/view/ecv-ice/).

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

This working group gathers international experts on chemical and biological measurements in sea ice to design and coordinate required intercomparison and intercalibration experiments. The group is synthesizing the results of past experiments, identifying what types of new experiments are needed, and supporting the community in executing those experiments.

Term of reference (TR) #1: Publish synthetic reviews compiled from measurements demonstrating large, unresolved discrepancies.

We compiled published and unpublished datasets (raw data, methodologies and associated protocols for data correction, instruments, and sampling design) on sea ice-air CO_2 flux and *in situ* primary production from the sea-ice research communities.

(1) Published and unpublished datasets, using various methodologies, have been collated for primary production, both in the Arctic and Antarctic sea ice: incubations (^{13}C, O_2, ^{14}C), under-ice microelectrode, and biomass accumulation rates (F. Fripiat, C.J. Mundy, F. Deman, and K. Campbell). The different methods will be compared and a mechanistic understanding of the observed discrepancies will be elaborated. Together, this dataset represents the largest compilation of primary production rates so far in sea ice.

(2) Published and unpublished datasets have been collated to compare gas flux measurements over sea ice using chamber techniques (D. Nomura and B. Else). A preliminary draft of this paper has been completed, and will be discussed at the upcoming ECV-Ice annual meeting in Winnipeg, MB, Canada.

(3) A paper comparing eddy covariance techniques for measuring CO_2 fluxes over sea ice was published (Butterworth and Else, 2018, 10.5194/amt-11-6075-2018). This paper showed that the majority of past eddy covariance measurements made with the open and closed path techniques without sample drying are likely contaminated by water vapour fluxes. A planned synthesis of past eddy covariance datasets will not be conducted because of this finding. The results of this finding have been disseminated through the ECV-Ice WG, and are resulting in changes to experimental approaches.

TR #2: Design and coordinate intercalibration experiments to evaluate different methods for key parameters.

Completed Intercalibration Experiments:

Sea ice light measurement: Saroma-Ko Lagoon, February 2019

Participants: D. Nomura, P. Wongpan, T. Toyota, T. Tanikawa, Y. Kawaguchi, T. Ono, T. Ishino, M. Tozawa, T.P. Tamura, I. Yabe, E.Y. Son, F. Vivier, A. Lourenco, M. Lebrun, Y. Nosaka, and M. Vancoppenolle.

Summary: An intercalibration experiment (two weeks; Lead: D. Nomura) was carried out at Saroma-ko lagoon (Japan) in February 2019 to evaluate different methodologies (sensors) assessing sea-ice over/under ice light measurement. The experiment was successful and peer-reviewed reports (Nomura et al., in prep.) are now being drafted. Draft papers will be discussed at the upcoming ECV-Ice WG meeting.

Planned Intercalibration Experiments:

Gas Concentrations: Roland Von Glasow Air-Sea-Ice Chamber (University of East Anglia)
Participants: B. Delille, M. Kotovich, L. Miller, B. Else, M. Thomas, D. Nomura, A. Fransson, J-L. Tison, and O. Crabeck

Summary: An intercalibration experiment is being planned for the University of East-Anglia (September 2019). The purpose is to use the Roland Von Glasgow Air-Sea-Ice Chamber facility to compare all the techniques available to measure gas concentration in sea ice (sampling, processing, storage, and analysis). An application to Eurochamps 2020 transnational access funding has been written (Lead: B. Delille). The procedure will be discussed at the upcoming ECV-Ice annual meeting.

Primary Production and Gas Fluxes: Cambridge Bay, Canada
Participants: Brent Else (co-lead), F. Fripiat (co-lead), D. Nomura (co-lead), J. Stefels, M. Van Leeuwe, J. Bowman, C.J. Mundy, J.-M. Rintala, M. Fernandez-Mendez, F. Deman, A.-J. Cavagna, N. Kanna, etc.

At the upcoming ECV-Ice WG meeting in Winnipeg (August 2019), we will continue to discuss (logistic, funding) the possibility to perform a large-scale intercalibration experiment in Cambridge Bay, in the new Canadian High Arctic Research Station, operated by Polar Knowledge Canada (POLAR). Recent developments in this coordination include an upcoming meeting of the Japanese Polar Institute with POLAR (July 2019), which will be attended by three ECV-Ice WG representatives (Else, Nomura, and a representative from Mundy's lab). We will attempt to do this experiment in 2021 (late March-early April), in order to target the sea-ice algal bloom in an ascending phase.

The purpose of this experiment is to compare all the techniques available to date to measure primary production (GPP, NPP, NCP) in sea ice (2-3 weeks): biomass/chl-a accumulation, under-ice eddy covariance, under-ice microelectrodes, isotopic tracer incubations (^{14}C & ^{13}C), O_2:Ar ratio, PI curve, and PAM fluorescence. We will also assess the most suitable tracer incubation protocols for general metabolic rate determinations in sea ice (e.g., bacterial production, nutrient transformations). That is, how to collect a representative in-situ sea-ice microbial community and to ensure tracer homogenization within the brine network prior incubation (e.g., direct vs. buffered melting, …). It was also noted that the experiment could be extended to include other inter-calibrations. Other suggested intercalibration include bacterial production, DNA/RNA, bacterial abundance, light measurements, nutrients, biomass, taxonomy, storage of ice cores for later analysis. A special emphasis will be also dedicated to solve the nutrient-chlorophyll paradox in productive sea ice. We are open to accommodating this, although we may run into logistical problems if there are too many people.

For gas (CO_2) fluxes over sea ice, we will compare with eddy covariance techniques developed by Butterworth and Else (2018) and enclosure chamber technique at same site and same period. We will also compare all the techniques available to date to measure gas concentration in sea ice (sampling, processing, storage, and analysis) to check for natural sea ice to compare with the upcoming experiment in the Roland Von Glasgow Air-Sea-Ice Chamber facility.

TR #3: Design intercomparison studies to facilitate validation and adoption of new technologies for assessing the complexity and heterogeneity of sea ice at various spatial and temporal scales.

We will try to merge as much as possible the future intercalibration experiments with emerging technologies.

TR #4: Create a guide of best practices for biological and biogeochemical studies in the sea-ice environment.

Based on the information available at this time, we will start to create a guide of best practices hosted on the ECV-Ice website as a living document. The first entry will be the Miller et al. (2015) methodological review from SCOR WG 140, and the results of additional methods evaluations and intercalibrations will be added, as they become available.

5. WG activities planned for the coming year. Limit 500 words

Virtual meetings: Expect to meet 2-3 times to discuss updates and working plans for the different terms of reference. F. Fripiat, B. Else, and D. Nomura and other members. 2-3 meetings are expected to discuss about each data collation related to TR1 (primary production and sea ice-air CO_2 exchange).

In-person meeting: Aug. 2019, ECV-Ice WG Meeting with BEPSII, Winnipeg, Canada. ECV-ice members and others. We will discuss progress on the terms of reference (present the data collations (TR2), pursue the elaboration of intercalibration experiments (TR #1 and #3), including reviewing results of primary production and light experiment in Saroma and plans for the gas concentration at UEA, 2019 and primary production and gas flux at Cambridge Bay, 2021.

Intercalibration experiment on gas concentrations: We will conduct an intercalibration experiment at the UEA ice-tank facility in fall 2019. EUROCHAMP 2020 funding will available for this intercalibration experiment. The funding will cover travel expenses for 1-3 international participants, and the costs of operating the facility. We will run at least one ice-growth experiment (~10 days). If feasible, a second experiment at a different temperature will be conducted.

6. Is the group 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

At this point, we appear to be on track, with a number of activities to forward the terms of reference.

7. Any special comments or requests to SCOR. Limit 100 words.

We would like to express heartfelt thanks for financial and technical supports. We would be very interested in any advice SCOR could provide on additional possible sources of support for more scientists to be able to directly participate in the intercalibration experiments.

Photo taken during Annual ECV-Ice Meeting (D. Nomura)

2.1.9 WG 153: Floating Litter and its Oceanic TranSport Analysis and Modelling (FLOTSAM) (2017)

Martinez Vicente, Myers

Chair: Stefano Aliani (Italy)

Vice-Chairs: Nikolai Maximenko (USA), Kara Lavender Law (USA), and Erik van Sebille (Netherlands)

Other Full Members: Bertrand Chapron (France), Irina Chubarenko (Russia), Atsuhiko Isobe (Japan), Victor Martinez-Vicente (UK), Peter Ryan (South Africa), Won Joon Shim (South Korea), and Martin Thiel (Chile)

Associate Members: Melanie Bergmann (Germany), Yi Chao (USA), Baylor Fox-Kemper (USA), Denise Hardesty (Australia), Tobias Kukulka (USA), Laurent Lebreton (New Zealand), Christophe Maes (France), and Miguel Morales Maqueda (UK)

Terms of Reference

- Identify gaps in our knowledge of the near-surface ocean dynamics that may affect litter distribution and transport.
- Improve future marine litter modelling capabilities.
- Evaluate existing and emerging remote sensing technologies that can be applied to marine litter in the open ocean.
- Improve awareness of the scientific understanding of marine debris, based on better observations and modelling results.

Executive Committee Reporter: Paul G. Myers

1. Name of group

Floating Litter and its Oceanic TranSport Analysis and Modelling (FLOTSAM)

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

The first meeting of SCOR WG 153 FLOTSAM was in San Diego (USA) before the 6th International Marine Debris Conference in March 2018. After the meeting and the sessions chaired at the conference, relevant discussions and exchange of ideas continued in subsequent email and phone exchanges throughout the year. Part of the group physically met again during other conferences throughout the year to discuss WG153 topics (see list reported later). The objective of all these meetings was to discuss and sort out the key concepts involved in floating litter transport and to set up a cutting-edge plan for the FLOTSAM 2019 annual meeting.

The second official WG153 meeting was held in Utrecht (NL) on 6-9 May 2019. Some partners participated physically and others online by continuous online streaming of the sessions. The program of the meeting is copied below in this report. A fruitful and intensive discussion resulted from the meeting and a draft for a review paper has been prepared and made available online on Google Drive for editing by partners and a selection of relevant invited external experts. Online writing and discussion is ongoing using web platforms and email exchanges. The assembly and writing of the draft is being led by SCOR Vice-Chair Erik van Sebille, with a final draft anticipated by September 2019.

Introduction and plan of the workshop

Marine plastic debris pollution floating on the surface of our ocean is a major environmental problem. At the same time, plastics are a unique tracer that provides an opportunity to learn more about the dynamics of our ocean across space and time scales. That is the goal of SCOR Working Group 153: Floating Litter and its Oceanic TranSport Analysis and Modelling (FLOTSAM).

The Terms of Reference of the SCOR Working Group are (see also http://scor-flotsam.it/):

1. Identify gaps in our knowledge of the near-surface ocean dynamics that may affect litter distribution and transport.
2. Improve future marine litter modelling capabilities.
3. Evaluate existing remote sensing technologies that can be applied to marine litter in the open ocean.
4. Improve awareness of the scientific understanding of marine debris, based on better observations and modelling results.

In the May 2019 workshop, we discussed where the knowledge gaps are, how floating marine debris is transported in our ocean, and how we will synthetize present knowledge in an open-access focussed review paper.

The workshop had the following detailed objectives and goals:

- Mapping sources and observations of floating plastic across scales.
- Revisiting the current state of knowledge on the dynamics and ocean phenomena that control the dispersion of floating marine debris;
- Identifying key knowledge gaps in this dispersion;
- Aligning these knowledge gaps with ongoing and planned international projects;
- Recommending future research directions, to address the knowledge gaps;
- Writing a review paper on the findings of the workshop.

The workshop started with very short introductions of the participants. There were no slides for this, just introduction of people and research interests in 2 minutes per person.

The rest of day 1 was a plenary session discussing the objectives and goals stated above, and agreeing on terminology and the scope of the review paper. One or two figures that were relevant to the goals and aims were used to kickstart discussions. These figures were from published or unpublished work.

On days 2 and 3, the session broke into smaller groups to work on different sections of the review paper and we ended with a preliminary draft ready at the end of the workshop. We plan to submit the review by the end of summer 2019.

An excellent group of people with expertise in so many aspects of oceanic dispersion gathered together and focussed on WG 153 ToRs. The names of SCOR WG members are highlighted in the following table. The other scientists participated as *ad hoc* external experts at their own costs.

Detailed Meeting Agenda

Meeting was at Minnaert Building (Mezzanine), Leuvenlaan 4, 3584 CE Utrecht

Day 1: Tuesday 7 May

09:30 Registration with coffee and tea
10:00 Welcome and introduction to the workshop
10:30 2-minute introductions by each participant (no slides)
11:30 Plenary discussion on most relevant processes/dynamics for dispersion of floating debris. Participants can show a figure that they brought (as a slide)
12:30 Lunch
13:30 Continued plenary discussion
15:00 Afternoon tea break
15:30 Continued plenary discussion
17:00 End for Day 1

19:00 Workshop Dinner at De Rechtbank

Day 2: Wednesday 8 May

09:30 Organise into break-out groups scoping sections of the paper
10:30 Morning coffee break
11:00 Continue into break-out groups to write sections
12:30 Lunch
13:30 Continue into break-out groups to write sections
15:00 Afternoon tea break
15:30 Plenary update of progress in break-out groups
17:00 End for Day 2

Day 3: Thursday 8 May

09:30 Organise into new break-out groups scoping sections of the paper
10:30 Morning coffee break
11:00 Continue into break-out groups to write sections
12:30 Lunch
13:30 Plenary wrap-up and task assignment for continued writing review
15:30 Afternoon tea break and end of workshop

List of participants in Utrecht

1. *Stefano Aliani*
2. *Kara Lavender Law*
3. *Nikolai Maximenko*
4. *Erik van Sebille*
5. *Irina Chubarenko*
6. *Atsuhiko Isobe*
7. *Victor Martinez-Vicente*
8. *Martin Thiel*
9. *Miguel Morales Maqueda*
10. Charlotte Laufkoetter
11. Bart Koelmans
12. Matt Hoffman
13. Philippe Delandmeter
14. David Wichmann
15. Mikael Kaandorp
16. *Paolo Corradi*
17. Shungu Garaba
18. Marie-Helene Rio
19. Matthias Egger
20. Lonneke Goddijn-Murphy
21. Ton van den Bremer
22. Ernesto Rodriguez
23. Giuseppe Suaria
24. Cleo Jongedijk

25. Lilia Khatmullina
26. Jose Alsina
27. Delphine Lobelle
28. *Laurent Lebreton*
29. Andrei Bagaev

List of participants remotely joining

1. *Baylor Fox-Kemper*
2. *Peter Ryan*
3. Andres Cozar
4. *Christophe Maes*
5. *Tobias Kukulka*

3. 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 WG activities and which acknowledge SCOR support

The website http://scor-flotsam.it has been regularly updated. It is hosted on GitHub and CNR servers and administrated by E. Van Sebille. WG 153 is also hosted in SCOR website (https://scor-int.org/group/153/.

FLOTSAM participants presented and discussed the outcome of the fist WG153 workshop at conferences worldwide and some papers have been submitted or drafted in 2018 -2019.

In June 2018, in Akureyri (IS), Stefano Aliani, chair of WG153 and other SCOR members were involved in the activities of the Arctic Council working group PAME. The main topic was to discuss about a desktop study of marine litter in the Arctic. New findings have been presented also relevant for FLOTSAM.

Also in June 2018, Erik van Sebille, vice-chair of WG153, gave the keynote presentation at the UK Challenger Society biannual conference in Newcastle, UK. He presented the aims and objectives of WG153 to the UK oceanographic community.

In August 2018, Kara Lavender Law gave a webinar hosted by the American Chemical Society entitled, “Ocean Plastics Pollution: Sources, Distribution and Impacts” in which the aims of WG153 were discussed.

Kara Lavender Law presented seminars at University of South Florida, College of Marine Science (Oct. 2018), University of Maine, School of Marine Sciences (Feb. 2019), Northeastern University, Marine Science Center (Mar. 2019) entitled, “Ocean Plastics: Trash, Tracer and Environmental Threat” in which the aims of WG153 were discussed.

In October 2018, Kara Lavender Law and Nikolai Maximenko attended the Plastic Awareness Global Initiative (PAGI): Ocean Science Workshop at Scripps Institution of Oceanography (La Jolla, CA), in which they discussed aims and contributions of WG153 with other invited experts.

In November 19-23th 2018 many partners met at Micro 2018 conference in Lanzarote (ES). Conference proceedings report partners' contribution https://micro2018.sciencesconf.org/.

In February 2019 in Rome (IT), Stefano Aliani, chair of WG153, provided SCOR expertise to the workshop on Floating Marine Macro Litter monitoring chaired by Georg Hanke, European Commission Joint Research Centre Directorate D Sustainable Resources and organized by the MEDSEALITTER project and the JRC.

In February 2019 in Frascati (ESA-ESRIN), Erik van Sebille and Nikolai Maximenko (invited), vice-chairs of WG153, spoke at the World Ocean Circulation User Consultation Meeting about physical processes controlling drift of marine debris.

In April 2019, Erik van Sebille, vice-chair of WG153, gave a keynote presentation about floating litter at the European Geosciences Union's General Assembly in Vienna, Austria. There, he explained the goals and objectives of WG 153 to a broad audience of geoscientists, raising the profile of the workgroup.

On May 14th, 2019 the session A4.01 at the ESA Living Planet Symposium in Milan was chaired by Stefano Aliani and Paolo Corradi from SCOR WG 153. The session was about multisensor approaches to marine litter detection and included 13 contributions, 6 were oral contributions and 7 posters.

In May 2019, Nikolai Maximenko was invited to NSF-sponsored workshop on Post-Disaster Materials and Environmental Management, held in Washington DC. He also co-organized or presented relevant materials at NASA Biodiversity and Ecological Forecasting Team meetings (April 2018 and May 2019, Washington DC), NASA Ocean Surface Topography Science Team Meeting (September 2018, Azores, Portugal), and Conference on Mesoscale and Submesoscale Processes (November 2018, Moscow, Russia).

A special session on WG153 topics has been organized at IAPSO/IUGG Assembly in Montreal, 10-17 July 2019. Leading author is Erik van Sebille. http://iapso.iugg.org/. Only preparatory work is reported here as the meeting hasn't started yet.

A breakout session at OceanObs'19 in Honolulu 16-20 September 2019 has been organised, with Nikolai Maximenko being a Co-chair. http://www.oceanobs19.net/. Only preparatory work and submission of proceedings are reported here as the meeting hasn't started yet.

Proposal for a session dedicated to FLOTSAM ToRs has been submitted to the 2020 Ocean Sciences meeting in San Diego by Kara Lavender Law and other FLOTSAM chairs.

Papers

Maximenko, N., P. Corradi, K. L. Law, E. Van Sebille, S. P. Garaba, R. S. Lampitt, F. Galgani, V. Martinez-Vicente, L. Goddijn-Murphy, J. M. Veiga, R. C. Thompson, C. Maes, D. Moller, C. R. Löscher, A. M. Addamo, M. Lamson, L. R. Centurioni, N. Posth, R. Lumpkin, M. Vinci, A. M.

Martins, C. D. Pieper, A. Isobe, G. Hanke, M. Edwards, I. P. Chubarenko, E. Rodriguez, S. Aliani, M. Arias, G. P. Asner, A. Brosich, J. T. Carlton, Y. Chao, A.-M. Cook, A. B. Cundy, T. S. Galloway, A. Giorgetti, G. J. Goni, Y. Guichoux, L. Haram, B. D. Hardesty, N. Holdsworth, L. Lebreton, H. A. Leslie, I. Macadam-Somer, T. Mace, M. Manuel, R. Marsh, E. Martinez, D. Mayor, M. Le Moigne, M. E. M. Jack, M. C. Mowlem, R. W. Obbard, K. Pabortsava, B. Robberson, A.-E. Rotaru, G. Ruiz, M. T. Spedicato, M. Thiel, A. Turra, C. Wilcox, Towards the Integrated Marine Debris Observing System (IMDOS), (accepted by *Frontiers* magazine).

In the paper, we review the properties and impacts of different types of marine debris, as well as techniques and technologies that are used or can be used in the next decade and beyond, while providing our vision of how direct observation, remote sensing, and numerical modelling can be integrated to compose a global observing system. With this paper, we aim to stimulate establishment of a best-practice-guide as well as optimization and expansion of the existing observational network to the Integrated Marine Debris Observing System (IMDOS) to improve the coverage of important areas of the ocean and to increase the accuracy of estimates and products.

It's a relevant wide effort, coordinated by SCOR co-chair Nikolai Maximenko, to prepare a global observing system for plastic at sea. A network of in situ observations, including reports from volunteers, citizen scientists and ships of opportunity, will be developed to provide data for calibration/validation of remote sensors and to monitor the spread of plastic pollution and other marine debris. IMDOS will interact with other observing systems monitoring physical, chemical, and biological processes in the ocean and on shorelines as well as state of the ecosystem, maritime activities and safety, drift of sea ice, etc.

Martinez-Vicente, V., J. Clark, P. Corradi, S. Aliani, M. Arias, M. Bochow, G. Bonnery, M. Cole, A. Cozar, R. Donnelly, F. Echevarria, S. P. Garaba, L. Goddijn-Murphy, L. Lebreton, H. A. Leslie, P. Lindeque, N. Maximenko, F. Martin-Lauzer, D. Moller, P. Murphy, L. Palombi, V. Raimondi, J. Reisser, L. Romero, Stefan Simis, S. Sterckx, R. C. Thompson, K. N. Topouzelis, E. van Sebille, J. M. Veiga, D. Vethaak. Measuring marine plastic debris from space: initial observation requirements, Remote Sensing of Environment (under review).

In this manuscript, we make initial steps towards the potential design of remote sensing system for marine debris by 1) identifying the properties of marine plastic debris amenable to remote sensing methods and 2) highlighting the oceanic processes relevant to scientific questions about marine plastic debris. Remote sensing approaches are reviewed and matched to the optical properties of marine plastic debris and the relevant scales of observation to identify challenges and opportunities in the field.

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

The WG made relevant progresses toward objective through meeting, sessions at scientific congresses, email exchanges and Skype calls.

TOR1 - Identify gaps in our knowledge of the near-surface ocean dynamics that may affect litter distribution and transport

During the year and at the workshop in Utrecht participants discussed and agreed on a list of relevant oceanographic processes affecting marine litter distribution and transport. Processes that at the present state of knowledge have been listed and ranked according to their relevance for marine debris studies. In the review paper under preparation, some Chapters relevant to ToR1 have been included.

TOR 2 - Improve future marine litter modelling capabilities

The current state of modelling of marine debris has been discussed in different occasions and summarised in Utrecht. In the review paper under preparation, some Chapters relevant to ToR2 have been included.

TOR3 - Evaluate existing and emerging remote sensing technologies that can be applied to marine litter in the open ocean

The community white paper already submitted to OceanObs19 in Hawaii has been presented and briefly discussed, and we discussed the first results of 2 ESA funded projects related to remote sensing of marine debris on the shoreline and in the open ocean. In the review paper under preparation, some Chapters relevant to ToR3 have been included.

TOR4 - Improve awareness of the scientific understanding of marine debris, based on better observations and modelling results.

FLOTSAM website has been updated.
Participants of WG153 chaired sessions at several conferences and in many institutions; among them ESA, East China Normal University (Shanghai).

Communication with media and interviews with newspapers. The WG member Martin Thiel presented a comprehensive outreach activity dedicated to students, school teachers and public on marine debris currently running in S. America and prepared in collaboration with German Institutions. A proposal for funds dedicated to translation in other languages is under consideration.

Kara Lavender Law gave six presentations to public audiences, including Quissett Harbor Preservation Trust (Falmouth, MA, Jul. 2018); Eckerd College (St. Petersburg, FL, Oct. 2018); Falmouth Forum (Falmouth, MA, Jan. 2019); Franklin and Marshall College (Lancaster, PA, Apr. 2019); Avenues: The World School (New York, NY, Apr. 2019) and University of Connecticut, Avery Point (Groton, CT, Apr. 2019). She was also a panelist in a keynote plenary discussion at the Solid Waste Association of North America SWANApalooza conference (Boston, MA, Feb. 2019), and in a "Science on the Hill" event

convened by *Scientific American* and Nature Springer (Washington, DC, Jun. 2019). She has also been a guest in multiple graduate, undergraduate, high school and elementary school classes to talk about ocean plastics.

5. WG activities planned for the coming year. Limit 500 words

The venue for the next FLOTSAM annual workshop hasn't been officially decided yet. Russia and Japan expressed their interest to host the last meeting and the group will take the final decision as soon as some logistical and cost information is available. The topics and the agenda of the last workshop will be drafted later.

WG 153 members plan to attend the following Conferences in 2019 and 2020

IUGG – July 2019, Montreal
OceanObs19 – Sep. 2019, Honolulu
Ocean Science -Feb 2020 San Diego
SCAR workshop on plastic in Antarctica, 28-30 October, University of Hull UK

WG participant will lead a session at IUGG/IAPSO meeting in Montreal, focussing on the Role of ocean processes in the transport and fate of floating plastic litter in the ocean and shelf-seas: theory, modelling and observations.

A number of papers about outcomes of WG153 workshop are going to be submitted to A Virtual Special Issue in *Marine Pollution Bulletin*, dedicated to IMDC. Special Issue content will be published in regular issues of *Marine Pollution Bulletin* as they are accepted.

A multi-authored paper lead by Victor Martinez Vicente has been submitted to *Frontiers in Marine Science* as a Perspective Paper. Towards global remote sensing of marine debris: scientific questions, current capabilities and research needs.

A paper by Wichmann et al (JGR, under revision) directly targets the question of which oceanographic processes are important for the horizontal dispersion of marine plastic litter. This paper has been greatly improved after discussions with WG 153 members, and so the SCOR WG is acknowledged.

6. Is the group 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

No difficulties encountered or foreseen to achieve TORs as scheduled.

7. Any special comments or requests to SCOR. Limit 100 words.

Additional information can be submitted and will be included in the background book for the SCOR meeting at the discretion of the SCOR Executive Committee Reporter for the WG and the SCOR Secretariat.

2.1.10 WG 154: Integration of Plankton-Observing Sensor Systems to Existing Global Sampling Programs (P-OBS) (2017) *Miloslavich*

Co-chairs: Emmanuel Boss (USA) and Anya Waite (Germany)

Other Full Members: Silvia Acinas (Spain), Ilana Berman-Frank (Israel), Marcela Cornejo (Chile), Katja Fennel (Canada), Heidi Sosik (USA), Sandy Thomalla (South Africa), Julia Uitz (France), and Hidekatsu Yamazaki (Japan)

Associate Members: Sonia Batten (Canada and PICES), Jørgen Berge (Norway), Herve Claustre (France), Gérald Grégori (France), Johannes Karstensen (Germany), Frank Muller-Karger (USA), Anthony Richardson (Australia), Bernadette Sloyan (Australia), and Rik Wanninkhof (USA)

Terms of Reference

General: To identify best practices (technologies and sampling protocols) and technical feasibility to incorporate plankton measurements into global ocean observing platforms (initially GO-SHIP and for expansion into the mooring array of OceanSITES).

Specific:

- Identify current technologies (sensors as well as water sample analysis) that can be integrated into existing observing infrastructure to provide input and guide studies of plankton for marine ecosystem and biogeochemistry studies.
- Provide the necessary details associated with every technology/measurement proposed (e.g., power, cost, and human effort).
- Document potential applications, including science case studies and lists of publications, and document measurement protocols. Develop adequate protocols when these are not available.
- Identify synergies with specific measurements done from other observing programs (e.g., BGC-Argo, space-based measurements, Continuous Plankton Recorder surveys) to provide cross-calibration and a better representation of the 4-D distribution of the parameter measured.
- Identify technological limitations and/or gaps, and identify areas of priority investments to develop and implement the required observation technologies and tools for specific needs.
- Increase awareness of the availability of biological oceanographic datasets internationally and identify barriers to their access and use, particularly in developing nations.

Executive Committee Reporter: Patricia Miloslavich

2-44

1. Name of group

SCOR Working Group 154 on Integration of Plankton-Observing Sensor Systems to Existing Global Sampling Programs (P-OBS)

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

This is our 2nd SCOR report.

Using left-over 2018 funds due to low costs of the WG meeting at Ocean Sciences in February we had a meeting of subgroups leads at LOV France last (7-9 Nov. 2018).
Our website is up (https://sites.google.com/maine.edu/p-obs/home) and we are in midst of preparation our report to GO-SHIP, for which we will have a draft ready to circulate before our upcoming meeting on the Saturday before the OceanObs19 meeting. We have also been invited to present our recommendation to the U.S. GO-SHIP meeting on the following Sunday and participate in an OCB-led get-together to discuss addition of biological measurements to GO-SHIP and BGC-Argo. This year our members contributed significantly to several OceanObs19 white papers, and in particular to Lombard et al., 2019 which outline a strategy for a holistic plankton sampling strategy.

3. 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 WG activities and which acknowledge SCOR support

Lombard, Fabien, Boss, Emmanuel, Waite, Anya M., Vogt, Meike, Uitz, Julia, Stemmann, Lars, Sosik, Heidi M., Schulz, Jan, Romagnan, Jean-Baptiste, Picheral, Marc, Pearlman, Jay, Ohman, Mark D., Niehoff, Barbara, Möller, Klas O., Miloslavich, Patricia, Lara-Lopez, Ana, Kudela, Raphael, Lopes, Rubens M., Kiko, Rainer, Karp-Boss, Lee, Jaffe, Jules S., Iversen, Morten H., Irisson, Jean-Olivier, Fennel, Katja, Hauss, Helena, Guidi, Lionel, Gorsky, Gaby, Giering, Sarah L.C., Gaube, Peter, Gallager, Scott, Dubelaar, George, Cowen, Robert K., Carlotti, François, Briseño-Avena, Christian, Berline, Léo, Benoit-Bird, Kelly, Bax, Nicholas, Batten, Sonia, Ayata, Sakina Dorothée, Artigas, Luis Felipe, and Appeltans, Ward, 2019. Globally Consistent Quantitative Observations of Planktonic Ecosystems. *Frontiers in Marine Science* 6:196. https://doi.org/10.3389/fmars.2019.00196DOI=10.3389/fmars.2019.00196

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

- Identify current technologies (sensors as well as water sample analyses) that can be integrated into existing observing infrastructure to provide input and guide studies of plankton for marine ecosystem and biogeochemistry studies -- *Finalized*
- Provide the necessary details associated with every technology/measurement proposed (e.g., power, cost, and human effort). -- *in progress*
- Document potential applications, including science case studies and lists of publications, and document measurement protocols. Develop adequate protocols when these are not available. – *in progress*
- Identify synergies with specific measurements done from other observing programs (e.g., BGC-Argo, space-based measurements, Continuous Plankton Recorder surveys) to provide cross-calibration and a better representation of the 4-D distribution of the parameter measured. – *Finalized (in Lombard et al., 2019)*
- Identify technological limitations and/or gaps, and identify areas of priority investments to develop and implement the required observation technologies and tools for specific needs. – *Finalized (in Lombard et al., 2019)*
- Increase awareness of the availability of biological oceanographic datasets internationally and identify barriers to their access and use, particularly in developing nations. – *not started*

5. WG activities planned for the coming year. Limit 500 words

- Draft and then finalize the report for GO-SHIP.
- Begin draft of report for OceanSites.
- 2nd in-face meeting of the group, in conjunction with Ocean Obs'19.
- Begin planning outreach activity.

6. Is the group 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

No difficulties at this time.

7. Any special comments or requests to SCOR. Limit 100 words.

None

Additional information can be submitted and will be included in the background book for the SCOR meeting at the discretion of the SCOR Executive Committee Reporter for the WG and the SCOR Secretariat.

2.1.11 WG 155: Eastern boundary upwelling systems (EBUS): diversity, coupled dynamics and sensitivity to climate change *Halpern* **(2017)**

Co-chairs: Ruben Escribano (Chile) and Ivonne Montes (Peru)

Other Full Members: Francisco Chavez (USA), Enrique Curchitser (USA), Boris Dewitte (France), Sara Fawcett (South Africa), Salvador Lluch-Cota (Mexico), Baye Cheikh Mbaye (Senegal), Andreas Oschlies (Germany), and Parv Suntharalingam (UK)

Associate Members: Edward Allison (USA), Javier Aristegui (Spain), Xavier Capet (France), Ming Feng (Australia), Iris Kriest (Germany), Eric Machu (France), Ryan Rykaczewski (PICES, USA), Lynne Shannon (South Africa), Damodar Shenoy (India), and Beatriz Yanicelli (Chile)

Terms of Reference

Executive Committee Reporter: David Halpern

1. Name of group

WG 155 Eastern Boundary Upwelling Systems (EBUS): Diversity, Coupled Dynamics and Sensitivity to Climate Change

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

Since January 2018, WG 155 EBUS has been developed:

1. Presentation of SCOR WG at the workshop on "The Effects of Climate Change on the Productivity in CCLME", 18-20 September 2018, Santa Cruz de Tenerife - Spain.
2. Presentation of SCOR WG at the Taller Bilateral Chile-Perú 'Intercambio de Experiencias en Oceanografía', 10 December 2018, Santiago de Chile - Chile.
3. Two online meetings (11 October 2018; 13 February 2019); mainly to organize the summer school and email discussions.
4. Email discussions to organize the review article (under preparation).
5. First in-person meeting that was held in conjunction of the PICES 4th International symposium ECCWO (Jun 3th), meeting report is in attachment.
6. Announcement of Open Science Conference Lima 2021 in different meetings (i.e., Ocean Deoxygenation Conference (Kiel-Germany), Coloquio Internacional 'El Océano frente a los cambios globales' (Lima-Perú), Taller Bilateral Chile-Perú (Santiago de Chile - Chile))

3. 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 WG activities and which acknowledge SCOR support

SCOR MEMBERS contributions:

1. Develop of SCOR WG webpage http://intranet.igp.gob.pe/scor/preamble.php
2. Garcon, V., B. Dewitte, I. Montes, and K. Goubanova, Section 3.3 Land-Sea-Atmosphere interactions exacerbating ocean deoxygenation, In IUCN, *Under review*.
3. Montes, I. and Escribano, R. (2018), Una revisión sobre los Sistemas de Bordes orientales: diversidad, dinámica acoplada y sensibilidad al cambio climático, Boletín Técnico "Generación de modelos climáticos para el pronóstico de la ocurrencia del Fenómeno El Niño", Instituto Geofísico del Perú, Junio, Vol. 5, Nº6, 5-9. (Dissemination article).
4. Escribano, R., I.Montes et al., Eastern Boundary Systems (EBUS): What do we know and need to learn to predict their responses to climate change?, *Submitted to EOS Journal*

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

Referring to ToR, Deliveries and actions:

1. ToR 1. Discussions are already being established to organize the peer-review publication based on scientific review of current trends and drivers of oceanographic, ecological and socioeconomic properties in EBUS from a propagation of errors on models. Summer school is already organized, this will be held in May 2020 in Dakar, Senegal (proposal in attachment); members are on the way to look for complementary funds.
2. ToR 2. We are evaluating the different platforms already existing (e.g., POMEO, EMODNET, CCLME ECO-GIS viewer) to adopt one or create a new one.
3. ToR 3. Not many advances until now on this TOR.

4. ToR 4. This will require completing TORs 1-3. The Open Science Conference is about to be organized. Until now we have identified the main partners: IOC is already involved; having as a draft of the organization
   * Conference Coordinators (e.g., SCOR, IOC, IMBeR, SOLAS, others)
   * Scientific Steering Committee (e.g., scientists from around the world)

5. WG activities planned for the coming year. Limit 500 words

1. To submit the peer-reviewed publication
2. To discuss and define a second in-person meeting
3. To write the draft proposal of Open Science conference
4. To define the web portal for ToR 2.

6. Is the group 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

Not difficulties yet.

7. Any special comments or requests to SCOR. Limit 100 words.

Our SCOR WG is coordinating activities tightly associated with shared members of other Projects and Panels working on EBUS issues, such as CLIVAR EBUS RF, SOLAS and IMBeR Upwelling WG, as to better define complementary actions and avoid overlapping goals and activities.

Additional information can be submitted and will be included in the background book for the SCOR meeting at the discretion of the SCOR Executive Committee Reporter for the WG and the SCOR Secretariat.

2.1.12 WG 156: Active Chlorophyll fluorescence for autonomous measurements of global marine primary productivity (2018) *Yoo*

Co-chairs: David Suggett (Australia) and Philippe Tortell (Canada)

Other Full Members: Aurea Ciotti (Brazil), Tetsuichi Fujiki (Japan), Maxim Gorbunov (USA), Zbignew Kolber (USA), Jacco Kromkamp (Netherlands), Mark Moore (UK), Kevin Oxborough (UK), Nina Schuback (Switzerland), and Sandy Thomalla (South Africa)

Associate Members: Ilana Berman-Frank (Israel), Doug Campbell (Canada), Kim Halsey (USA), Anna Hickman (UK), Yannick Huot (Canada), Ondrej Prasil (Czech Republic), Greg Silsbe (USA), Stefan Simis (UK), and Deepa Varkey (Australia)

Terms of Reference

1. To inter-compare active Chla induction measurements across instruments and approaches, identifying key aspects of instrument configuration, deployment and parameter acquisition that may introduce variability in retrieved data.
2. To develop, implement and document internationally agreed best practice for data acquisition, standardised output formats and archiving approaches.
3. To develop, implement and document internationally agreed best practice for processing raw fluorescence data to retrieve photosynthetic parameters and primary productivity estimates, taking into account taxonomic and environment factors driving diversity in chlorophyll fluorescence signals in the ocean. From this work we will develop freely available software and documentation to allow non-specialist users to process fluorescence data according to these best practices.
4. To produce a new synthesis of parallel ^{14}C and active Chla induction measurements that can be used to examine the relationship between these two productivity metrics under a range of field conditions. We will also consider other metrics of Net Primary Production alongside ^{14}C.
5. To develop a global database structure for hosting quality-controlled active Chla induction measurements, creating standards for data and meta-data collection, submission and archiving.
6. To build a framework through which in situ active Chla induction data can be used to validate and refine relevant remote sensing measurements (e.g., sun-induced fluorescence yields).
7. To share knowledge and transfer skills in instrumentation, best practice, quality control and data stewardship with the rapidly expanding user community in developing nations.

Executive Committee Reporter: Sinjae Yoo

1. Name of group

WG156: Active Chlorophyll fluorescence for autonomous measurements of global marine primary productivity

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

This is our first SCOR report.

3. 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 WG activities and which acknowledge SCOR support

N/A. This was the first meeting of our working group.

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

Progress towards each WG milestones throughout 2018-2019 are bulleted as follows (*note that our timeline originally proposed was to focus on term of reference i-ii (and to a lesser extent iii) for this year*):

i. To inter-compare active Chla induction measurements across instruments and approaches, identifying key aspects of instrument configuration, deployment and parameter acquisition that may introduce variability in retrieved data.

- Largely complete. As detailed in "2. Activities…", the workshop conducted in June consisted of two weeks of discussions and laboratory exercises to address this term of reference. Presentations and discussions from amongst the WG identified the list of factors contributing to variability in retrieved data, including instrument calibration and protocols. Detailed notes from the presentations and discussions were captured in a comprehensive summary document, which will form the basis of a best-practices guide for end-users. We also plan to develop a paper that reviews this material, conducting sensitivity analysis of potential sources of variability on retrieved data.
- Various commercially available instruments (including ones that will be new to the market soon) were inter-compared using phytoplankton cultures and natural water samples – we therefore produced a comprehensive data set to quantitatively assess how protocols and engineering configurations influence FRRF data retrieval. Building on this activity, several WG members will participate in a second workshop to further explore multispectral protocol issues (this is an existing workshop that is being run in 2020, see "5. WG Activities for the coming year…').

ii. To develop, implement and document internationally-agreed best practice for data acquisition, standardized output formats and archiving approaches.

- In progress. We have produced a large synthesis document from the June workshop that forms the basis of best practice considerations. Additional verification of some of the proposed best practice is underway over the next 6 months. At that stage, this document will be synthesized into a series of chapters (in the form of an e-book) that will begin with a "quick start" guide for best practice followed by a detailed review underpinning these recommendations. All of this will be supported by a decision tree up-front. We discussed

potential distribution methods, including freely (or low cost) e-book to ensure broad distribution. WG members were each tasked to work on one or more component, with the idea of having draft chapters completed before the next meeting (before the Feb. 2020 OSM meeting in San Diego).

iii. To develop, implement and document internationally-agreed best practice for processing raw fluorescence data to retrieve photosynthetic parameters and primary productivity estimates, taking into account taxonomic and environment factors driving diversity in chlorophyll fluorescence signals in the oceans. From this work we will develop freely available software and documentation to allow non-specialist users to process fluorescence data according to these best practices.

- Initiated. Several open source software products were developed and examined during the workshop: (i) A beta version already produced for spectral correction of FRRF data was explored during the workshop; (ii) Novel software platforms (likely through JuPyter notebooks) are being developed to treat data from different (current) instruments, convert data to standard formats and process using different physiological models (also reporting the parameters & measures of statistical quality).

iv. To produce a new synthesis of parallel 14C and active Chla induction measurements that can be used to examine the relationship between these two productivity metrics under a range of field conditions. We will also consider other metrics of Net Primary Production alongside ^{14}C.

- Initiated. Whilst this activity will be addressed predominantly in Year 2, we considered the validity of existing data sets, and discussed approaches for the collection of new data (FRRf, ^{14}C and MIMS) during the June workshop. Importantly, we tested a novel incubation technique ("simultaneous triple incubation" of ^{14}C, O_2 and ETR) that may be proposed as one of several new standards moving forward. Discussions considered future robust measures of carbon uptake (and O_2 evolution) for comparative purposes. Manuscripts have been proposed to (a) document the novel triple incubation approach and (b) argue that FRRf-based electron transport rates be considered as central productivity metrics as a means to understand 'the reducing power of the oceans'.

v. To develop a global database structure for hosting quality-controlled active Chla induction measurements, creating standards for data and meta-data collection, submission and archiving.

- Initiated. Whilst this activity will be addressed predominantly in year 3, substantial discussions during the June workshop by WG members (alongside invited members from NASA) identified possible databases. Discussions examined required meta-data and formats, and also identified potentially suitable data repositories already in existence.

vi. To build a framework through which in situ active Chla induction data can be used to validate and refine relevant remote sensing measurements (e.g. sun-induced fluorescence yields).

- Not yet started. To be initiated in years 3-4. That said, we discussed during the workshop exploring the capacity of existing instrumentation (Soliense FRRf) to quantify passively retrieved data (alongside existing 'active' protocols) and thus ground-truthing satellite passive fluorescence signatures. We will discuss with NASA how this can feed through to a dedicated funding proposal.

vii. To share knowledge and transfer skills in instrumentation, best practice, quality control and data stewardship with the rapidly expanding user community in developing nations.

- On-going. In addition to inclusion of several PhD students and early career researchers to the June workshop, we have:

- Initiated a community voice of WG activities, outputs, interests and opportunities via Twitter (@SCOR_WG156)
- Discussed with key instrument manufacturers possibility of providing some visibility to the WG activities via their existing web sites (similarly, amongst all WG members).
- Begun to develop proposal for new training workshops in central and south America, potentially through collaboration with the Millennium Institute of Oceanography in Chile.
- WG chairs spoke with Schmidt Ocean Institute to develop an EOI that would focus on at sea activities linked back to classrooms in Canada, Australia, South Africa etc.
- Proposed bespoke sessions at high-profile meetings to ensure visibility amongst wider community needed to identify additional opportunities for regional workshops in best practice. Suggett and Tortell will present a 30-minute tutorial session at the upcoming OSM in San Diego, and will chair a dedicated research session (see below).

5. WG activities planned for the coming year. Limit 500 words

Several key activities are planned:

- Field campaign deployments of FRRfs (coupled with ^{14}C) have been proposed/already underway: South African WG members (cross-seasonal evaluations of temperate to sub-polar environments), Canadian and U.S. WG members (sub-Arctic & Arctic environmental gradients), Australian and UK members (Atlantic and/or western Pacific environmental gradients. Importantly, these take advantage of developments in year 1 to (a) validate proposed best practice (or further test unknowns needed to inform best practice) – terms of reference i-iii, (b) add novel data sets comparing FRRf-based productivity measures with MIMS, ^{14}C etc. – terms of reference iv.

- Year 2 meeting has also been identified: Ocean Sciences 16-21 February 2020 San Diego. This important milestone will be to (i) review and revise the draft best practice documents, as well as advance possible paper submissions from year 1 workshop/field campaigns, (ii) develop the framework for the novel synthesis exercise of ^{14}C (but also other measures) with FRRf, and (iii) initiate the discussions for year 3 milestones. As part of this, we will also be presenting a tutorial presentation "*Establishing Active Fluorescence as a Primary Productivity metric for the worlds coasts and oceans*", and also holding a dedicated research session "*Active optics to sense marine productivity throughout the world's coasts and oceans".*

- Proposal submissions to enhance capacity. Several WG members are planning joint targeted proposal submissions to their respective research councils, to leverage funding for the final 2 years of the WG (post 2020); also an EOI submission to Schmidt Ocean Institute for funding 2021-22. This will specifically leverage the need for key information as identified by the SCOR terms of reference. Key information (knowledge and knowledge gaps, novel data etc.) documented through the year 1 workshop will directly support these submissions.

- Additional workshop to re-focus on multispectral FRRf issues. Several WG members (including the instrument manufacturers) have agreed to convene at a second workshop already organized to examine productivity: Lake Erie, Stone Lab Put-in-Bay (https://ohioseagrant.osu.edu/education/stonelab). Whilst the research will be based on work in freshwaters, it will enable a robust test of multispectral FRRf capabilities relevant to coastal waters. This unique opportunity will also further examine FRRf-^{14}C (and other currency) coupling by natural (cyanobacterial) dominated) communities. This further extends capabilities and strengths of terms of reference i-iv for optically complex waters.

6. Is the group 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

At this stage, there are no problems in achieving terms of reference/time schedules have been identified.

7. Any special comments or requests to SCOR. Limit 100 words.

Additional information can be submitted and will be included in the background book for the SCOR meeting at the discretion of the SCOR Executive Committee Reporter for the WG and the SCOR Secretariat.

2.1.13 WG 157: Toward a new global view of marine zooplankton biodiversity based on DNA metabarcoding and reference DNA sequence databases (MetaZooGene) (2018) *Miloslavich*

Chair: Ann Bucklin (USA)

Vice-chairs: K.T.C.A. (Katja) Peijnenburg (Netherlands) and Ksenia Kosobokova (Russia)

Other Full Members: Leocadio Blanco-Bercial (Bermuda), Georgina Cepeda (Argentina), Tone Falkenhaug (Norway), Jenny Huggett (South Africa), Chaolun Li (China-Beijing), Ryuji Machida (China-Taipei), and Todd O'Brien (USA)

Associate Members: Ruben Escribano (Chile), Erica Goetze (USA), Junya Hirai (Japan), Aino Hosia (Norway), Silke Lakmann (Germany), Pennie Lindeque (UK), Maria Grazia Mazzocchi (Italy), Mary Mar Noblezada (Philippines), Naiara Rodriguez-Ezpeleta (Spain), and Agata Weydmann (Poland)

Terms of Reference

1. Create an open-access web portal for DNA barcodes for marine zooplankton
2. Design an optimal DNA barcoding pipeline for marine zooplankton
3. Develop best practices for DNA metabarcoding of marine zooplankton biodiversity

Executive Committee Reporter: Patricia Miloslavich

1. Name of group

MetaZooGene: Toward a new global view of marine zooplankton biodiversity based on DNA metabarcoding and reference DNA sequence databases

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

WG157 website: A MetaZooGene project website (see https://metazoogene.org/) was created to allow posting of a broad range of informational materials and resources. (See #3 below)

Email questionnaires to WG157 members: Email discussions have been facilitated by creation of a listserv email address including all Full and Associate members. Two comprehensive planning survey questionnaires were sent to all MetaZooGene members; replies were compiled and summarized by the Chair and co-Vice Chairs. This information was used as a basis for planning the first year's goals and activities, including setting venue and date for the first meeting. This process was used to obtain commitments from WG157 members to attend the first annual meeting, participate in the MetaZooGene Symposium, contribute to a special issue of a journal, and join as co-authors in the first WG157 review paper.

MetaZooGene Symposium Planning: A SCOR-sponsored Symposium is being organized in association with the first annual WG157 meeting. The goal is to create opportunities for new international collaborations and to showcase MetaZooGene research activities. The Symposium, *Rediscovering pelagic biodiversity: Progress, promise, and challenges of metabarcoding of microbes to mammals*, will be convened by Ann Bucklin (UConn, WG157 chair) and Bengt Karlson (SCOR Sweden Representative), on September 13, 2019 at the Swedish Exhibition & Congress Centre, Gothenburg, Sweden. The Symposium is also associated with UNESCO - Intergovernmental Oceanographic Commission (IOC) and International Council for the Exploration of the Sea (ICES) 2019 Annual Science Conference.

3. 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 WG activities and which acknowledge SCOR support

WG157 website: A MetaZooGene project website (see https://metazoogene.org/) was created to allow posting of a broad range of informational materials and resources. In addition to information about upcoming meetings and workshops, the site offers Recommended Readings (DOI links or PDFs for open-access papers), and a portal for registration and submission of abstracts for the MetaZooGene Symposium (see https://metazoogene.org/symposia).

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

1) Create an open-access web portal for DNA barcodes for marine zooplankton
Work has begun on a MetaZooGene review paper, *Toward A Global Reference Database of COI Barcodes for Marine Zooplankton*, with lead author Ann Bucklin and considerable effort by WG157 member and webmaster Todd O'Brien, who is leading efforts in data collection from all available sources, including co-authors and web resources, including NCBI GenBank and BOLD (Barcode of Life Database). The goal is a comprehensive summary and analysis of COI barcodes available for holopelagic mesozooplankton taxa, organized by ocean region with explicit intent to achieve global coverage. The DNA barcode data and metadata now being assembled for the review paper will be posted to an open-access web portal, which will include deep links to the GenBank records and associated publications. The DNA sequence data will be downloadable for use as a reference sequence database for species identification of marine zooplankton from metabarcoding analysis of environmental samples.

2) Design an optimal DNA barcoding pipeline for marine zooplankton
The important issue of 'best practices' for barcode data submission and distribution is being discussed as part of design of the MetaZooGene data portal (see Term of Reference 1). The need for a publicly available, taxonomically comprehensive, global DNA barcode database is being addressed during preparation of the review paper. Progress and next steps for this Term of Reference will be discussed and evaluated during the first annual meeting of WG157.

3) Develop best practices for DNA metabarcoding of marine zooplankton biodiversity
This topic will be a focus of a structured discussion during the first annual meeting, which will be designed as a WG157 workshop (with opportunities for WG157 members to participate virtually) to review and compare present approaches and best practices for multi-gene DNA barcoding pipelines from bug-to-database.

5. WG activities planned for the coming year. Limit 500 words

1) First MetaZooGene WG157 Meeting
The first WG157 meeting will be held in association with the ICES Annual Science Conference in Gothenburg, Sweden, on September 13-14, 2019. The first day is a co-sponsored SCOR-IOC-ICES Symposium: Rediscovering pelagic biodiversity: Progress, promise, and challenges of metabarcoding. We are encouraging participation via working groups of the sponsoring organizations, and are encouraging anyone and everyone interested in the topic to request oral and poster presentations at the MetaZooGene symposium, with abstract submission via the link on this page:
http://www.metazoogene.org/symposia/symposium2019.

2) Second MetaZooGene WG157 Meeting
The 2020 annual meeting of MetaZooGene will be held in association with the ASLO/AGU/TOS Ocean Sciences Meeting, which is scheduled for February 16-21, 2010 in San Diego, USA. There are several OSM 2020 theme session proposals that relate to MetaZooGene goals, which will allow showcasing ongoing research and encourage broad

participation among all MetaZooGene members. WG157 chair Ann Bucklin is a member of the OSM 2020 Program Committee, and will be reviewing session proposals.

3) Special Journal Issue for MetaZooGene research
We are planning for a special issue of a journal focused on the MetaZooGene research, based on expressions of interest from WG157 members and resulting in part on the Symposium presentations. We will be asking for manuscript submission information during the summer. Manuscripts will be due in late 2019, with a targeted 2020 publication date. We have communicated with editorial staff members from *Frontiers in Marine Science* and the *ICES Journal of Marine Science,* and both journals have expressed interest.

4) MetaZooGene review paper
The MetaZooGene review paper on COI barcoding of marine holozooplankton, with lead authors Ann Bucklin and Todd O'Brien, and 8 MetaZooGene member co-authors, will provide a taxonomically comprehensive global summary and analysis of COI sequence data, with gap analysis and prioritization of research needs. The review has been invited by an editor of *Marine Biology Reviews*.

5) Reference database for COI barcodes for marine holozooplankton
The DNA barcode data and metadata now being assembled for the review paper (see above) will also be posted to an open-access web portal (see Term of Reference #1). The database will include deep links to the GenBank records and associated publications, and the DNA sequence data will be downloadable for use as a reference sequence database for species identification of marine zooplankton from metabarcoding analysis of environmental samples.

6. Is the group 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

No difficulties identified to date.

7. Any special comments or requests to SCOR. Limit 100 words.

SCOR is indeed providing the global perspective and infrastructure support that is a primary goal for MetaZooGene WG157 goals and activities!

Additional information can be submitted and will be included in the background book for the SCOR meeting at the discretion of the SCOR Executive Committee Reporter for the WG and the SCOR Secretariat.

2.2 Working Group Proposals

2.2.1 Roadmap for a Standardised Global Approach to Deep-Sea Biology for the Decade of Ocean Science for Sustainable Development (DeepSeaDecade) *Miloslavich*

DeepSeaDecade
Roadmap for a Standardised Global Approach to Deep-Sea Biology for the Decade of Ocean Science for Sustainable Development

1. Summary

The deep-sea remains one of the least known parts of our planet, yet our basic ecological knowledge of this region is limited because of an historical piecemeal approach to research, and significant spatial bias in the data collected (northern hemisphere, developed nations exclusive economic zones). Fundamental ecological data forms the input parameters to all ecosystem models. Our lack of knowledge of the deep sea means it remains the 'black box' in global model simulations. The road map for the UN Decade of Ocean Science for Sustainable Development (UN DOSSD) recognises the deficit of deep-sea data and the impact of this on sustainable management of the oceans. It calls on the deep-sea science community to address this deficit under the UN DOSSD. The community have responded by identifying the key questions to be answered and the potential role of new technology in addressing those questions. What is now required is an unprecedented level of global coordination to effect a giant leap in understanding by the end of the UN DOSSD. This working group will 1) develop a global survey and sampling modular design, 2) agree methods and standards for the acquisition of biological data, including potential use of novel technologies, 3) build on the global design with habitat-specific approaches, 4) integrate developed plans with other global initiatives and 5) build global capacity for conducting deep-sea research. We will produce a series of multi- author peer reviewed papers that will form the reference point for deep-sea research for the next decade and beyond.

2. Scientific Background and Rationale

The composition and functioning of the deep sea, comprising the largest living space on Earth, is still poorly understood, with a minimal proportion of the deep seafloor sampled and investigated to date (Ramirez-Llodra et al., 2010). To most of society, the deep sea is thought of as a remote, featureless, and inaccessible space. However the combination of particular geological, physical and geochemical attributes of the deep seafloor and water column, create a set of complex habitats with unique characteristics. Each of these habitats supports faunal communities with specific physiological and behavioural adaptations to high pressure, darkness, low temperatures (or steep temperature gradients in the case of hydrothermal vents), food limitation (particularly at abyssal plains) and in some cases geographic isolation (e.g. seamounts, vents, trenches, and seeps). Deep-sea biodiversity at bathyal and abyssal depths is amongst the highest on the planet (Grassle and Maciolek, 1992; Mora et al. 2011), and in poorly sampled regions, such as the abyssal Pacific, up to 90% of species collected may be new to science (Glover et al. 2002). Our limited knowledge of very basic baseline information is the major challenge when addressing issues of biodiversity, ecosystem function, and the potential impacts of - and resilience to - human activities in the deep sea (Mengerink et al. 2014).

The United Nations Decade of Ocean Science for Sustainable Development (DOSSD) is due to commence in 2021, and we are currently in the preparation phase. The stated motivation for the decade is to reverse the cycle of decline in ocean health and create improved conditions for sustainable development of the ocean. The roadmap developed for the DOSSD recognises the deficit of biological data for the deep-sea ecosystem, and specifically calls on the scientific community to use the Decade to conduct research to understand better the deep-sea ecosystem and its functions. Deep-sea scientists have responded to this call by holding a series of international meetings. Firstly to agree to science priorities and knowledge gaps for the DOSSD (1-day meeting, Sept 2018, Monterey, USA, and follow-up meeting October 2018, Aveiro, Portugal), and secondly to explore the potential for new technology to address them (Royal Society funded meeting – Beyond Challenger Nov 2018). We now have community-level agreement on the key research questions in deep-sea science, and have identified new technologies on the horizon that may help us to address these questions.

2.1 The questions

i. What is the diversity of life in the deep ocean?

We lack fundamental ecological data for much of the deep sea. Poor knowledge of what lives there, how it is distributed from global to local 'patch' scales, as well as over environmental gradients, prevents us from establishing a baseline and knowing what is common and what is rare. Critically, fundamental ecological data form the input to **all** biological ecosystem models. Our ability to forecast how marine biodiversity will respond to environmental change and other anthropogenic pressures, depends on good base knowledge such as species distributions, physical and chemical drivers of distribution, abundance, biomass, growth rates, etc. Efforts to model species distributions to fill data gaps are currently severely limited by a lack of fundamental ecological data. Existing models are simplistic, and of questionable accuracy due to limited, and / or poor quality input data (Davies and Guinotte, 2011; Howell et al., 2016).

ii. How are populations & habitats connected?

At present, we do not know the linkages between habitats and populations, including migration routes, ontogenetic or seasonal movement between habitats, larval dispersal pathways and genetic connectivity, or energy flow pathways in the form of trophic links and food webs. Understanding these linkages, collectively termed connectivity, is critical to effective ocean management and sustainable use. Connectivity promotes healthy and resilient populations; disruptions to the connections, for example through changes in ocean circulation patterns, can impact their persistence and population recovery after disturbance, as well as the effectiveness of Marine Protected Area networks. Understanding population connectivity is also important for our mechanistic understanding of species divergence and ultimately speciation in the ocean, and the role that physical mechanisms play in this (Cowen et al, 2000).

iii. What is the role of living organisms in ecosystem function & service provision?

We are at an early stage in understanding the role of the deep sea in provision of goods and services (for example food provision or nutrient cycling), and detail on mechanisms of delivery are scant. What are the key species/habitats involved in carbon sequestration? Are some groups more important than others? For example, we know sponges may play an important role in global Si cycling (Maldonado et al. 2005), as well as having a key role as a sink for inorganic

nitrogen, surpassing that of marine sediments at equivalent depths (Hoffmann et al. 2009). To ensure the ongoing provision of those services, and to understand better marine system processes such as biogeochemical cycling, we need to identify the functional groups present, their role in ecosystem function, and how that function relates to delivery of goods and services. Again, fundamental ecological data are critical to this understanding and to our ability to bring biology into wider ecosystem models.

iv. How do species, communities and ecosystems respond to disturbance?

Understanding how the interactions and synergies play out between climate stressors and direct disturbance is essential to effective management of the deep ocean. This is an understanding that can only be gained through use of modelling approaches, and fundamental ecological data provide the input terms to such models.

2.2 The challenge

Although deep-sea science has a history of successful, international collaborative research programmes, none to date have provided the level of integration and standardisation required in order to deliver answers to the above questions. The Census of Marine Life programme made significant advances in joining-up international efforts around a common goal to understand marine ecosystems, including various deep-sea systems (e.g. seamounts, abyssal plains, continental slopes, etc.). However, the lack of an agreed common survey / sampling design and standardized methodologies among contributing projects meant that datasets could not be combined to address larger questions. Recently, there have been efforts within the deep-sea community to develop frameworks for globally consistent datasets (Woodall et al., 2018). Still, these efforts need to go further in generating a globally coherent underpinning design, and standardised methods. Only then can we hope to make the leaps in knowledge required to effectively manage the deep sea going forward, and deliver the societal outcomes identified by the DOSSD roadmap.

2.3 The need for a SCOR working group

The deep-sea science community has identified the need for a new international programme of research for the UN DOSSD that is global and inclusive. They have also identified the questions that such a programme would address. However, before any further progress can be made there needs to be a concerted effort for dialogue within the community to agree on standards and methods used to address the questions identified, and ensure future research efforts are integrated and inclusive. This requires bringing together a diverse group of researchers including deep-sea habitat specialists (seamount, vent, abyssal plain, continental slope, etc.), macro-ecologists, and process specialists (connectivity, diversity, ecosystem function, etc.). This working group will assemble a team of scientists to work jointly towards delivering an overarching plan that will form the basis of deep-sea biological research for the next decade. It will provide essential data to move towards the targets of the UN Sustainable Development Goals (in particular SD13 on Climate Action and SDG14 on Life Below Water), and it will also help inform the UN World Ocean Assessment II.

3. Terms of Reference

1. To develop a global plan for survey / sampling deep-sea ecosystems to underpin deep-sea research for the UN Decade of Ocean Science.

2. To agree on methods and standards for the acquisition of biological data, including the role of existing and novel technologies.
3. To develop habitat-specific approaches for survey / sampling the deep-sea ecosystem (following the Census of Marine Life model), that integrate the global approaches developed under ToRS 1 and 2, but allow greater specialisation.
4. To integrate ToRs 1-3 with wider efforts under the Global Ocean Observing System (GOOS) via the Deep Ocean Observing Strategy (DOOS).
5. To actively facilitate efforts to build capacity in developing nations for deep-sea science.

4. Working plan

Please see the Gantt chart provided in Appendix 1 for timing of key events associated with the UN Decade of Ocean Science for Sustainable Development, and proposed timings of SCOR working groupmeetings (both physical and virtual) and deliverables (draft and final). While each physical meeting will have a key focus outlined below, multiple ToRS will be discussed at each to ensure good integration of ideas both within the working group and with other UN DOSSD initiatives. The Challenger Society's Deep Sea Special Interest Group will provide funding to support an initial meeting in September 2019, and a funding application for support will be submitted to the Deep Sea Biology Society.

To address ToR 1 we will develop a coherent well-designed global survey and sampling plan, but one that is modular. The underlying principle will be that each survey / sampling module can be placed within a local, regional and/or habitat-specific context and thus be readily integrated with local, regional, research team interests. However, results from all modules can ultimately be combined to answer global scale questions, and provide 'one giant leap' for human understanding of the ocean. This plan will be developed using two in-person workshops, beginning with the Challenger Deep-Sea Special Interest Group, followed by the first SCOR working group meeting (SCOR-WG workshop 1). A virtual meeting will also be scheduled between the two workshops to develop further our ideas. The rapid timing of this ToR is important in order to interface with the UN Decade of Ocean Science's preparation phase and the finalisation of the Decade implementation plan in mid-2020.

ToR 2 is the next logical progression from ToR 1. Having agreed on a modular framework, combining data in the future will only be possible if methods are standardised. SCOR-WG workshop 2 will focus on standardisation of methods of data acquisition and processing. Building on published outputs from the Census of Marine Life (Clark et al., BLAH), a more recent workshop (Woodall et al., 2018), and a Royal Society (UK) funded meeting in Nov 2018, we will identify those measurements / samples best acquired using novel technology, and those that may be acquired using more traditional, cheaper, or more accessible technologies. Consideration of methods is important in democratising deep-sea research and enabling participation of all nations, many of whom lack access to expensive novel technologies. The outcomes of ToRs 1 and 2 will be written up as an open-access peer reviewed publication that will provide a key reference text for deep-sea science for the next 10 years and beyond, underpinning future research efforts.

ToR 3 will be developed in parallel to ToRs 1, 2 and 4. We will look at habitat-specific considerations not covered by the global plan alongside the development of that plan. A

sampling / survey design that works globally may not fully consider habitat-specific issues. For example, a global programme may require depth-stratified sampling of seamounts; however, a single series of depth-stratified transects on a seamount will not enable us to address seamount specific questions that may require replication on different sides of seamounts. For this ToR we will hold virtual workshops, following each of the first two SCOR workshops, for habitat-specific working groups chaired by appropriate members of the SCOR-WG to engage the wider deep-sea science community fully in the formulation of sampling plans. These virtual groupings will be advertised via the DOSI, INDEEP, Deep-Sea Biology Society and Challenger Society networks in order to reach a wide audience.

At outset, the SCOR working group will work with DOOS (via overlapping participants) to identify ways the SCOR activities advance the DOOS goals (ToR4) and develop a plan to integrate these into DOOS actions and communications. With DOOS we will focus in particular on the integration of biology with the existing deep ocean physical and biogeochemical measurement programs (e.g. ARGO, deep ARGO, BGC Argo, GoSHIP, Ocean Sites, Observatories). Specifically, once we have established both global and habitat-specific plans, ToR 4 will review the plans against existing wider community efforts under the Global Ocean Observing System (GOOS) via the DOOS in SCOR-WG workshop 3. We will identify synergies between our plans and DOOS, ensure there is no duplication of effort, and that these different global strategies are integrated. Specifically, we anticipate key collaboration with the DOOS Essential Ocean Variable Biology and Ecosystem panel (which itself is working with the GOOS Biology and Ecosystem panel), the DOOS demonstrations projects, and with the DOSI/INDEEP/DOOS SDG 14 voluntary commitments. Critical links to the existing deep-ocean physical and biogeochemical measurement programs (e.g. ARGO, deep ARGO, BGC Argo, GoSHIP, Ocean Sites, Observatories) can also be achieved through DOOS.

ToR 5 will be partially addressed throughout the development of ToRs 1-4. The proposed working group membership draws scientists from developing nations. In addition, we will seek input from other scientists from developing nations, including early-career scientists through DOSI (in particular the DOSI working group on capacity building), INDEEP, Deep-Sea Biology Society and Challenger Society networks. We intend to consult as widely as possible on the development of deliverables to ensure broad uptake in the future. Our aim is for a truly inclusive working group. We will also hold a specific virtual workshop to develop an action plan to provide sea-going training opportunities for students from developing nations. We anticipate the action plan will consist of a statement of commitment that members of the deep-sea research community can sign-up to; a mechanism through which to advertise opportunities for students; a transparent application, assessment, and selection process; and a requirement for a short post-cruise reflection report. We will ensure engagement with similar initiatives developed under other programmes e.g. POGO.

5. Deliverables

1. An open-access peer-reviewed publication detailing a global plan for survey / sampling the deep-sea ecosystem, including use of standardised methodologies to underpin deep-sea research for the UN Decade of Ocean Science. (ToRs 1 and 2)
2. A series of open-access peer reviewed publications consisting of habitat-specific plans (following the Census of Marine Life model, and similar to German et al., 2011) to

advance the global plan developed under ToRs 1 and 2 ensuring no duplication of effort with wider initiatives. (ToRS 3 and 4)

3. A research community-endorsed action plan to provide training opportunities and peer support for students from developing nations in order to broaden the research base and nurture talent (ToR 5).

6. Capacity Building

Deep-sea research, exploration and exploitation has historically been led by a small number of developed nations. This is also reflected in availability of samples, bias in available data (Fig. 6.1), and overall understanding of deep-sea ecosystems, which is currently severely limited. The least-studied parts of the deep sea are often within developing nations' EEZs and / or on the High Seas / the Area, away from the continental slopes. In addition, deep-sea research is currently conducted in a very piecemeal and poorly coordinated fashion. Individual projects tackle aspects of larger questions. The projects are often constrained by available budgets, time, and the logistics of sampling in the deep sea. There are often trade-offs made in experimental design or resolution of data against greater temporal / spatial coverage, or to provide data to satisfy multiple competing aims. While this approach has helped us continue to advance our knowledge of the deep-sea ecosystem, it has failed to make the great leaps needed to manage our ocean more effectively.

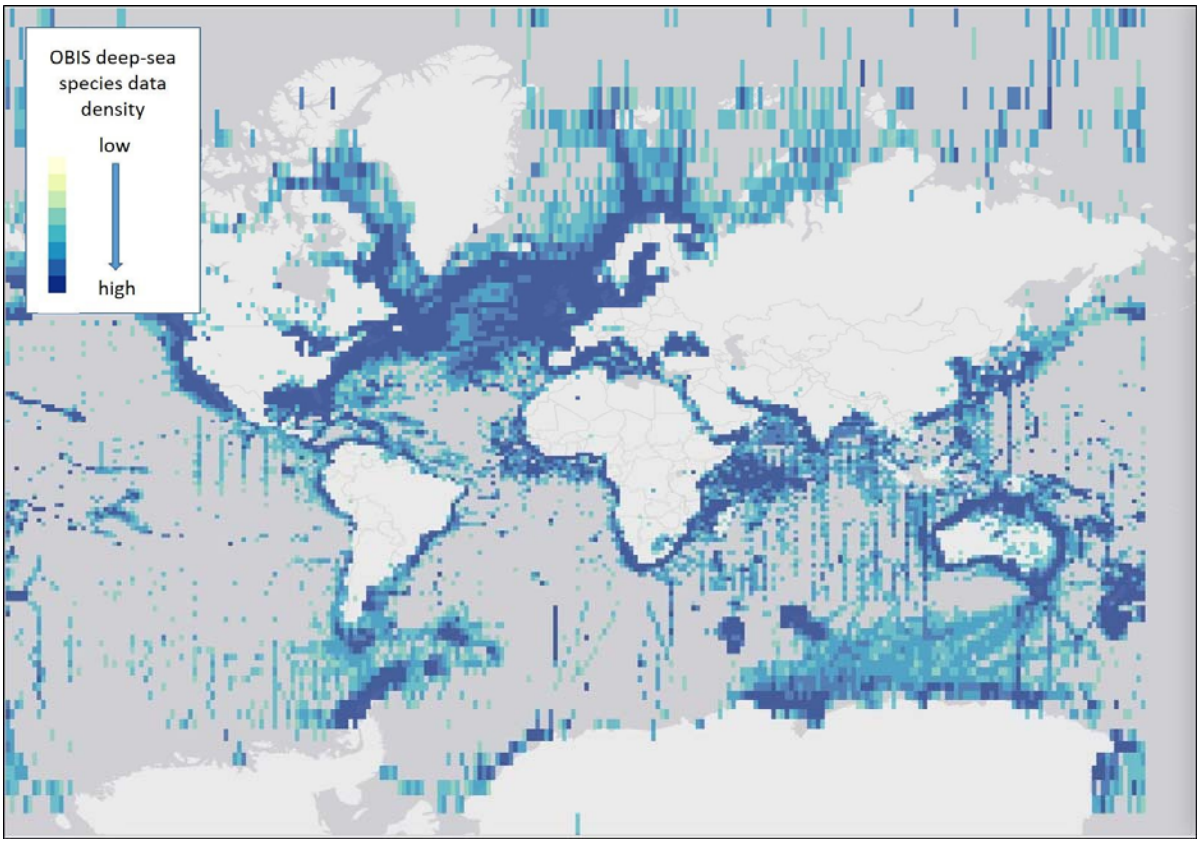


Figure 6.1 Density of deep-sea species records currently held by the Ocean Biogeographic Information System, showing clear bias in sampling effort.

International collaboration is the key to both broadening our knowledge of the deep-sea, and to make deep-sea research more accessible to scientists from all nations. This working group, through developing agreed global habitat-specific plans, will build long-lasting capacity for the research community to tackle the long-held, and unanswered, questions outlined above. The published plans will enable the global deep-sea research community to contribute to answering these long-standing questions through regional and local research programmes, in a targeted or opportunistic fashion. The modular design and standardised methodologies will enable separate programmes to adopt a particular module where it fits in with, or contributes to their project-specific research aims. Scientists working at regional scales will generate data for their own programmes, but also for the global research effort. Over the next decade, this globally coherent dataset will grow, and by the end of the decade, we will finally be able to answer the questions posed with confidence.

This working group will also significantly advance efforts to build capacity for deep-sea research in the next generation of scientists, and in developing nations. ToR 5 will specifically address the lack of opportunity for students and researchers from nations lacking in deep-sea science infrastructure to gain experience in sea-going deep-sea research. The development of an action plan to support students, early-career scientists, and researchers from developing nations to gain access to research vessel opportunities will help broaden and diversify the deep-sea research community. It will also help fulfil the aspirations of the Decade of Ocean Science. The Decade Roadmap clearly states that the Implementation Plan, to be developed by 2020, will include a plan for capacity development, training and education (R&D priority 7).

7. Working Group composition

7.1 Full Members

Name	**Gender**	**Place of work**	**Expertise relevant to the proposal**
Kerry Howell (co- chair)	Female	Plymouth University, UK	Deep-sea ecologist, ecological modeller, use of AI, links to DOSI, INDEEP, Challenger Society. Seamount & canyon ecology.
Elva Escobar	Female	Universidad Nacional Autónoma de Mexico, Mexico.	Biological oceanography, biodiversity, macroecology. Link to UN DOSSD executive planning group. Abyssal ecology. Regional capacity needs.

Alex Rogers	Male	REV Ocean, Norway	Marine molecular ecology, biodiversity. Links to UN and philanthropic funded programmes. Seamount Ecology
Malcom Clark	Male	National Institute for Water and Atmospheric Research, New Zealand	Deep-sea fish, fisheries. CoML lead, link to ISA. Seamounts, oceanic ridges.
Ana Hilario (co-chair)	Female	University of Aviero, Portugal	Reproductive ecology, connectivity and biogeography of deep-sea ecosystems. Vent ecology.
Paul Snelgrove	Male	Memorial University of Newfoundland, Canada.	Deep-sea benthos, biodiversity drivers and roles in sediments, links to UN BBNJ process.
Lisa Levin	Female	Scripps Institution of Oceanography, USA.	Deep-sea benthos and climate change, links to DOOS, DOSI, and IPCC
Christopher German	Male	Woods Hole Oceanographic Institution, USA	Deep-sea exploration, including innovative use of robotic vehicles and telepresence.
Kerry Sink	Female	South African National Biodiversity Institute, South Africa.	Deep-water ecology, South Atlantic, SW Indian Ocean, regional capacity needs
Roberto Danovaro	Male	Stazione Zoologica Anton Dohrn, Naples & Polytechnic University of Marche, Italy.	Deep-Sea benthos, biodiversity loss, ecosystem functions, climate change.

7.2 Associate Members

Name	**Gender**	**Place of work**	**Expertise relevant to the proposal**
Bhavani Narayanaswamy	Female	Scottish Association for Marine Science, UK	Deep-sea ecologist, biodiversity, effects of biological/anthropogenic inputs, continental margins, seamounts NE Atlantic, SW Indian and Arctic Oceans

Paulo Sumida	Male	University of São Paulo, Brazil.	Deep-sea ecology. South Atlantic regional capacity needs
Anna Metaxas	Female	Dalhousie University, Canada.	Biological oceanography, evolutionary ecology.
Lenaick Menot	Male	Ifremer, France.	Deep-sea ecologist. Vents, Abyss.
Nick Higgs	Male	Cape Eleuthera Institute, Bahamas.	Deep-sea biodiversity, marine observatories, whale fall. Caribbean regional capacity needs.
Eva Ramirez-Llodra	Female	Norwegian Institute for Water Research, Norway.	Deep-sea ecologist, biodiversity, connectivity. Links with DOSI, INDEEP, IUCN-CEM Deep-sea ecosystems and mining.
Hiromi Watanabe	Female	Japan Agency for Marine- Earth Science and Technology, Japan	Deep-sea benthos, larval dispersal, population connectivity, hydrothermal vents.
Awantha Dissanayake	Male	University of New South Wales, Sydney, Australia	Ecological physiology, Experimental Biology, Climate Change.
Craig McClain	Male	Louisiana Universities Marine Consortium, USA.	Macroecology, macroeveolution, biodiversity, body size, energy flow.
Javier Sellanes	Male	Catholic University of the North, Chile.	Deep-sea benthos ecology and taxonomy. SE Pacific, regional

8. Working Group contributions

Kerry Howell (co-chair) is a deep-sea ecologist and modeller, co-proposer of the SCOR working group, co-chair of the DOSI DOSSD working group, and chair of the Challenger Deep-Sea Special Interest Group. She brings expertise in rugged terrain deep-sea habitats (seamounts, canyons, continental slopes) and various types of ecological modelling including food web, connectivity and habitat suitability modelling.

Elva Escobar contributes with knowledge in biological oceanography studying the marine biodiversity and macroecology of the seabed ecosystems in the Mexican EEZ. She is co-lead of DOSI, and a member of the IOC's Executive Planning Group for the UN DOSSD. She will ensure the working group's activities are communicated to the IOC and UN.

Alex Rogers brings expertise in biodiversity of marine ecosystems, including environmental drivers, interspecies interactions, connectivity, longer term-evolutionary processes and human impacts. He has undertaken numerous UN projects and is currently science director for REV Ocean. He will communicate the working group's plans to REV Ocean and looks for areas of shared interest.

Malcom Clark brings expertise in deep-water fish and fisheries, deep-sea ecosystems including seamount and oceanic ridges, and sampling techniques. He headed the Census of Marine Life on Seamounts, and currently sits on the Legal and Technical Commission of the International Seabed Authority.

Ana Hilario (co-chair) is a deep-sea ecologist and co-chair of the DOSI DOSSD working group and INDEEP Population Connectivity working group. She contributes with expertise on reproductive ecology, larval dispersal, population connectivity and its implications for biogeography and spatial management; as well as experience on capacity building activities in developing countries.

Paul Snelgrove brings expertise on biodiversity and ecosystem functioning in deep-sea ecosystems, and particularly seafloor environments. He has been actively involved in discussions on Biodiversity Beyond National Jurisdiction.

Lisa Levin contributes expertise on continental margin benthic ecosystems, their ecosystem services, exposure and response to climate change, and to other forms of human disturbance in the deep ocean. Through her involvement in IPCC (AR5, AR6 and Special Report on Oceans and Cryosphere), DOOS and DOSI she will identify for SCOR the major deep-ocean ecological function and service information that can contribute to ongoing climate assessment and create direct SCOR linkages to DOOS and DOSI planning and activities.

Christopher German contributes expertise in Deep Ocean exploration and, in particular, the innovative use of advances technologies to conduct that work including autonomous underwater vehicles, collaborative robotic systems and telepresence. He has experience in national and international project leadership including as Co-Chair of InterRidge, the Census of Marine Life ChEss Project, SCOR WG135 and NASA's new Network for Ocean Worlds.

Kerry Sink contributes expertise in marine ecosystem classification and assessment for the Southwest Indian, Southeast Atlantic and Southern Ocean. Kerry will provide developing country context, identify regional capacity needs and help align efforts across projects and programs.

Roberto Danovaro is a deep-sea biologist and ecologist, specialist in the assessment of the interactions between biodiversity loss and impairment of ecosystem functions and on evaluation of the impact of climate change on deep-sea habitats and ecosystems.

9. Relationship to other international programs and SCOR Working groups

There are a number of current SCOR WGs focused on standardization of methods and developing global approaches to studying marine systems (WG147 & WG143). Some current WGs are considering biology specifically (WG149), including the role of novel technologies in global efforts (WG156 & WG 157) and integrations with global programmes (WG154). While these current WGs have aspects in common with our proposed WG, none are considering the wider biological component of marine systems or the deep sea. This demonstrates the opportunity offered by our proposal.

Perhaps the most comparable SCOR WGs are historical. SCOR WG 76, approved in 1983, was focused on the ecology of the deep sea floor. As with our proposal, this WG recognized the great technical and statistical difficulties of obtaining adequate information on the deep-sea benthic ecosystem.

They proposed a critical review of the then state-of-the-art, clearly identifying what would be desirable, but at the time impracticable to do. Our proposed WG is a natural progression from where this WG concluded 36 years ago. We understand information needs, how new technology may help gather that information, and have recognised that an international programme of collaborative research is required.

SCOR WG5, the International Indian Ocean Expedition, had a single ToR: to plan and organize international co-operative exploration of the Indian Ocean. This resulted in a large-scale multinational hydrographic survey of the Indian Ocean, which took place from 1959 to 1965. It involved over 45 research vessels from 14 countries. Our proposed WG has a series of ToRs that are analogous to the single ToR of SCOR WG5. Our aim is to produce a road map for international co- operative biological research on the global ocean under the Decade of Ocean Science.

Our proposed WG has very clear links to the UN DOSSD that have been identified throughout, as well as the GOOS and DOOS initiatives. Our proposed membership includes a representative of the IOC's DOSSD Executive Planning Group, and a Co-Chair of the DOOS initiative. Their participation will ensure good communication and integration with these international programmes. The DOSSD roadmap outlines six critical societal outcomes (SO), and a further seven priority areas for research and development (R&D), which the Decade seeks to address by 2030 (Fig. 9.1). The questions that the deep-sea science community have identified (section 2.1) have direct relevance to the DOSSD SOs and R&D priority areas. Deliverables 1 and 2 of our proposed working group will specifically identify how the scientific plans developed will

also address the decades SOs and R&D priorities (Table 9.1, Fig. 9.1). In addition, deliverable 3 will directly contribute to R&D priority area 7 (Fig. 9.1).

Table 9.1 How the questions identified by the deep-sea science community contribute to societal outcomes and research and development priority areas identified by the DOSSD road map.

Questions	Societal Outcomes (SO) of the Decade of Ocean Science for Sustainable Development						Research & Development (R&D) Priority Areas						
	1	2	3	4	5	6	1	2	3	4	5	6	7
i													
ii													
iii													
iv													

The six Societal Outcomes (SO) of the Decade of Ocean Science for Sustainable Development

1. A clean Ocean whereby sources of pollution are identified, quantified and reduced, and pollutants removed from the Ocean
2. A healthy and resilient Ocean whereby marine ecosystems are mapped and protected, multiple impacts (including climate change) are measured and reduced, and provision of ocean ecosystem services is maintained
3. A predicted Ocean whereby society has the capacity to understand current and future ocean conditions, forecast their change and impact on human wellbeing and livelihoods
4. A safe Ocean whereby human communities are protected from ocean hazards and where safety of operations at sea and on the coast is ensured
5. A sustainably harvested and productive Ocean ensuring the provision of food supply and alternative livelihoods
6. A transparent and accessible Ocean whereby all nations, stakeholders and citizens have access to Ocean data and information, technologies, and have the capacities to inform their decisions.

The seven Research & Development (R&D) Priority Areas

1. Comprehensive map (digital atlas) of the oceans
2. A comprehensive ocean observing system
3. A quantitative understanding of ocean ecosystems and their functioning as the basis for their management and adaptation
4. Data and information portal
5. Ocean dimension in an integrated multihazard warning system
6. Ocean in earth-system observation, research and prediction, with engagement of social and human sciences and economic valuation
7. Capacity building and accelerated technology transfer, training and education, ocean literacy.

From the *Revised Roadmap for the UN Decade of Ocean Science for Sustainable Development*

Figure 9.1 Societal outcomes and research and development priority areas identified in the Decade of Ocean Science for Sustainable Development roadmap.

10. References

Cowen, R.K., Lwiza, K.M., Sponaugle, S., Paris, C.B. and Olson, D.B., 2000. Connectivity of marine populations: open or closed?. Science, 287(5454), pp.857-859.

Davies, A., Guinotte, J. 2011. Global Habitat Suitability for Framework-Forming Cold-Water Corals. PLoS ONE 6.

German, C.R., Ramirez-Llodra, E., Baker, M.C., Tyler, P.A., and the ChEss Scientific Steering Committee. 2011. Deep-Water Chemosynthetic Ecosystem Research during the Census of Marine Life Decade and Beyond: A Proposed Deep-Ocean Road Map. PLOS ONE 6, (8). e23259

Grassle JF, Maciolek NL (1992) Deep-sea species richness: regional and local diversity estimates from quantitative bottom samples. Am Nat 139: 313–341.

Hoffmann, F., Radax, R., Woebken, D., Holtappels, M., Lavik, G., Rapp, H.T., Schläppy, M.L., Schleper, C., Kuypers, M.M., 2009. Complex nitrogen cycling in the sponge *Geodia barretti*. Environ. Microbiol. 11, 2228–2243.

Howell, K.L., Piechaud, N., Downie, A.-L., Kenny, A. 2016. The distribution of deep-sea sponge aggregations in the North Atlantic and implications for their effective spatial management. Deep Sea Research Part I: Oceanographic Research Papers 115, 309-320.

Maldonado, M.,Carmona,M.C.,Velásquez,Z.,Puig,A.,Cruzado,A.,López,A.,Young, C.M., 2005. Siliceous sponges as a silicon sink: an over looked aspect of bentho-pelagic coupling in the marine silicon cycle. Limnology and Oceanography. 50, 799–809.

Mengerink, K.J., Van Dover, C.L., Ardron, J., Baker, M., Escobar-Briones, E., Gjerde, K., Koslow, J. A., Ramirez-Llodra, E., Lara-Lopez, A., Squires, D., Sutton, T., Sweetman, A.K., Levin, L.A. 2014. A call for Deep-Ocean Stewardship. Science 344, 696-698.

Mora C., Tittensor D.P., Adl S., Simpson A.G.B., Worm B., 2011. How Many Species Are There on Earth and in the Ocean? PLoS Biology 9(8): e1001127.

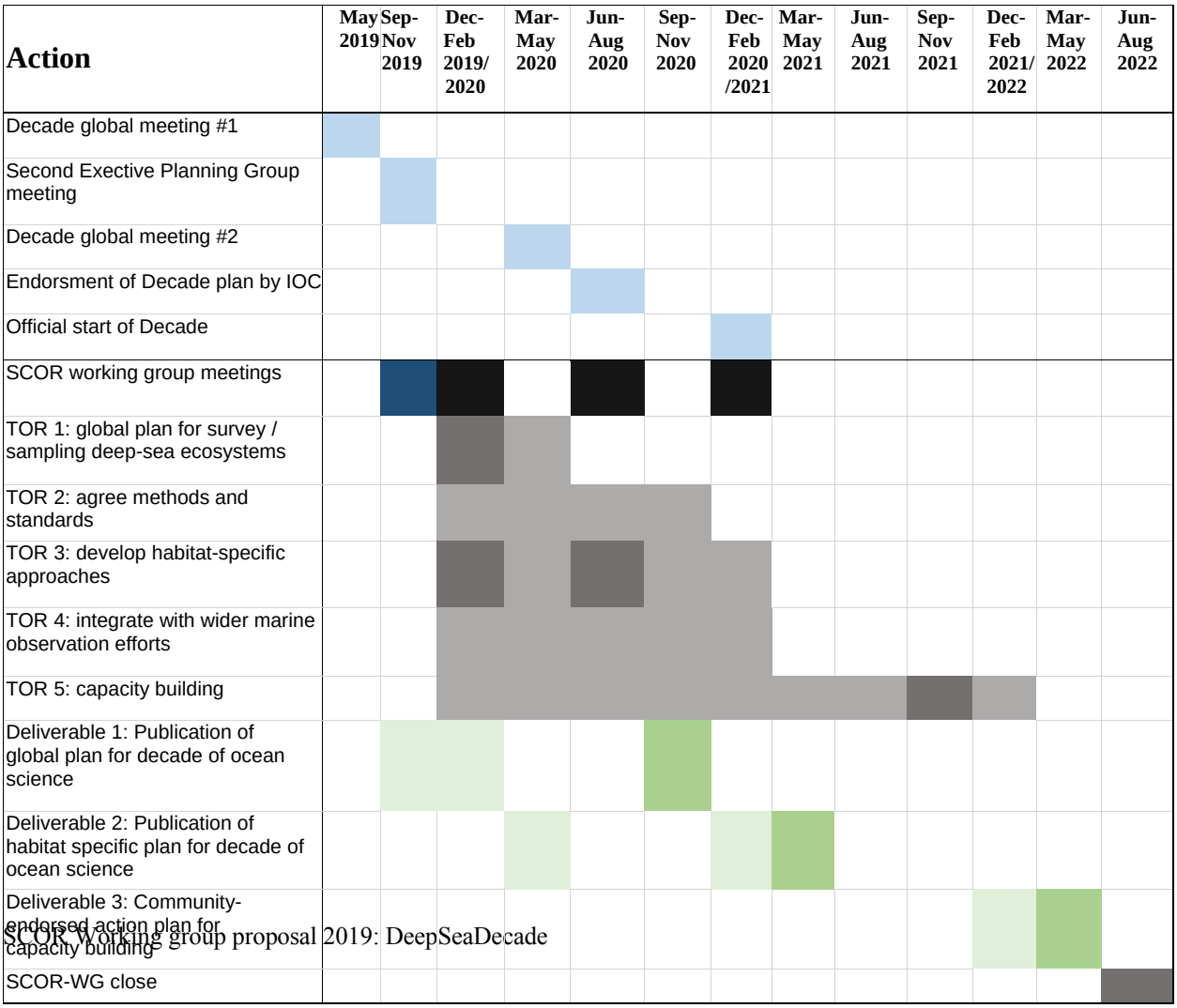
Ramirez-Llodra, E., Brandt, A., Danovaro, R., De Mol, B., Escobar, E., German, C.R., Levin, L.A., Martinez Arbizu, P., Menot, L., Buhl-Mortensen, P., Narayanaswamy, B.E., Smith, C.R., Tittensor, D.P., Tyler, P.A., Vanreusel, A., Vecchione, M. 2010. Deep, diverse and definitely different: unique attributes of the world's largest ecosystem. Biogeosciences 7, 2851-2899

Woodall, L.C., Andradi-Brown, D.A., Brierley, A.S., Clark, M.R., Connelly, D., Hall, R.A., Howell, K.L.,

Huvenne, V.A.I., Linse, K., Ross, R.E., Snelgrove, P., Stefanoudis, P.V., Sutton, T.T., Taylor, M., Thornton, T.F., Rogers, A.D. 2018. A Multidisciplinary Approach for Generating Globally Consistent Data on Mesophotic, Deep-Pelagic, and Bathyal Biological Communities. Oceanography. 31, 76-89.

Appendix

Gantt chart: Timing of key points in the road map for the UN Decade of Ocean Science for Sustainable Development (light blue), and proposed timings for SCOR working group meetings (SCOR funded – black, externally funded – dark blue), virtual meetings (dark grey), ToRs (light grey), and deliverables (draft – light green, final – dark green).



Full member selected relevant publications

Kerry Howell (co-chair)

Piechaud, N., Culverhouse, P.F., Hunt, C., **Howell, K.L.** in press. Automated Identification of benthic epifauna from images using computer vision. Marine Ecology Progress Series.

Woodall LC, Andradi-Brown, DA, Brierley AS, Clark MR, Connelly D, Hall RA, **Howell KL**, Huvenne VAI, Linse K, Ross RE, Snelgrove, P, Stefanoudis, PV, Sutton, TT, Taylor, M, Thornton, TF, Rogers AD. 2018 A Multidisciplinary Approach for Generating Globally Consistent Data on Mesophotic, Deep-Pelagic, and Bathyal Biological Communities. Oceanography. 31, 76-89.

Ross RE, Nimmo-Smith WAM & **Howell KL** 2016 'Increasing the Depth of Current Understanding: Sensitivity Testing of Deep-Sea Larval Dispersal Models for Ecologists' PLOS ONE 11, (8)

Ross, R, **Howell, K.L.** 2012. Use of predictive habitat modelling to assess the distribution and extent of the current protection of 'listed' deep-sea habitats. Diversity and Distributions. DOI: 10.1111/ddi.12010

Howell, K.L., Heymans, J.J., Gordon, J.D.M., Duncan, J., Ayers, M., Jones, E.G. 2009. DEEPFISH Project: Applying an ecosystem approach to the sustainable management of deep-water fisheries. Part 1: Development of the Ecopath with Ecosim model. Scottish Association for Marine Science, Oban. U.K. Report no. 259a. http://www.sams.ac.uk/sheila-heymans/deepfish-1-english

Elva Escobar

Niner, H.J., Ardron, J.A., **Escobar, E.G.,** Gianni, M., Jaeckel, A., Jones, D.O., Levin, L.A., Smith, C.R., Thiele, T., Turner, P.J. and Van Dover, C.L., 2018. Deep-Sea mining with No net loss of biodiversity— an impossible aim. *Frontiers in Marine Science*, *5*, p.53.

Sahling, H., Borowski, C., **Escobar-Briones, E.,** Gaytán-Caballero, A., Hsu, C.W., Loher, M., MacDonald, I., Marcon, Y., Pape, T., Römer, M. and Rubin-Blum, M., 2016. Massive asphalt deposits, oil seepage, and gas venting support abundant chemosynthetic communities at the Campeche Knolls, southern Gulf of Mexico. Biogeosciences, 13(15), pp.4491-4512.

Portail, M., Olu, K., Dubois, S.F., **Escobar-Briones, E**., Gelinas, Y., Menot, L. and Sarrazin, J., 2016. Food-web complexity in Guaymas Basin hydrothermal vents and cold seeps. PloS one, 11(9), p.e0162263.

Portail, M., Olu, K., **Escobar-Briones, E**., Caprais, J.C., Menot, L., Waeles, M., Cruaud, P., Sarradin, P.M., Godfroy, A. and Sarrazin, J., 2015. Comparative study of vent and seep macrofaunal communities in the Guaymas Basin. Biogeosciences, 12(18), pp.5455-5479

Wei, C.L., Rowe, G.T., **Escobar-Briones, E.,** Boetius, A., Soltwedel, T., Caley, M.J., Soliman, Y., Huettmann, F., Qu, F., Yu, Z. and Pitcher, C.R., 2010. Global patterns and predictions of seafloor biomass using random forests. PloS one, 5(12), p.e15323.

Alex Rogers

Popova, E., Vousden, D., Sauer, W.H.H., Mohammed, E.Y., Allain, V., Downey-Breedt, N., Fletcher, R., Gjerde, K.M., Halpin, P.N., Kelly, S., Obura, D., Pecl, G., Roberts, M., Raitsos, D.E., **Rogers, A.D.,** Samoilys, M., Sumaila, U.R., Tracey, S., Yool A. (2019) Ecological connectivity between the areas beyond national jurisdiction and coastal waters:

Safeguarding interests of coastal communities in developing countries. Journal of Marine Policy, 104, 90-102.

Woodall LC, Andradi-Brown, DA, Brierley AS, Clark MR, Connelly D, Hall RA, Howell KL, Huvenne VAI, Linse K, Ross RE, Snelgrove, P, Stefanoudis, PV, Sutton, TT, Taylor, M, Thornton, TF, **Rogers AD.** 2018 A Multidisciplinary Approach for Generating Globally Consistent Data on Mesophotic, Deep-Pelagic, and Bathyal Biological Communities. Oceanography. 31, 76-89.

Rogers, A. (2018). "The biology of seamounts: 25 years on." in Advances in Marine Biology, ed. C. Sheppard (Academic Press, London), 137–224. doi: 10.1016/BS.AMB.2018.06.001

Ashford, O.S., Kenny, A.J., Barrio Froján, C.R., Bonsall, M.B., Horton, T., Brandt, A., Bird, G.J., Gerken, S. and **Rogers, A.D.**, 2018. Phylogenetic and functional evidence suggests that deep-ocean ecosystems are highly sensitive to environmental change and direct human disturbance. Proceedings of the Royal Society B, 285(1884), p.20180923.

Tittensor, D.P., Baco, A.R., Hall-Spencer, J.M., Orr, J.C. and **Rogers, A.D.,** 2010. Seamounts as refugia from ocean acidification for cold-water stony corals. Marine Ecology, 31, pp.212-225.

Malcom Clark

Clark, M.R., Durden, J.M. and Christiansen, S., 2019. Environmental Impact Assessments for deep- sea mining: Can we improve their future effectiveness? Marine Policy.

Sutton, T.T., **Clark, M.R**., Dunn, D.C., Halpin, P.N., Rogers, A.D., Guinotte, J., Bograd, S.J., Angel, M.V., Perez, J.A.A., Wishner, K. and Haedrich, R.L., 2017. A global biogeographic classification of the mesopelagic zone. Deep Sea Research Part I: Oceanographic Research Papers, 126, pp.85-102.

Clark, M.R., Consalvey, M., Rowden, A.A. 2016. Biological Sampling in the Deep Sea. 451pp. Wiley & Sons, Ltd.

Clark, M.R., Althaus, F., Schlacher, T.A., Williams, A., Bowden, D.A. and Rowden, A.A., 2015. The impacts of deep-sea fisheries on benthic communities: a review. ICES Journal of Marine Science, 73(suppl_1), pp.i51-i69.

Clark, M.R., Althaus, F., Williams, A., Niklitschek, E., Menezes, G.M., Hareide, N.R., Sutton, P. and O'Donnell, C., 2010. Are deep-sea demersal fish assemblages globally homogenous? Insights from seamounts. Marine Ecology, 31, pp.39-51.

Ana Hilario (co-chair)

Stratoudakis Y, **Hilário A**, Ribeiro C, Abecasis D, Gonçalves E, Andrade F, Carreira G, Gonçalves J, Freitas L, Pinheiro LM, Batista M, Henriques M, Oliveira PB, Afonso P, Arriegas PI, Henriques S (2019) Environmental representation in marine protected area networks over large and partly unexplored seascapes: the case of Portugal. *Global Ecology and Conservation* 17, e00545. doi: 0.1016/j.gecco.2019.e00545

Leal MC, **Hilario A**, Munro MHG, Blunt JW, Calado R (2016) Natural products discovery needs improved taxonomic and geographic information. *Natural Product Reports* 33, 747-750, doi: 10.1039/C5NP00130G

Hilário A, Metaxas A, Gaudron S, Howell K, Mercier A, Mestre N, Ross RE, Thurnherr A, Young CM (2015) Estimating dispersal distance in the deep sea: challenges and applications to marine reserves. *Frontiers In Marine Science* 2, 6, 1-14.

Tunnicliffe V, St. Germain C, **Hilário A** (2014) Phenotypic variation and fitness in a metapopulation of tubeworms (*Ridgeia piscesae* Jones) at hydrothermal vents. *PLoS One* 9(10), e110578, doi: 10.1371/journal.pone.0110578.

Hilário A, Comas MC, Azevedo L, Pinheiro L, Ivanov MK, Cunha MR (2011) First record of a Vestimentifera (Polychaeta: Siboglinidae) from chemosynthetic habitats in the western Mediterranean Sea - Biogeographical implications and future exploration. *Deep Sea Research I* 58, 200-207, doi: 10.1016/j.dsr.2010.11.009.

Paul Snelgrove

Campanya I Llovet, N., **Snelgrove, P.V.R.** (2018) Fine-scale infaunal community and food web patch mosaics from Barkley methane hydrates (British Columbia, Canada): The role of food quality. Deep- Sea Research Part I 140: 186–195.

Campanya I Llovet, N., **Snelgrove, P.V.R.** (2018) Effects of temporal variation in food sources on infaunal community structure of chemosynthetic and non-chemosynthetic environments in Barkley Hydrates, British Columbia, Canada. Deep-Sea Research Part I 140: 118–127.

Snelgrove, P.V.R., Soetaert, K., Solan, M., Thrush, S., Wei, C.-L., Danovaro, R, Fulweiler, R.W., Kitazato, H., Ingole, B., Norkko, A., Parkes, R.J., Volkenborn, N. (2018) Contrasting biogeochemical and biological estimates of carbon turnover on the global seafloor. Trends Ecol. Evol. 33, 96-105.

Danovaro R., Corinaldesi C., Dell'Anno A., **Snelgrove P.V.R.** (2017) Deep-sea biology under global change. Current Biology 27, R461–R465.

Danovaro R., Aguzzi, J., Fanelli E., Billett D., Gjerde K., Jamieson A., Ramirez-Llodra E., Smith C.R., **Snelgrove P.V.R**., Thomsen L., Van Dover C. (2017) A new international ecosystem-based strategy for the global deep ocean. Science 355, 452-454.

Lisa Levin

Levin, Lisa A., Brian J. Bett, Andrew R. Gates, Patrick Heimbach, Bruce M. Howe, Felix Janssen, Andrea McCurdy, Henry A. Ruhl, Paul Snelgrove, Karen I. Stocks and 28 others. 2019. Global Observing Needs in the Deep Ocean. Frontiers in Marine Science. In revision.

Le, Jennifer T., **Lisa A. Levin,** Richard T. Carson Incorporating ecosystem services into environmental management of deep seabed mining Deep-sea Research II 137: 486–503 (2017).

Levin, Lisa A. Amy R. Baco, David Bowden, Ana Colaco, Erik Cordes, Marina R. Cunha, Amanda Demopoulos, Judith Gobin, Ben Grupe, Jennifer Le, Anna Metaxas, Amanda Netburn, Greg Rouse, Andrew R. Thurber, Verena Tunnicliffe, Cindy Van Dover, Ann Vanreusel, and Les Watling. Hydrothermal vents and methane seeps: rethinking the sphere of influence. Frontiers in Marine Science 3:72. doi: 10.3389/fmars.2016.00072 (2016)

Levin, Lisa A. and Nadine Le Bris. Deep oceans under climate change. *Science* 350: 766-768. (2015)

Mengerink, K.J., C.L. Van Dover, J. Ardron, M. Baker, E. Escobar-Briones, K. Gjerde, J. A. Koslow, E. Ramirez-Llodra, A. Lara-Lopez, D. Squires, T. Sutton, A.K. Sweetman, **L.A. Levin A.** Call for Deep- Ocean Stewardship. *Science* 344: 696-698. (2014)

Christopher German

K.P. Hand and C.R. German. Exploring ocean worlds on Earth and beyond. Nature Geoscience 10, 2- 4, doi: 10.1038/s41561-017-0045-9, 2018.

L. Levin, P.R. Girguis, C.R. German, M.L. Brennan, S. Tuzun, J. Wagner, C. Smart, A. Kruger, K. Inderbitzen, J. Le, M. Martinez, C. Martinez, E. Kappel, N. Gallo & B.M. Grupe. Exploration and discovery of methane seeps and associated communities in the California Borderland. Oceanography 29, 40-43, 2016.

S.E. Beaulieu, E.T. Baker & C.R. German. Where are the undiscovered hydrothermal vents on oceanic spreading ridges? Deep Sea Res. II 121, 202-212, 2015.

C.R. German, E.Z. Ramirez-Llodra, M.C. Baker, P.A. Tyler & the ChEss Scientific Steering Committee. Deep-water Chemosynthetic Ecosystem Research during the Census of Marine Life decade and beyond: A proposed deep-ocean road map. PLoS One 6, e23259, 2011.

E. Ramirez-Llodra, A. Brandt, R. Danovaro, B. DeMol, E. Escobar, C.R. German, L.A. Levin, P. Marttinez Arbizu, L. Menot, P. Buhl-Mortensen, B.E. Narayanaswamy, C.R. Smith, D.P. Tittensor, P.A. Tyler, A. Vanreusel and M. Vecchione. Deep, Diverse and Definitely Different: Unique Attributes of the World's Largest Ecosystem. Biogeosciences 7, 2851-2899.

Kerry Sink

Kirkman, Stephen P., Stephen Holness, Linda R. Harris, **Kerry J. Sink,** Amanda T. Lombard, Paulus Kainge, Prideel Majiedt, Silvi E. Nsiangango, Kumbi K. Nsingi, and Toufiek Samaai. 2019. Using Systematic Conservation Planning to support Marine Spatial Planning and achieve marine protection targets in the transboundary Benguela Ecosystem." *Ocean & Coastal Management* 168: 117-129.

Atkinson LJ and **Sink KJ** (eds) 2018. Field Guide to the Offshore Marine Invertebrates of South Africa, Malachite Marketing and Media, Pretoria, pp. 498.

Karenyi, Natasha, **Kerry Sink,** Ronel Nel, Allan E. Clark, and Res Altwegg. 2018. Imperfect detection distorts depth-related trends in marine macrofaunal species richness. *Ecography* Vol 41 (10) 1698- 1706.

Cordes EE, Jones DOB, Schlacher TA, Amon DJ, Bernardino AF, Brooke S, Carney R, DeLeo DM, Dunlop KM, Escobar-Briones EG, Gates AR, Génio L, Gobin J, Henry L-A, Herrera S, Hoyt S, Joye M, Kark S, Mestre NC, Metaxas A, Pfeifer S, Sink K, Sweetman AK and Witte U. 2016. Environmental Impacts of the Deep-Water Oil and Gas Industry: A Review to Guide Management Strategies. Front. Environ. Sci. 4:58

Karenyi N., **Sink** K and Nel R. 2016. Defining **seascapes** for marine unconsolidated shelf sediments in an eastern boundary upwelling region: the southern Benguela as a case study. Estuarine, Coastal and Shelf Science 169 195-206.

Roberto Danovaro

Danovaro Roberto, Jacopo Aguzzi, E Fanelli, D Billett, K Gjerde, A Jamieson, E Ramirez-Llodra, CR Smith, PVR Snelgrove, L Thomsen, CL Van Dover (2017) An ecosystem-based deep-ocean strategy Science 355: 452-454

Danovaro R, A Dell'Anno, C Corinaldesi, E Rastelli, R Cavicchioli, Mart Krupovic, Rachel T Noble, Takuro Nunoura, David Prangishvili (2016) Virus-mediated archaeal hecatomb in the deep seafloor, Science advances 2 (10), e1600492

Danovaro R, M Molari, C Corinaldesi, A Dell'Anno (2016) Macroecological drivers of archaea and bacteria in benthic deep-sea ecosystems. Science advances 2 (4), e1500961

Danovaro R, PVR Snelgrove, P Tyler (2014) Challenging the paradigms of deep-sea ecology. Trends in ecology & evolution 29 (8), 465-475

A Dell'Anno, C Corinaldesi, R **Danovaro** (2015) Virus decomposition provides an important contribution to benthic deep-sea ecosystem functioning. Proceedings of the National Academy of Sciences 112 (16), E2014-E2019

Marine Species Distribution Modelling in the global ocean (MSDM-GO)

Abstract

Understanding the drivers that control the distribution of species and habitats is a fundamental requirement for conservation and management, particularly when predicting their response to anthropogenic stressors including climate change. Over the last decade, the use of species distribution modelling (SDM) in the marine environment has proliferated, driven largely by 1) an increased accessibility of distributional data, 2) global datasets of environmental predictors, 3) a diversity of modelling tools and 4) increased demands by managers and conservationists to be better informed about the distribution of species now and into the future. SDMs typically build a statistical understanding of the relationship between species occurrences and/or their biological responses and environmental drivers (e.g., temperature, depth, food supplies), requiring a multidisciplinary understanding that bridges statistics, biology and physical oceanography. With a lower barrier to entry, SDMs are being used by increasing numbers of researchers. However, without robust guidance and benchmarking standards, the quality of studies generated by increased SDM use varies widely, reducing confidence and uptake by stakeholders. This SCOR WG will develop community-driven best-practice guidance that will enable the development of next-generation marine distributional models that will drive policy and practice globally. Given the international effort to map the global seabed at high-resolution by 2030 (Nippon Foundation-GEBCO), the 2021 launch of the UN Decade of Ocean Science for Sustainable Development, and an ever-increasing amount and quality of available observation and environmental data, it is important that these guidelines are established in order to maximize the scientific and societal impact of marine SDMs.

Scientific Background and Rationale

Many marine environments are under intense and increasing anthropogenic pressure, both from climate change and direct impact from sources such as commercial fishing, oil and gas exploration, and aggregate or mineral extraction activities (e.g., Davies et al. 2007). This pressure is especially problematic given that much of the global ocean remains unmapped, uncharacterized and under-explored, particularly with respect to biodiversity (Ramirez-Llodra et al. 2010). Consequently, scientists and stakeholders face unique challenges and urgency in the study and management of most ocean ecosystems (e.g., Auster et al. 2011). Recent technological advancements in ocean data collection have greatly advanced our ability to explore, observe and ultimately exploit ocean ecosystems (Danovaro et al. 2014). Coupled with improved access to data through open access initiatives, global scale environmental datasets and the emergence of spatially and taxonomically comprehensive databases, these advances have the potential to enable the marine scientific community to better understand the ocean environment and the organisms that reside within. However, success is contingent on engagement across the broader community of marine scientists, policy makers and managers. SCOR and its partners have the means to achieve this, providing access and influence beyond a

single national project and will draw global attention to our outputs which are tailored to support near- and long-term management and policy decisions.

Our current knowledge of marine systems is spatially variable, biased towards locations near well developed countries and shallow, continental shelf depths (Robinson et al. 2011; Vierod et al. 2014; Robinson et al. 2017). However, the wider ocean, particularly areas that lie beyond national jurisdiction where anthropogenic impacts nonetheless occur and are likely to increase, remains largely data poor (e.g. Southern Ocean, South Pacific). This general paucity of information, and ever-expanding footprint of anthropogenic activity, leads to an urgent need for the development of scientific methods that accurately describe the distribution of species and biodiversity in the marine environment.

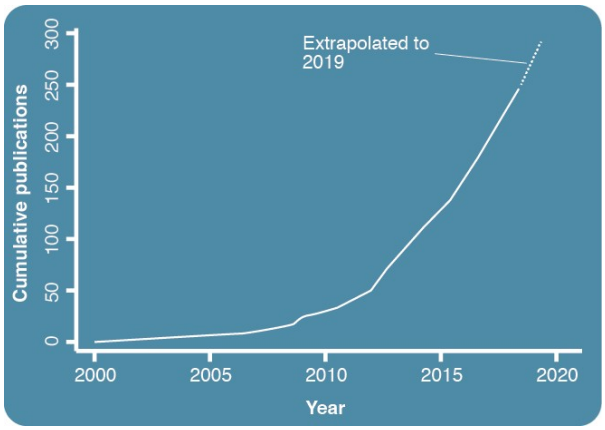


Fig 1: Cumulative number of publications from Scopus (Mar 2019) for the search term: (Ocean AND ("species distribution model" OR "habitat suitability model")).

Application of SDM in marine systems

One tool that can address gaps in our knowledge and has seen rapid adoption in a variety of marine ecosystems is species distribution modelling (SDM; Figs 1 and 2) (Robinson et al. 2011; Robinson et al. 2017). Constructing marine SDMs (MSDM) is a challenging and multi-faceted process (Fig 2), that requires a broad understanding of not only statistical modelling techniques, but also of species biology and ecology, bathymetric, geological and habitat mapping, physical oceanography and data handling (Vierod et al. 2014). SDMs take three main forms, 1) correlative, 2) hybrid correlative and process-based, and 3) mechanistic (Fig 2). Correlative models are currently the most commonly used in marine systems. They are empirical models that relate data from species occurrences (and sometimes absences) to a selection of ecologically relevant biological, environmental or spatial variables, deriving an understanding of a species niche (Guisan and Zimmermann 2000). These models can then be extrapolated geographically into areas where environmental data are available to predict the potential distribution of a species in unsurveyed locations or times. Hybrid and mechanistic models are rarely used in marine systems, largely due to the specific data requirements that are needed to apply such approaches, but adoption is emerging (e.g. Schibalski et al. 2018; Thomas and Bacher 2018).

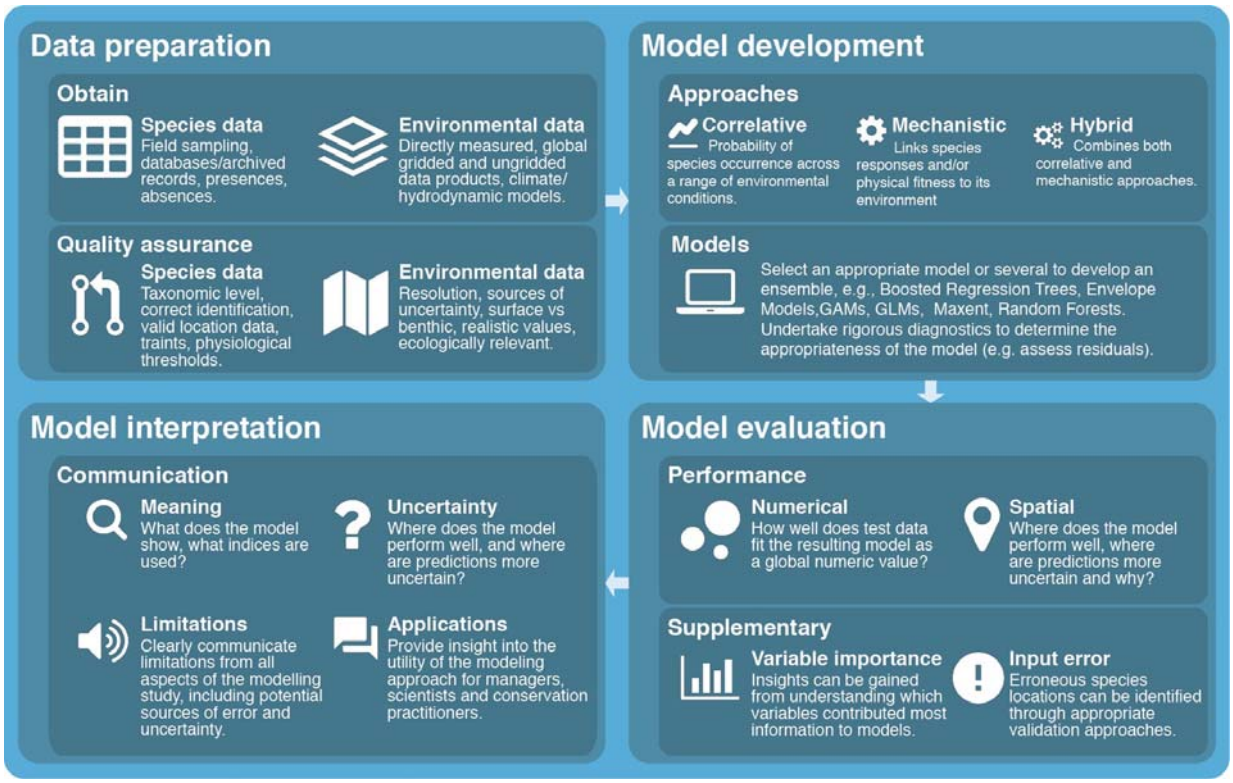


Fig 2: Flow diagram of the MSDM development.

SDMs have been employed in many marine environments, ranging from shallow coastal waters (Robinson et al. 2017) to the deep ocean (Vierod et al. 2014), at a variety of spatial scales, including local, regional and global. In terms of taxonomic application, fish are the most common group modeled, followed by marine mammals, macroalgae, seabirds and corals (Robinson et al. 2011; Robinson et al. 2017). MSDMs have been used for a variety of purposes, including 1) marine spatial planning (both management and conservation perspectives) (e.g., Gormley et al. 2014), 2) MPA network planning (e.g., Hooker et al. 2011), 3) distribution assessment of taxa or living marine resources (e.g., Yesson et al. 2012), 4) extent assessment of vulnerable marine ecosystems (e.g., Howell et al. 2016), delineation of essential fish habitats, including the abundance of juveniles (e.g., Asjes et al. 2016), the abundance of adults at spawning stage (e.g., González-Irusta and Wright 2015) and fish egg distribution (e.g., Loots et al. 2011), 6) studying responses to anthropogenic impacts (e.g., Foster et al. 2015), 7) determining species responses to climate change (e.g., Jueterbock et al. 2013), and 8) studying biological invasions and disease risk (e.g., Tanaka et al. 2017) (Fig 3).

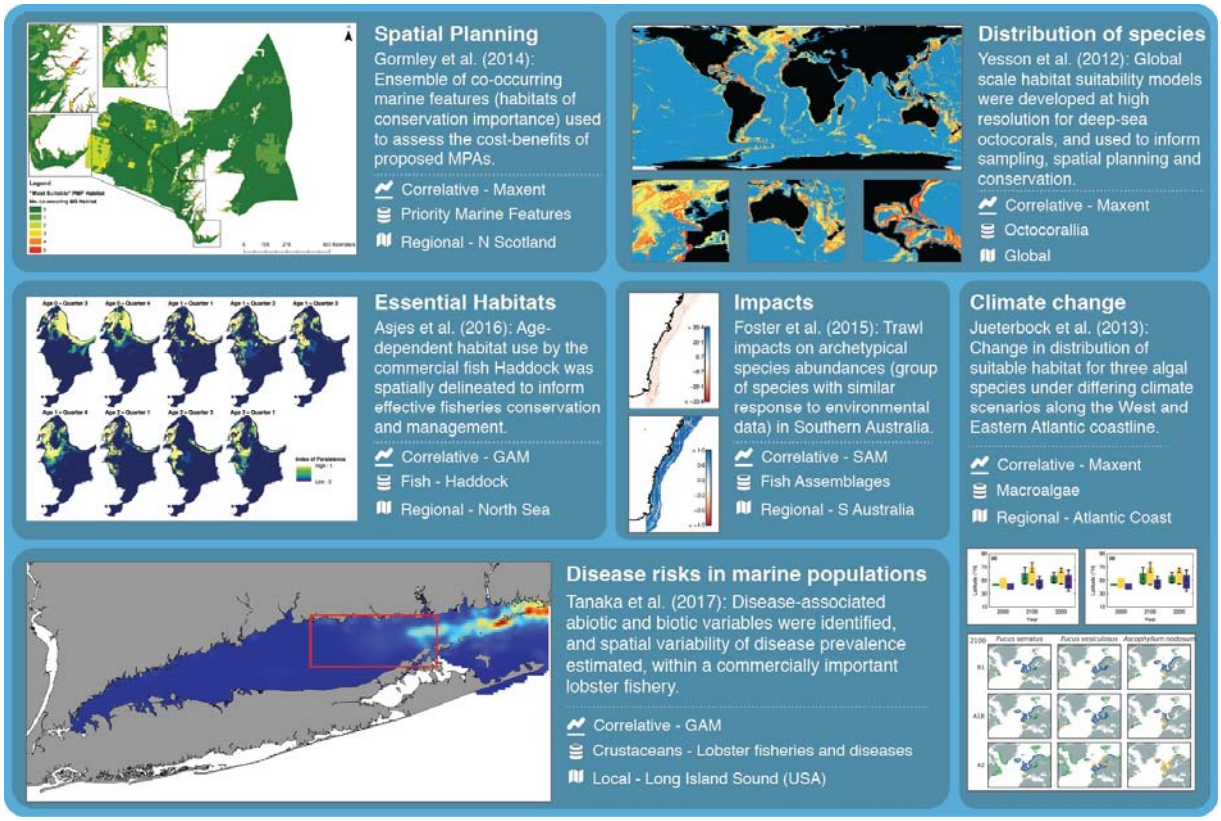


Fig 3: Examples of the potential uses of published MSDMs.

Challenges for MSDMs

The underlying data and techniques required for robust MSDMs have developed rapidly in the last decade, but there are limitations that hinder the adoption of outputs by the marine scientific and policy communities. If they are to embrace MSDMs in planning, five main criteria must be met and clearly explained:

- *Relevance*: MSDMs should be relevant to the management, scientific or conservation task at hand. For example, much of the distribution data for marine organisms comes with a level of taxonomic uncertainty (e.g., identifying species from images can be difficult) and spatial bias (i.e., datasets largely comprised of ad hoc rather than structured data collection), which are often not considered in detail within MSDM studies.
- *Scale*: MSDMs should be developed at an appropriate resolution, not coarser or finer than is required by stakeholders, as this can create difficulties in adopting them into spatial management plans, or at scales that are unsuitable for input data (e.g., how the variance in observations is related to the spatial and temporal variance in covariates).
- *Appropriate and conservative approaches*: Reliance on a model approach without sufficient diagnostics or consideration of assumptions, can reduce confidence in MSDMs. Well justified single or multiple model approaches are more trusted by stakeholders and can be particularly important in data-poor regions.

- *Verifiable*: The use of appropriate and understandable validation approaches (e.g., correlation metrics, area under curve, *k*-fold, cross-validation), that may include independent test data or field validation and consider the sampling bias evident in many marine observations, are highly valued by stakeholders.
- *Uncertainty*: Understanding the uncertainty in input data and resulting predictions is important for communicating the limitations of outputs. Any sources of error in an MSDM output must be explained and, if appropriate, demonstrated spatially, a particularly useful resource for designing spatial management measures.

Meeting these criteria has been an issue for many MSDM efforts, largely due to highly variable data quality, lack of access to appropriate tutorials regarding best-practice and a disconnect with end-user stakeholders. There is also a need for openness and reproducibility associated with MSDMs and their inputs (e.g., distribution or environmental), and outputs (e.g., predictive surfaces, uncertainty surfaces), and the approaches used, which would facilitate uptake and advance the scientific community. This SCOR WG, through its global and multifaceted approach will address these issues, leading to coherent improvement in the application of MSDM. We will engage the MSDM community in creating a best-practice framework, and supplement this by providing developers with the appropriate tools and examples to enhance practice. Ultimately, we aim to strengthen the adoption of MSDMs by management and policy makers. With multiple international efforts, currently ongoing or planned, which aim to enhance data collection in the ocean (e.g., Nippon Foundation-GEBCO, UN Decade of Ocean Science for Sustainable Development), there is a pressing need to ensure that practitioners are able to adopt a rigorous and effective MSDM framework that is accepted by stakeholders.

Terms of Reference

1. Identify best practices for the development of marine species distribution models (MSDMs), identify current gaps and limitations in MSDM applications, provide guidance on future MSDM development and publish this in a peer-reviewed output.
2. Increase access to prior-published MSDM outputs (including input and output datasets) and computer code by a) promoting open access, transparency and repeatability and b) the development of a data portal (oceanmodels.org) that will consolidate and curate both model predictions and meta-data records from published MSDM outputs.
3. Coordinate the development of a massive open online course (MOOC) to build capacity and competency in this field, with materials provided by WG participants, designed to incorporate best practices and cover environmental and species data processing, multiple modelling approaches, model development and model validation.
4. Build capacity by mentoring early career scientists who aim to develop and publish MSDMs in the adoption of appropriate approaches, best-practices and application/impact strategy.

Deliverables

Deliverable 1: Peer-reviewed output(s) that reviews the current development of MSDMs:

> **Milestone 1.1:** Review of the current state-of-the-art in MSDM applications, identifying specific challenges and solutions.
> **Milestone 1.2:** Review available ocean datasets (both species and environmental) and data processing procedures to create MSDM inputs.
> **Milestone 1.3:** Present future directions that should be explored by scientists interested in building impactful MSDMs in the future.

Deliverable 2: Produce a community-driven code of practice that encourages the developers of MSDMs to embrace the open access, repeatability and transparency of MSDM inputs, outputs and code:

> **Milestone 2.1:** Draft code of practice produced as a technical report for dissemination and feedback from the MSDM community.
> **Milestone 2.2:** Finalized code of practice submitted as a perspective manuscript in a relevant journal.

Deliverable 3: Develop a web-mapping portal (oceanmodels.org) dedicated to assimilating published MSDM studies and promotes open access and sharing:

> **Milestone 3.1:** Develop the interactive website and populate this with information from the WG.
> **Milestone 3.2:** Populate the web-mapping portal with studies published between 2000 and present.

Deliverable 4: Create training materials and opportunities covering theoretical and applied concepts of MSDMs to assist in capacity building:

> **Milestone 4.1:** Report outlining the online course structure and materials to be developed and released.
> **Milestone 4.2:** MOOC Module 1: “Introduction to MSDM”. MOOC Module 2: “Effective species and environmental data for MSDMs”. MOOC Module 3: “Forecasting impacts using MSDMs”.
> **Milestone 4.3:** Hold an early career/introductory MSDM workshop utilizing the SCOR Capacity Development program to support participants from developing countries.

Working plan

To achieve the terms of reference for this WG:

Year 1 - 2020

We will hold an initial 3-day workshop among the participants during Summer 2020 at the University of Rhode Island (USA).

This workshop will:

a. Outline the current state of the art for the development of MSDMs and likely future directions.
b. Discuss the challenges facing MSDM practitioners and begin the development of best-practice guidelines and codes of practice for building management relevant MSDMs.
c. Discuss the scope and structure of the proposed MSDM data portal and online course.
d. Allocate tasks among participants.

Following the meeting, we will:

a. Release website pages that summarize the activities and outputs of the working group (Aug 2020; Milestone 3.1).
b. Start a draft working document that summarizes the current state of the art, challenges and future directions for MSDMs (Feb 2020; Milestones 1.1-1.3).
c. Release a draft data-sharing and open-access code of practice as a technical report for review by the MSDM community. (Dec 2020; Milestone 2.1).
d. Consult with the SCOR Committee on Capacity Building (SCOR CCB) to gain insight on how to solicit participation of scientists from developing countries and to integrate our work with capacity- building activities within SCOR (Oct 2020; Terms of Reference 4 and Deliverable 4).

Year 2 – 2021

During year two, we will progress several of our proposed outputs, and hold a series of virtual meetings between sub-groups of the WG that are responsible for delivering specific tasks, we will:

a. Formalize the draft data-sharing and open access code of practice and submit a peer-reviewed output (Oct 2021; Milestone 2.2).
b. Release the web-mapping component of the data-portal with meta- data extracted from peer-reviewed marine SDM publications dating from 2000-present (August 2021; Milestones 3.1-3.2).
c. Release the first module for the online course, “Introduction to MSDM” (Sept 2021; Milestone 4.2) and trial it with early career scientists and others identified by SCOR CCB.

Year 3 – 2022

We will hold a further 3-day workshop among the participants during 2022. Plus, a 2-day training workshop on marine species distribution modelling for early career scientists and scientists from developing countries. We would aim to plan this around a major conference, possibly the 6th World Congress of Marine Biodiversity.
The participants' workshop will:

a. Discuss future directions for the working group and highlight potential additional sources of funding to maintain progress.
b. Finalize best-practice guidance for MSDMs based on community and peer-review.

Following the participants workshop we will:

a. Finalize current MSDM state of the art, best-practice guidance and future directions as peer-reviewed outputs (Dec 2022; Milestones 1.1-1.3).
b. Release the final modules for the online course (Aug 2022; Milestone 4.2).

The training workshop (Milestone 4.3) will:

a. Provide a series of training sessions regarding best-practice in MSDM development.
b. Give early career scientists and scientists from developing countries the opportunity to receive mentorship from established MSDM practitioners.
c. Establish a network of early career scientists and scientists from developing countries interested in developing marine SDMs.

Capacity Building

Our outputs will provide a lasting contribution to the field of MSDM and enhance the capability of stakeholders to better manage and conserve marine ecosystems in light of increased demands in much of the global ocean. By building this momentum, the WG will follow capacity building initiatives through three streams and will explore funding to achieve these:

Stream 1 - Established MSDM Community: By providing coherent guidance in the form of published best practice, benchmarks and training materials, we will ensure that the established MSDM community produces outputs that meet minimum agreed standards, improving confidence in MSDMs. Policy makers, management and conservation practitioners will benefit significantly from improved outputs, ensuring that MSDMs develop into the accepted tool that many scientists and policy makers think they can be. We will increase transparency and discoverability of MSDM approaches and input/output data by producing an online data-portal which will be supported and maintained by the University of Rhode Island in perpetuity at no cost to this WG Group. The data-portal will be linked to SCOR resources website for Students and Early Career Scientists and for Scientists and Institutions.

Capacity Building 1: Increased demand for MSDMs following the establishment of best practice and improved stakeholder confidence will lead to further funding and project opportunities for MSDM practitioners around the world.

Capacity Building 2: Continue the WG as an informal or potentially a formal society following completion of WG activities that is devoted to the continued development of MSDMs and practitioners.

Stream 2 - Early Career Scientists (ECSs): We will reduce barriers for early career scientists who aim to adopt MSDMs by providing rigorous training through the development of online courses and the provision of training workshop. This will be a platform for building a network of early career MSDM practitioners who will continue the future development of the approaches with rigorous standards and an understanding of the strengths and weaknesses of approaches. ECSs will have the opportunity to collaborate with experienced practitioners and enhance their scientific networks.

Capacity Building 3: Establish a network for early career researchers, including opportunities to share current work, explore problems and disseminate outputs to potential stakeholders, potentially through email listserv, social media, oceanmodels.org.

Stream 3 - Scientists from Understudied Regions: Much MSDM research has been concentrated in areas around developed countries. Our objectives to produce high quality and freely accessible training materials through online courses, is specifically designed to increase access and uptake to MSDMs by scientists and stakeholders in developing countries and regions of the world that are fundamentally understudied. Linking with the SCOR CCB will enable us to use that experience and expertise to effectively target individuals and institutions who could most benefit from participation. The WG Chair will apply for SCOR CCB travel funds to support this effort.

Capacity Building 4: Explore how to better build links with stakeholders and scientists interested in building MSDMs in understudied regions through working with the SCOR CCB. Providing collaboration, mentorship and expertise to help advance national and international MSDM-related research.

<u>Relationship to other international programs and SCOR Working groups</u>

This working group has arisen from a 2018 workshop on deep-sea species distribution modelling that was co-organized by the EU Horizon 2020 projects SponGES (grant agreement: 679849) and ATLAS (grant agreement: 678760) and supported by the Convention on Biological Diversity and Fisheries and Oceans Canada. This workshop brought together for the first time, global experts working on MSDM in the deep sea, the core of whom are members of this proposed WG. Our discussions noted the need for the continued development of MSDM and establishment of best-practices, particularly due to the increased pressures that are being faced in many ocean ecosystems around the world and set the foundation for the objectives and

deliverables proposed as part of this SCOR WG. We anticipate benefiting from and contributing to major international projects working on marine ecosystems such as the Horizon 2020 iAtlantic project (several members are involved, and iAtlantic may be able to contribute to the working group), global seabed mapping by the Nippon Foundation-GEBCO and the 2021 launch of the UN Decade of Ocean Science for Sustainable Development.

We have built a proposal that brings together a geographically diverse group of internationally recognized scientists and created terms of reference that has potential to have long-lasting influence on our understanding of ocean ecosystems at a global scale and leave a digital legacy as well as a powerful leap forward in capacity development in this field. SCOR offers the international profile and experience in capacity building that is needed to achieve our goals. We note that SCOR has not supported a similar working group in this field, and that MSDMs are a true multi-disciplinary application that benefits from and contributes to multiple sectors of oceanographic and marine biological research.

Working Group composition

Our working group covers an expansive geographic network that reflects the global utility of MSDMs. Please note, due to significant Canadian expertise and interest in MSDMs, we have elected to offer a third tier of membership, Observer Members, to ensure that individuals and agencies who wish to be involved can do so, and not be omitted due to geographic locality.

Full Members

Name	**Gender**	**Place of work**	**Expertise relevant to proposal**
Andrew J Davies	M	USA	Proposed Chair - Oceanographic drivers of distributions, MSDMs, deep-sea data.
Margaret FJ Dolan	F	Norway	Multibeam and habitat mapping, geo-bio interactions, geomorphic characterization.
Piers K Dunstan	M	Australia	Multispecies MSDMs, SAM & RCP, marine data.
Kerry Howell	F	UK	Atlantic MSDMs, marine spatial planning, MPA networks, connectivity.
Ellen Kenchington	F	Canada	MSDMs, international science into policy (e.g. RFMOs, FAO-NANSEN, FAO expert)
Telmo Morato	M	Portugal	Forecasting MSDMs, climate change, anthropogenic impacts.
Ashley Rowden	M	New Zealand	Policy and stakeholder applications of MSDMs, survey planning and integration.

AJ Smit	M	South Africa	Marine biogeography, coastal oceanography, marine data.
Jarno Vanhatalo	M	Finland	Statistician developing MSDMs including joint species SDMs.
Chris Yesson	M	UK	Invasive species, MSDMs, climate refugia, education.

Associate Members

Name	Gender	Place of work	Expertise relevant to proposal
Ward Appeltans	M	Belgium	Species occurrence and marine data, lead of the OBIS database project.
José Manuel González Irusta	M	Spain	Application of MSDM to ecosystem management.
Christian Mohn	M	Denmark	Physical oceanography, hydrodynamic modelling, interfacing across disciplines.
Jose Angel A. Perez	M	Brazil	Diversity and distribution of deep-sea fauna and habitats, anthropogenic impacts
Chris Rooper	M	Canada	MSDM, validation surveys and linkages to management applications
Kisei Tanaka	M	USA	Shallow water MSDMs, climate variability, climate change impacts on biogeography.
Joana Xavier	F	Portugal	Taxonomy, diversity and distribution of deep-sea habitats/VMEs

Observer Members

Name	Gender	Place of work	Expertise relevant to proposal
Lindsay Beazley	F	Canada	MSDMs, marine biodiversity, habitat mapping.
Jessica Finney	F	Canada	Mapping lead at DFO, worked on best-practice guidance for MSDM.
Scott Foster	M	Australia	Development of multispecies statistical models and sampling programs
Kevin Friedland	M	USA	Fisheries expert, MSDM development in data rich regions.

Anders Knudby	M	Canada	MSDM comparison, evaluation, uncertainty estimations
F Javier Murillo	M	Canada	MSDMs, marine biodiversity, habitat mapping.
Emily Rubidge	F	Canada	Species-environment interactions, mapping diversity, ecological connectivity
Rodrigo Sant'Ana	M	Brazil	Bayesian spatial, temporal and spatial-temporal hierarchical models.
Ryan Stanley	M	Canada	Genetically informed SDMs, marine connectivity.
Benjamin Weigel	M	Finland	Joint species distribution models.
Skipton Wooley	M	Australia	Developer of statistical methods to quantify single or multiple species distributions.

Working Group contributions

Andrew J Davies: Has improved global understanding of the distribution of marine species using SDMs and observational techniques, with his work on cold-water coral distribution being amongst the highest cited deep-sea MSDM publications.

Margaret FJ Dolan: Leading analyst of bathymetric data in the context of benthic habitat mapping, who has significantly advanced awareness of marine geomorphometry and the integration of benthic terrain data into modern MSDMs and habitat maps.

Piers K Dunstan: Internationally renowned ecological modeler with specific expertise in the development and application of multispecies distribution models, species archetype models and regions of common profile models.

Kerry Howell: Focuses on the application of MSDM for marine conservation. Currently lead and participant in several international research programs that use MSDM for Atlantic-wide marine spatial planning.

Ellen Kenchington: Significant experience in providing advice at an international level, to managers and policy makers, regarding marine spatial planning and the application of MSDMs to vulnerable marine ecosystems.

Telmo Morato: Focused on the development of MSDMs for deep-sea fish species and habitats. Currently leading international efforts to map how species distributions will change under future climate conditions.

Ashley Rowden: Internationally leading researcher, with interests including the use of MSDM to inform policy and stakeholders. Substantial experience in planning surveys to best take advance of MSDM techniques in logistically challenging environments.

AJ Smit: Expertise in coastal systems modelling, marine biogeography and environmental data layer development for MSDMs.

Jarno Vanhatalo: Statistician with experience in developing predictive models and MSDM in multiple marine habitats.

Chris Yesson: Substantial experience in the field of MSDM, with data products used in a variety of conservation and management settings including defining EBSAs in NE Atlantic. Taught SDM workshops in 6 countries and has supervised numerous research students in this field.

References

Asjes A et al. (2016) Age-related and seasonal changes in haddock *Melanogrammus aeglefinus* distribution: implications for spatial management. Mar Ecol Prog Ser 553: 203-217

Auster PJ et al. (2011) Definition and detection of vulnerable marine ecosystems on the high seas: problems with the" move-on" rule. ICES J Mar Sci 68: 254-264

Danovaro R et al. (2014) Challenging the paradigms of deep-sea ecology. Trends Ecol Evol 29: 465-475

Davies AJ et al. (2007) Preserving deep-sea natural heritage: Emerging issues in offshore conservation and management. Bio Conserv 138: 299-312

Foster SD et al. (2015) The cumulative effect of trawl fishing on a multispecies fish assemblage in south-eastern Australia. Journal of Animal Ecology 52: 129-139

González-Irusta JM, Wright PJ (2015) Spawning grounds of Atlantic cod (*Gadus morhua*) in the North Sea. ICES J Mar Sci 73: 304-315

Gormley KSG et al. (2014) Can management effort be predicted for marine protected areas? New considerations for network design. Marine Policy 47: 138-146

Guisan A, Zimmermann NE (2000) Predictive habitat distribution models in ecology. Ecol Model 135: 147-186

Hooker SK et al. (2011) Making protected area networks effective for marine top predators. Endangered Species Research 13: 203-218

Howell K-L et al. 2016. The distribution of deep-sea sponge aggregations in the North Atlantic and implications for their effective spatial management. Deep Sea Research Part I: Oceanographic Research Papers 115, 309-320.

Jueterbock A et al. (2013) Climate change impact on seaweed meadow distribution in the North Atlantic rocky intertidal. Ecology and Evolution 3: 1356-1373

Loots C et al. (2011) Understanding what controls the spawning distribution of North Sea whiting (*Merlangius merlangus*) using a multi-model approach. Fisheries Oceanography 20: 18-31

Ramirez-Llodra E et al. (2010) Deep, diverse and definitely different: unique attributes of the world's largest ecosystem. Biogeosciences 7: 2851-2899

Robinson LM, Elith J, Hobday AJ, Pearson RG, Kendall BE, Possingham HP, Richardson AJ (2011) Pushing the limits in marine species distribution modelling: lessons from the land present challenges and opportunities. Global Ecology and Biogeography 20: 789-802

Robinson NM et al. (2017) A Systematic Review of Marine-Based Species Distribution Models (SDMs) with Recommendations for Best Practice. Frontiers in Marine Science 4
Schibalski A et al. (2018) Novel model coupling approach for resilience analysis of coastal plant communities. Ecological Applications 28: 1640-1654
Tanaka KR et al. (2017) A statistical model for monitoring shell disease in inshore lobster fisheries: A case study in Long Island Sound. PloS one 12: e0172123
Thomas Y, Bacher C (2018) Assessing the sensitivity of bivalve populations to global warming using an individual-based modelling approach. Global Change Biology 24: 4581-4597
Vierod ADT et al. (2014) Predicting the distribution of vulnerable marine ecosystems in the deep sea using presence-background models. Deep Sea Research Part II: Topical Studies in Oceanography 99: 6-18
Yesson C et al. (2012) Global habitat suitability of cold-water octocorals. J Biogeogr 39: 1278-1292

Appendix

For each Full Member, five key publications related to the proposal:

Andrew J Davies

Davies, A., Guinotte, J. 2011. Global Habitat Suitability for Framework-Forming Cold-Water Corals. PLoS ONE 6.

Davies, A.J., Duineveld, G.C.A., Lavaleye, M.S.S., Bergman, M.J.N., Van Haren, H., Roberts, J.M. 2009. Downwelling and deep-water bottom currents as food supply mechanisms to the cold-water coral *Lophelia pertusa* (Scleractinia) at the Mingulay Reef Complex. Limnology and Oceanography 54, 620-629.

Davies, A.J., Wisshak, M., Orr, J.C., Roberts, J.M. 2008. Predicting suitable habitat for the cold-water reef framework-forming coral *Lophelia pertusa* (Scleractinia). Deep Sea Research Part I: Oceanographic Research Papers 55, 1048-1062.

Guinotte, J.M., Davies, A.J. 2014. Predicted deep-sea coral habitat suitability for the US West Coast. PLoS ONE 9, e93918.

Vierod, A.D.T., Guinotte, J.M., Davies, A.J. 2014. Predicting the distribution of vulnerable marine ecosystems in the deep sea using presence-background models. Deep Sea Research Part II: Topical Studies in Oceanography 99, 6-18.

Margaret FJ Dolan (Wilson)

Dolan, M.F.J., Grehan, A.J., Guinan, J.C., Brown, C. 2008. Modelling the local distribution of cold-water corals in relation to bathymetric variables: Adding spatial context to deep-sea video data. Deep-Sea Research Part I-Oceanographic Research Papers 55, 1564-1579.

Dolan, M.F.J, Lucieer, V.L. 2014. Variation and uncertainty in bathymetric slope calculations using geographic information systems. Marine Geodesy 37(2) 187- 219.

Guinan, J., Grehan, A.J., Dolan, M.F.J., Brown, C. 2009. Quantifying relationships between video observations of cold-water coral cover and seafloor features in Rockall Trough, west of Ireland. Marine Ecology-Progress Series 375, 125-138.

Lecours, V., Dolan, M.F.J., Micallef, A., Lucieer, V.L. 2016. A review of marine geomorphometry, the quantitative study of the seafloor. Hydrology and Earth System Sciences 20, 3207.

Wilson, M.F.J., O'Connell, B., Brown, C., Guinan, J.C., Grehan, A.J. 2007. Multiscale terrain analysis of multibeam bathymetry data for habitat mapping on the Continental Slope. Marine Geodesy 30, 3-35.

Piers K Dunstan

Dunstan, P.K., Foster, S.D., Hui, F.K.C., Warton, D.I. 2013. Finite Mixture of Regression Modelling for High-Dimensional Count and Biomass Data in Ecology. Journal of Agricultural, Biological, and Environmental Statistics 18, 357-375.

Dunstan, P.K., Foster, S.D., King, E., Risbey, J., O'kane, T.J., Monselesan, D., Hobday, A.J., Hartog, J.R., Thompson, P.A. 2018. Global patterns of change and variation in sea surface temperature and chlorophyll a. Sci Rep 8, 14624.

Foster, S.D., Dunstan, P.K., Althaus, F., Williams, A. 2015. The cumulative effect of trawl fishing on a multispecies fish assemblage in south-eastern Australia. Journal of Animal Ecology 52, 129-139.

Jansen, J., Hill, N.A., Dunstan, P.K., Mckinlay, J., Sumner, M.D., Post, A.L., Eleaume, M.P., Armand, L.K., Warnock, J.P., Galton-Fenzi, B.K., Johnson, C.R. 2018. Abundance and richness of key Antarctic seafloor fauna correlates with modelled food availability. Nat Ecol Evol 2, 71-80.

Leaper, R., Dunstan, P.K., Foster, S.D., Barrett, N.S., Edgar, G.J. 2014. Do communities exist? Complex patterns of overlapping marine species distributions. Ecology 95, 2016-2025.

Kerry Howell

Howell, K.-L., Piechaud, N., Downie, A.-L., Kenny, A. 2016. The distribution of deep-sea sponge aggregations in the North Atlantic and implications for their effective spatial management. Deep Sea Research Part I: Oceanographic Research Papers 115, 309-320.

Marshall, C.E., Glegg, G.A., Howell, K.L. 2014. Species distribution modelling to support marine conservation planning: the next steps. Marine Policy 45, 330-332.

Piechaud, N., Downie, A., Stewart, H.A., Howell, K.L. 2015. The impact of modelling method selection on predicted extent and distribution of deep-sea benthic assemblages. Earth and Environmental Science Transactions of The Royal Society of Edinburgh 105, 251-261.

Ross, L.K., Ross, R.E., Stewart, H.A., Howell, K.L. 2015. The influence of data resolution on predicted distribution and estimates of extent of current protection of three 'listed' deep-sea habitats. PLoS ONE 10, e0140061.

Ross, R.E., Howell, K.L. 2013. Use of predictive habitat modelling to assess the distribution and extent of the current protection of 'listed' deep-sea habitats. Diversity and Distributions 19, 433-445.

Ellen Kenchington

Beazley, L., Wang, Z., Kenchington, E., Yashayaev, I., Rapp, H.T., Xavier, J.R., Murillo, F.J., Fenton, D., Fuller, S. 2018. Predicted distribution of the glass sponge *Vazella pourtalesi* on the Scotian Shelf and its persistence in the face of climatic variability. PLoS ONE 13, e0205505.

Kenchington, E., Beazley, L., Lirette, C., Murillo, F.J., Guijarro, J., Wareham, V., Gilkinson, K., Koen-Alonso, M., Benoît, H., Bourdages, H. 2016. Delineation of coral and sponge significant benthic areas in Eastern Canada using Kernel Density Analyses and Species Distribution Models. Canadian Science Advisory Secretariat.

Kenchington, E., Callery, O., Davidson, F., Grehan, A., Morato, T., Appiott, J., Davies, A.J., Dunstan, P.K., Du Preez, C., Finney, J., González-Irusta, J.M., Howell, K.L., Knudby, A., Lacharité, M., Lee, J., Murillo, F.J., Beazley, L., Roberts, J.M., Roberts, E.M.T., Rowden, A., Rubige, E., Stanley, R., Stirling, D., Tanaka, K.R., Vanhatalo, J., Weigel, B., Wooley, S., Yesson, C. 2019. Use of Species Distribution Modelling in the Deep Sea. Canadian Technical Report of Fisheries and Aquatic Sciences 3296: ix + 76 p.

Knudby, A., Kenchington, E., Murillo, F.J. 2013. Modelling the distribution of *Geodia* sponges and sponge grounds in the Northwest Atlantic. PLoS ONE 8, e82306.

Murillo, F.J., Kenchington, E., Tompkins, G., Beazley, L., Baker, E., Knudby, A., Walkusz, W. 2018. Sponge assemblages and predicted archetypes in the eastern Canadian Arctic. Marine Ecology Progress Series 597, 115-135.

Telmo Morato

Fulton, B., Morato, T., Pitcher, T.J. 2007. Modelling seamount ecosystems and their fisheries.

Seamounts: Ecology, Fisheries and Conservation. Fisheries and Aquatic Resource Series, Blackwell Scientific 296-332.
Gollner, S., Kaiser, S., Menzel, L., Jones, D.O.B., Brown, A., Mestre, N.C., Van Oevelen, D., Menot, L., Colaço, A., Canals, M. 2017. Resilience of benthic deep- sea fauna to mining activities. Marine Environmental Research 129, 76-101.
Morato, T., Watson, R., Pitcher, T.J., Pauly, D. 2006. Fishing down the deep. Fish and Fisheries 7, 24-34.
Morato, T., Dominguez-Carrió, C., Davies, A.J., Carreiro-Silva, M., Sweetman, A., Wei, C.L. 2019. Pilot modelling of the habitat suitability of VME indicator taxa under future climate scenarios, in two RFMOs. Pages 104-120 in Levin L, Baker M, Thompson A, eds. Deep-ocean climate change impacts on habitat, fish and fisheries, FAO Fisheries and Aquaculture Technical Paper No. XX. Rome, FAO.
Parra, H.E., Pham, C.K., Menezes, G.M., Rosa, A., Tempera, F., Morato, T. 2017. Predictive modelling of deep-sea fish distribution in the Azores. Deep Sea Research Part II: Topical Studies in Oceanography 145, 49-60.

Ashley Rowden

Anderson, O.F., Guinotte, J.M., Rowden, A.A., Clark, M.R., Mormede, S., Davies, A.J., Bowden, D.A. 2016. Field validation of habitat suitability models for vulnerable marine ecosystems in the South Pacific Ocean: implications for the use of broad- scale models in fisheries management. Ocean & Coastal Management 120, 110- 126.
Georgian, S.E., Anderson, O.F., Rowden, A.A. 2019. Ensemble habitat suitability modelling of vulnerable marine ecosystem indicator taxa to inform deep-sea fisheries management in the South Pacific Ocean. Fisheries Research, 211, 256- 274
Rowden, A.A, Anderson, O.F, Georgian, S.E., Bowden, D.A, Clark, M.R., Pallentin, A. Miller A. 2017. High-resolution habitat suitability models for the conservation and management of vulnerable marine ecosystems on the Louisville Seamount Chain, South Pacific Ocean. Frontiers in Marine Science. 4:335.
Rowden, A.A., Stephenson, F., Clark, M.R., Anderson, O.F., Guinotte, J.M., Baird, S.J., Roux, M.J., Wadhwa, S., Cryer, M., Lundquist, C.J. 2019. Examining the utility of a decision-support tool to develop spatial management options for the protection of vulnerable marine ecosystems on the high seas around New Zealand. Ocean & Coastal Management 170, 1-16.
Tittensor, D.P., Baco, A.R., Brewin, P.E., Clark, M.R., Consalvey, M., Hall- Spencer, J., Rowden, A.A., Schlacher, T., Stocks, K.I., Rogers, A.D. 2009. Predicting global habitat suitability for stony corals on seamounts. Journal of Biogeography 36, 1111-1128.

AJ Smit

De Lecea, A.M., Cooper, R., Smit, A.J. 2016. Identifying the drivers of the pelagic ecosystem of an oligotrophic bight (KwaZulu–Natal, South Africa) using stable isotopes (δ13C, δ15N) and C: N ratio analysis. Marine and Freshwater Research 67, 1750-1761.
García-Reyes, M., Sydeman, W.J., Schoeman, D.S., Rykaczewski, R.R., Black, B.A., Smit, A.J., Bograd, S.J. 2015. Under pressure: Climate change, upwelling, and eastern boundary upwelling ecosystems. Frontiers in Marine Science 2, 109.
Livingstone, T.C., Harris, J.M., Lombard, A.T., Smit, A.J., Schoeman, D.S. 2018. Classification of marine bioregions on the east coast of South Africa. African Journal of Marine Science 40, 51-65.

Smit, A.J., Bolton, J.J., Anderson, R.J. 2017. Seaweeds in two oceans: beta- diversity. Frontiers in Marine Science 4, 404.
Smit, A.J., Roberts, M., Anderson, R.J., Dufois, F., Dudley, S.F.J., Bornman, T.G., Olbers, J., Bolton, J.J. 2013. A coastal seawater temperature dataset for biogeographical studies: large biases between in situ and remotely-sensed data sets around the coast of South Africa. PLoS ONE 8, e81944.

Jarno Vanhatalo

Bakka, H., Vanhatalo, J., Illian, J.B., Simpson, D., Rue, H. 2019. Non-stationary Gaussian models with physical barriers. Spatial Statistics.
Kallasvuo, M., Vanhatalo, J., Veneranta, L. 2016. Modelling the spatial distribution of larval fish abundance provides essential information for management. Canadian Journal of Fisheries and Aquatic Sciences 74, 636-649.
Kotta, J., Vanhatalo, J., Jänes, H., Orav-Kotta, H., Rugiu, L., Jormalainen, V., Bobsien, I., Viitasalo, M., Virtanen, E., Sandman, A.N. 2019. Integrating experimental and distribution data to predict future species patterns. Scientific Reports 9, 1821.
Mäkinen, J., Vanhatalo, J. 2018. Hierarchical Bayesian model reveals the distributional shifts of Arctic marine mammals. Diversity and Distributions 24, 1381- 1394.
Vanhatalo, J., Hosack, G.R., Sweatman, H. 2017. Spatiotemporal modelling of crown-of-thorns starfish outbreaks on the Great Barrier Reef to inform control strategies. Journal of Applied Ecology 54, 188-197.

Chris Yesson

Fernandez, M., Yesson, C., Gannier, A., Miller, P.I., Azevedo, J.M.N. 2017. The importance of temporal resolution for niche modelling in dynamic marine environments. Journal of Biogeography 44, 2816-2827.
Gallardo, B., Aldridge, D.C., González-Moreno, P., Pergl, J., Pizarro, M., Pyšek, P., Thuiller, W., Yesson, C., Vilà, M. 2017. Protected areas offer refuge from invasive species spreading under climate change. Global Change Biology 23, 5331-5343.
Yesson, C., Bedford, F., Rogers, A.D., Taylor, M.L. 2017. The global distribution of deep-water Antipatharia habitat. Deep Sea Research Part II: Topical Studies in Oceanography 145, 79-86.
Yesson, C., Bush, L.E., Davies, A.J., Maggs, C.A., Brodie, J. 2015. The distribution and environmental requirements of large brown seaweeds in the British Isles. Journal of the Marine Biological Association of the United Kingdom 95, 669-680.
Yesson, C., Taylor, M.L., Tittensor, D.P., Davies, A.J., Guinotte, J., Baco, A., Black, J., Hall-Spencer, J.M., Rogers, A.D. 2012. Global habitat suitability of cold- water octocorals. Journal of Biogeography 39, 1278-1292.

DISCOVER-C:
DIagnoSis of Carbon in the Ocean: Variability, uncERtainty and the Coasts

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1. Summary

A number of recent studies have applied novel statistical and machine-learning methods to *in situ* surface ocean carbon dioxide (CO_2) observations to estimate the ocean carbon sink with unprecedented spatio-temporal resolution. These studies suggest that the oceanic CO_2 sink for carbon dioxide is more variable on multiyear timescales than previously estimated from biogeochemical model simulations. This newly-identified variability challenges our model-based mechanistic understanding, and puts into question our projections of the future ocean carbon sink. These observation-based estimates, however, rely on extensive interpolation of limited observations, and thus their reliability is unclear, particularly in data-sparse regions and seasons. Furthermore, inconsistencies regarding the ocean area covered by open and coastal ocean estimates hampers our ability to constrain CO_2 fluxes across the full aquatic continuum. The goal of this working group will be to assess critical uncertainties in existing data-based products, determine how best to integrate observation-based open ocean and coastal ocean estimates of CO_2 air-sea fluxes, and evaluate the impacts of CO_2 release associated with river discharge. These efforts will lead to better constraints on the contemporary ocean carbon sink and its variability. The results of this SCOR Working Group will assist the global carbon community in informing the 5-yearly global update of progress toward fulfilling the UNFCCC Paris Agreement, and thus contribute to sustainable development goal (SDG) 13. It will also provide guidance where we lack essential knowledge to assess the rate of ocean acidification and the saturation states of aragonite and calcite, which are direct indicators (SDG 14.3.1) for the wellbeing of marine life, related to SDG 14.

2. Scientific Background and Rationale

Global assessments suggest that, in the past decade, the ocean has annually taken up about 25% of the CO_2 emitted by human activities (Le Quéré et al. 2018) which, in turn, leads to ocean

acidification harmful for entire ecosystems. Despite the ocean's crucial role, we still lack essential knowledge regarding variability of ocean carbon uptake in time and space. Without building up this knowledge towards the first UN stocktake in 2023, where the collective progress of all countries in reducing emissions will be established, we might be unable to measure the success of the Paris Agreement (Peters et al. 2017).

For many years, the strength of the ocean CO_2 sink has been estimated using ocean forward models that have been tuned to match a variety of observational estimates for the 1990s and the cumulative uptake over the industrial period. These models reproduce the increase in the surface ocean partial pressure of CO_2 (pCO_2) that is expected from the increase in anthropogenic CO_2 in the atmosphere and indicate only small to moderate climate variability around the anthropogenic trend. If this is the case, then the observed variations in the atmospheric growth rate of CO_2 must be due almost exclusively to variability in the land sink. Recently, the Global Carbon Project reported that we are unable to balance the global carbon budget, finding a residual term of ~0.5 PgC yr^{-1} (or roughly 5% of current fossil fuel emissions) remains (Le Quéré et al. 2018). Despite the fact that the ocean sink is better constrained than the land sink, we cannot exclude the ocean as a possible source for this substantial discrepancy.

Over the past decade, the number of publicly available surface ocean CO_2 observations has increased rapidly from 6 million in the first release of the Surface Ocean CO_2 Atlas (SOCAT) database (Pfeil et al. 2013, Bakker et al. 2014, Bakker et al. 2016) in 2011 to 23 million data in 2018. These valuable observations and synthesis effort have enabled scientists around the world to create a variety of new observation-based estimates of the ocean carbon sink, taking advantage of novel data-interpolation techniques based on statistics and machine-learning to fill observational gaps. These studies suggest much stronger variability on interannual to decadal timescales than earlier model estimates (Rödenbeck et al. 2015, Landschützer et al. 2016, Gregor et al. 2018, Le Quéré et al. 2018), calling into question both the mechanistic understanding gained from ocean models, and our ability to precisely predict the future ocean carbon sink (Figure 1). These surface ocean CO_2-based estimates, however, suffer from heterogeneous data distribution and large ocean regions with little data coverage. A study by Rödenbeck et al. (2015) highlights that substantial differences of up to 1 PgC yr^{-1} occur between methods, i.e. twice the current carbon budget imbalance, highlighting the need to better constrain observation-based air-sea CO_2 fluxes.

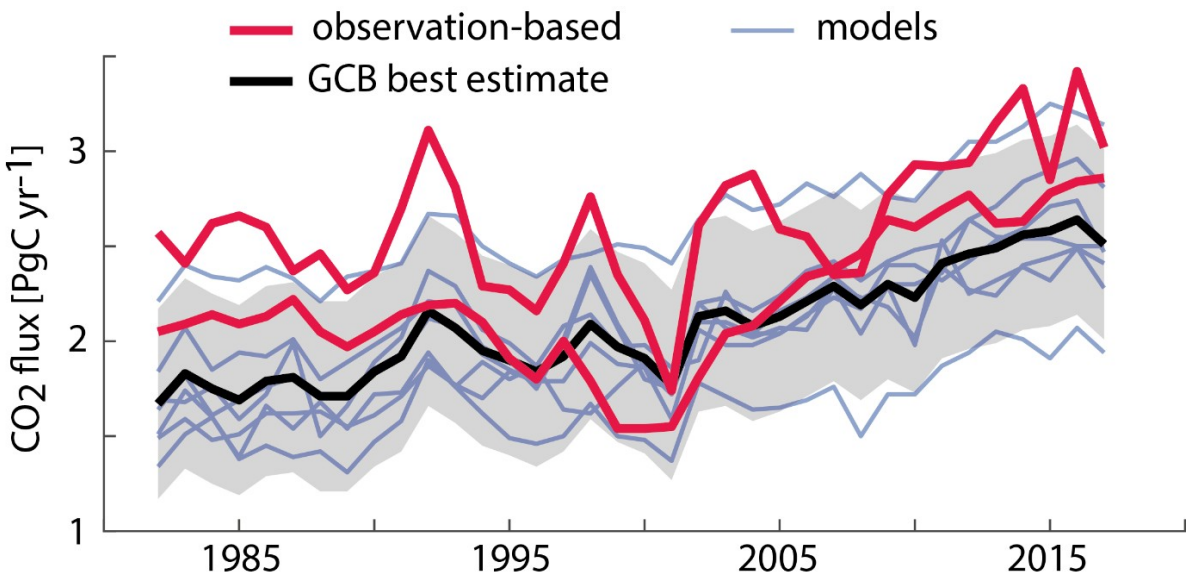

Figure 1: Air-sea CO2 exchange and its difference between different methods from Le Quéré et al. (2018). Observation-based estimates are highlighted in red, model-based estimates are in grey and the Global Carbon Budget best estimate with uncertainty shading is highlighted in black.

Substantial discrepancies do not only exist between observation-based estimates due to methodological differences (see e.g. Figure 1), but further as a result of differences in the ocean regions covered by observation-based estimates (Rödenbeck et al 2015). The majority of surface ocean CO_2 measurement-based methods do not include significant carbon sinks such as the Arctic Ocean and coastal waters. Yet, the polar oceans as well as the Eastern Boundary upwelling systems (Gruber et al. 2012) will be among the first ocean regions to experience critical declines in ocean pH. We are in desperate need to close this gap and investigate the role of these regions before we can compare products and provide a best global ocean carbon sink constraint. While there have been recent developments in constraining the coastal ocean CO_2 fluxes (Laruelle et al. 2017) and Arctic Ocean CO_2 fluxes (Yasunaka et al. 2016), these have not yet been integrated with the global ocean flux products.

Another issue is that the area of the ocean represented in the different approaches varies significantly. Based on the 1° x 1° global ocean mask of RECCAP (Canadell et al. 2011), ocean models cover 89-99% of the total ocean area. The data-based products include only 77-87%, often leaving out much of the Southern Ocean, a region of significant carbon uptake (Gruber et al. 2019). These differences alone lead to global mean flux discrepancies of up to 0.5 PgC yr^{-1}. The Global Carbon Budget (Le Quéré et al. 2018) has not addressed these masking issues, instead attribute mean differences between modelled and observation-based estimates to riverine inputs of natural carbon from 0.45 to 0.78 PgC yr^{-1} (Jacobson et al. 2007, Resplandy et al. 2018).

In summary, there are a wide range of issues – coastal, riverine, masking - that need to be resolved. All these issues impact the quality of our current estimates of the ocean carbon sink,

both of its mean and its variability. These issues require expert attention and the development of clear recommendations that can support more reliable diagnoses in the years to come.

There are currently several active efforts to assess recent ocean carbon fluxes and placing these in context with the global anthropogenic carbon cycle, such as the REgional Carbon Cycle Assessment and Processes phase 2 (RECCAP2) (https://www.reccap2-gotemba2019.org), the Global Carbon Project's annual Global Carbon Budget (Le Quéré et al. 2018), and the IPCC AR6 assessment. As the primary goal of these ongoing assessments is to integrate ocean fluxes into a global carbon cycle meta-analyses, these projects will have the time to put focused attention on accounting for inconsistencies between ocean flux estimates. This is why this effort is needed. This working group will support these other efforts by understanding and remedying methodological discrepancies and quantifying the resulting uncertainty.

As we improve our diagnosis of ocean carbon fluxes based on models and existing data, new data streams based on autonomous measuring devices (such as Biogeochemical Argo (BGC-Argo) floats) have emerged. There is great potential from these data, but better understanding of the impacts of adding new data with different error statistics is required for robust product development. Further, discrepancies between open-ocean and coastal ocean estimates that this WG identifies will provide important direction for future field campaigns.

The United Nations has presented 17 sustainable development goals (SDG) from which SDG 14 (Life below water) and SDG 13 (Climate action) will directly benefit from this working group. We will better constrain the representation of internal or forced variability based on the to-date most reliable air-sea CO_2 flux estimates from observations and models. These estimates are critical to assessing how changes in anthropogenic emissions are impacting atmospheric CO_2 concentration and thus are a critical component of the 5-yearly global stocktake under article 14 of the UNFCCC Paris Agreement with the first stocktake in 2023. For climate pledges to be renewed and strengthened, it is important that the global carbon science community be able to quantify natural carbon sources and sinks accurately.

Better quantification of past, present and future carbon fluxes will also improve estimates of trends in ocean acidification and the saturation states of aragonite and calcite, which are direct indicators (SDG 14.3.1) for the wellbeing of marine life. Combining available air-sea CO_2 flux estimates from models, open ocean, coastal and marginal sea products to enhance our ability to monitor the changing carbon state of the ocean is the only way to monitor our progress toward this critical development goal.

In this SCOR Working Group (WG) we will 1) compare monthly estimates of ocean carbon uptake and estimate uncertainties, 2) determine how to integrate coastal and open ocean air- sea CO_2 fluxes, 3) make recommendations for improving estimates of global ocean carbon uptake (Section 3).

3. Terms of Reference

Objective 1: Compare air-sea CO_2 fluxes standardized at monthly temporal and 1º x 1º spatial resolution and estimate uncertainties. We will:

1. Gather and compare publicly available estimates of global and regional air-sea CO_2 fluxes based on *in situ* surface ocean observations and numerical models
2. Identify differences in ocean mask, riverine carbon input, treatment of ice-covered regions and resolution and the effect of these on CO_2 air-sea flux estimates
3. Assess uncertainty based on the spread across these estimates, and recommend more sophisticated approaches for formal uncertainty quantification

Objective 2: Determine how to integrate CO_2 air-sea flux estimates for the coastal seas, Arctic Ocean and open oceans. We will discuss the following issues that complicate integration of coastal fluxes with open ocean fluxes, and determine an optimal approach.

1. Coastal and Arctic Ocean flux estimates overlap in space with open ocean estimates in some areas, while there are gaps elsewhere.
2. Coastal flux estimates do not include variability beyond the seasonal cycle, while open ocean fluxes also have interannual variability.

Objective 3: Recommend a path forward to improve air-sea CO_2 flux estimates. We will:

1. Identify the regions and seasons where additional observations will most improve regional and global flux estimates
2. Make recommendations with respect to integration of BGC-Argo floats into a surface ocean CO_2 monitoring system
3. Combine observation-based CO_2 flux estimates with model output to improve our mechanistic understanding regarding the air-sea flux variability in time

4. Working Plan

Expected start: January 2020

Month 1 until month 6: In order to deliver the 3 objectives, the working group will contact representatives of the Global Carbon Project, RECCAP2, the large modelling centres and the providers of observation-based air-sea flux estimates (e.g., via the Surface Ocean CO_2 Mapping project (SOCOM), but also newer estimates that are not yet included in SOCOM) to gather the most up to date air-sea CO_2 flux estimates. Full Members of this proposed WG are directly involved with each of these projects, and thus we don't expect this process to take more than 6 months.

During the data-gathering phase, we will hold the first working group meeting, bringing together representatives from the measurement, modelling, and global carbon budget analysis

communities. We propose to organize this meeting during the Ocean Sciences meeting in February 2020 in San Diego, USA, and to discuss the following issues:

- The current availability and methodologies implemented to create the suite of data-based products and the suite of hindcast models. Each participant will be asked to lead discussion for one or more data-based products or models.
- Masking issues, riverine carbon inputs and coastal CO_2 fluxes, and other pressing first steps in comparing flux estimates globally and regionally.

The main goal of the meeting is for the community to understand and discuss the methodological discrepancies between data-based open ocean and coastal ocean CO_2 flux products as well as model output in order to **fulfill Objective 1 of the working group**.

Month 6 until month 18:

After the data gathering phase, the working group will **proceed to examine Objective 2**. A detailed plan will be developed to best integrate data-based flux estimates for the open ocean, coastal ocean and other regions, such as the Arctic Ocean. Bi-monthly, i.e. every two months, teleconferences will be held in order to work towards common metrics to combine and evaluate these estimates.

The group will establish ways to best represent uncertainties of the air-sea CO_2 flux, e.g. based on random subsampling or bootstrapping approaches, using synthetic data from internally consistent output from ocean model simulations and by examining the spread between the different observational data interpolation approaches. Furthermore, the working group will discuss ways to best incorporate shipboard measurements in combination with sensor data from autonomous platforms such as BGC Argo floats. We further plan to make these merged best-estimate products based on measurements available to the public and directly transfer our results to intercomparison studies such as RECCAP2 and global budget analyses such as the GCB. Furthermore, a revised observation-based air-sea CO_2 flux estimate including open ocean, coastal ocean and Arctic Ocean, will be submitted to an open-access peer- reviewed journal, **completing Objective 2 of the working group**.

Month 18 until month 30:

Following the first working group meeting in San Diego, two additional key conferences will be identified, to which the majority of working group members are planning to travel. We suggest combining the working group meetings with other conferences to keep our carbon footprint as low as possible. The 11^{th} International Carbon Dioxide Conference (ICDC11) in late 2021 is a possible venue for the next second WG meeting. The location of ICDC11 is not yet determined, and as our goal is to spread the meetings geographically, we will have to determine if this is the best choice once the location is announced.

A side-event will be organized at the 11th International Carbon Dioxide Conference meeting in late 2021 (or at the alternative venue) for the second working group meeting, where the revised observation-based air-sea flux, including the uncertainty estimates, will be presented. We further plan to liaise with IOCCP to co-host a hands-on workshop that will introduce other scientists to the methodologies being used to upscale sea surface pCO_2 observations. This will provide them with hands-on experience in the creation and best use of available air-sea CO_2 flux estimates. We further intend to provide tools for analysis of the suite as well as their uncertainty calculation.

Once we have established a set of merged observation-based air-sea CO_2 flux estimates that cover a consistent global ocean area, the working group will continue to combine these with state-of-the-art biogeochemical models in order to identify remaining regional and temporal discrepancies that were not originally linked to area differences, **so as to address Objective 3**. The working group will establish where these differences occur on the regional level and whether these differences can be linked to data paucity. At this stage, we will start and subsample process model output to perform Observing System Simulation Experiments (OSSEs) using the available mapping methods in order to identify key regions where observations are essential to reduce the uncertainty in our best air-sea flux estimate. Bi- monthly teleconferences will be held to coordinate this effort.

Month 30 until Month 42:

The working group will meet for its 3rd and last time at a conference in the Asia/Oceania region. We aim to organise a conference session, where the results of the observation-based CO_2 flux and model CO_2 flux intercomparison study will be presented. We will also present the revised best marine carbon sink estimate and we will communicate where the observing system simulations identified the need to further collect surface ocean CO_2 measurements. Using the revised air-sea flux estimate we will further examine the remaining global carbon budget imbalance.

As a last step, **to fulfil Objective 3**, the working group will examine the temporal variability of the air-sea exchange using both the new consistent global observation-based flux estimates and a suite of ocean biogeochemical models. The new combined observation-based estimates will allow a fair comparison between data and models. The working group will focus on the amplitude of the interannual-to-decadal variability in the air-sea CO_2 exchange. Furthermore, combining both observations and models, the working group will investigate the drivers of the dominant modes of variability, providing a realistic estimate of the expected variations in the ocean carbon sink on top of the anthropogenic forcing for the UN stocktake period. Bi-monthly teleconferences will be held to coordinate this effort.

Month 42 until month 48:

The results of the observing system simulations and data-model comparison study will be submitted to an open access journal. This article will also serve as a new standard for data-

model intercomparison and its results will be directly communicated to the GCP and RECCAP2.

5. Deliverables

The discussions of this working group will be critical to the development of several key open-access scientific publications from the WG members and their collaborators. These publications are well-aligned with the individual research directions of the WG members, which will support their timely completion. The fact that this WG will allow for a broader engagement of the community than would otherwise be possible will enhance their scope. These publications will be comprehensive guidelines that can push forward our community's efforts in diagnosis of the ocean carbon sink and its variability. These publications will:

1. Identify the impacts of differences in ocean mask, riverine carbon input, treatment of ice-covered regions on CO_2 air-sea flux estimates; assess uncertainty based on the spread across estimates; and recommend standard operational procedures (SOPs) for the integration and formal uncertainty quantification of observation-based air-sea CO_2 flux estimates.
2. Integrate open ocean with Arctic Ocean and coastal ocean air-sea CO_2 fluxes and create a first fully global observation-based air-sea flux estimate.
3. Use model experiments to locate ocean regions where large flux discrepancies are driven by data paucity, and thus illustrate where additional CO_2 measurements are essential to better constrain the ocean carbon uptake. The role for BGC-Argo floats in filling these holes will be addressed.
4. Constrain the origin and magnitude of interannual air-sea CO_2 flux variability and work towards reducing the global carbon budget imbalance.

6. Capacity Building

The working group will **provide standard operational procedures (SOPs)** combining observation-based estimates from various sources (open ocean, coast, Arctic Ocean) providing the baseline for a representative global air-sea CO_2 flux product. This will provide the baseline for future intercomparison studies such as RECCAP2, the global carbon budget and future studies to come.

At our second meeting, we will host a 1-day training workshop for early-career scientists and others that will introduce the range of methodologies being used to interpolate sparse in situ pCO_2 data to full coverage estimates. IOCCP will be asked to assist in this activity. Uncertainty estimation will be discussed. We will provide basic analysis scripts and provide time for discussion on important directions for detailed analyses. This workshop will increase the community of scientists who are knowledgeable about how these data-based products are created, but so that they can become more knowledgeable users and also so they can apply these techniques to their own data sets.

This first fully global observation-based air-sea CO_2 flux product provides the **baseline for ocean acidification studies** as the surface ocean pH can be directly inferred from the surface ocean pCO_2 in combination with salinity-based total alkalinity estimates (Lauvset et al. 2015). This is highly **relevant for the UN SDG 14** and for monitoring trends in marine ecosystem stressors.

Combining observation-based estimates with process model output will **provide valuable insight into the drivers and magnitude** of the interannual to decadal variability. This will **directly benefit the WCRP grand challenge on Carbon Feedbacks in the Climate System** and will build towards improved future CO_2 flux predictions.

The working group efforts are further well-aligned with the first stages of the UN Decade for the Ocean Science for Sustainable Development (2021-2030) and will **build toward** a more better constrained ocean carbon sink, which is a necessary requirement **for the UN stocktake periods** and monitoring the success of the Paris climate accord.

7. Working Group Composition

7.1 Full Members (chairs are highlighted in bold letters)

Name	Gender	Place of Work	Expertise
1 Peter Landschützer	**M**	**Max Planck Institute for Meteorology, Hamburg, Germany**	**Expert in observation-based air-sea flux estimates, open ocean carbon cycle and its variability**
2 Galen A. McKinley	**F**	**LDEO and Columbia University, New York, USA**	**Expert in mechanisms of air-sea CO_2 flux variability; models and data**
3 Dorothee C. E. Bakker	F	UEA, Norwich, United Kingdom	Lead-scientist in the Surface Ocean CO_2 Atlas (SOCAT) data synthesis effort
4 Shin-ichiro Nakaoka	M	NIES, Tsukuba, Japan	Expert in CO_2 observations, CO_2 mapping and marine carbon cycle
5 Sara Mikaloff Fletcher	F	National Institute of Water and Atmospheric research, Wellington, New	Global biogeochemical cycles of CO_2 and other trace gases as well as ocean acidification
6 Pedro Monteiro	M	Southern Ocean Carbon-Climate Observatory (SOCCO), CSIR, Cape Town, South Africa	Expert in observing, modelling and assessing variability and trends of surface ocean CO_2 fluxes through the seasonal cycle

7 Raphaëlle Sauzède	F	Laboratory of Oceanography of Villefranche, Villefranche-Sur- Mer, France	Expert in interpreting biogeochemical Argo data, global data analysis and synthesis
8 Goulven G. Laruelle	M	Université Libre de Bruxelles, Bruxelles, Belgium	Expert in observation-based coastal ocean CO_2 mapping and the coastal ocean carbon cycle
9 Leticia Cotrim da Cunha	F	Universidade do Estado do Rio de Janeiro Faculdade de Oceanografia, Rio de Janiero, Brazil	Coastal and open ocean biogeochemistry, CO_2 observations
10 Laure Resplandy	F	Princeton University, USA	Expert in Ocean carbon modelling and biophysical processes; eddy- scale to global scale variability.

7.2 Associate Member

Name	Gender	Place of Work	Expertise
1 Christian Rödenbeck	M	Max Planck Institute for Biogeochemistry, Jena, Germany	Surface Ocean CO_2 mapping (SOCOM) lead-scientist, atmospheric inverse estimates
2 Brendan Carter	M	NOAA Pacific Marine Environmental Laboratory, USA	Analysis of ocean carbonate system data, data-model intercomparison
3 Geun-Ha Park	F	East Sea Research Institute, Korea Institute of Ocean Science and Technology, Uljin, Korea	CO_2 mapping and marine carbon cycle
4 Sayaka Yasunaka	F	Japan Agency for Marine-Earth Science Technology, Japan	Arctic Ocean carbon cycle, CO_2 mapping
5 Siv K. Lauvset	F	NORCE Norwegian Research Centre, Norway	Surface ocean and interior ocean carbon measurements, data analysis and synthesis

6 Tatiana Ilyina	F	Max Planck Institute for Meteorology, Hamburg, Germany	Ocean modelling CO_2 projections and decadal CO_2 predictions, WCRP grand challenge co- chair
7 Kim Currie	F	National Institute of Water and Atmospheric research, Wellington, New Zealand	Measurements of ocean pCO_2 and carbonates in the coastal and open ocean, marine chemistry, ocean acidification
8 Nicolas Gruber	M	ETH, Zürich, Switzerland	Observation based CO_2 estimates from surface and interior, Ocean Modelling, RECCAP2 ocean leader
9 Nicole Lovenduski	F	University of Boulder, Colorado, USA	Ocean Modelling, CO_2 projections
10 Yosuke Iida	M	Japanese Meteorological Agency, Tokyo, Japan	CO_2 mapping based on surface ocean CO_2 observations and marine carbon cycle

8. Working Group Contributions

The working group will:

- Combine data-based open ocean with coastal ocean and Arctic Ocean estimates and provide SOPs for the future. This will add to our estimates regions that include some of the most vulnerable ecosystems to climate change.
- Identify key ocean areas where data collection is a high priority and future field campaigns should set their focus
- Provide an improved baseline for model validation, e.g. within the CMIP6 effort and thereby contribute towards a data-driven global carbon budget
- Contribute to Sustainable Development Goal 13 by supporting the 5-yearly global stocktake under article 14 of the UNFCCC Paris Agreement
- Advance ocean acidification studies in order to achieve the United Nations Sustainable Development Goal 14
- Reduce the working group's carbon footprint by planning working group meetings in combination with conferences
- Combine these meetings with a training event that will broaden the user base of these products and advance the careers of the next generation of scientists

During the working group meetings, the working group chairs will identify group members to lead the tasks above.

9. Expertise

Peter Landschützer is an expert in ocean pCO_2 mapping using machine-learning algorithms and is an expert in the analysis of the decadal variability of the global ocean uptake of CO_2.

Galen A. McKinley is an expert in assessment of the mechanisms of variability and long-term change of CO_2 fluxes using pCO_2 observations and ocean biogeochemical models.

Dorothee C. E. Bakker is expert in the collection and synthesis of CO_2 observations and she is carrying a lead role in the SOCAT effort.

Shi-Ichiro Nakaoka is an expert in collecting surface ocean CO_2 observations, their analysis and interpretation through advanced statistical methods.

Sara Mikaloff Fletcher is an expert in modelling atmospheric CO_2 and other gases that are linked to ocean biogeochemistry. She serves on the WMO IG^3IS Scientific Advisory Panel, and is an Editor for the journal *Global Biogeochemical Cycles*.

Pedro Monteiro is an expert in understanding the role of climate variability in the ocean carbon cycle based on numerical models with a special focus on the Southern Ocean.

Raphaëlle Sauzède is an expert in the synthesis of BGC-Argo data for 4-dimensional reconstructions of biogeochemical parameters using machine learning-based methods.

Goulven G. Laruelle is expert in coastal ocean biogeochemistry and in mapping the exchange of CO_2 in coastal regions based on observations and models.

Leticia Cotrim da Cunha is an expert in marine biogeochemistry observations, and is at present part of the Reference Group for GLODAP (Global Ocean Data Analysis Project).

Laure Resplandy is an expert in the analysis and modeling of bio-physical interactions controlling CO_2 air-sea fluxes, and the use of oceanic and atmospheric data to constrain the global carbon cycle.

10. Relationship to other International Programs

We will interact with many international projects, analysis and synthesis efforts. In particular, the working group sets out to provide guidance for the air-sea CO_2 flux comparison in assessment studies by the **Global Carbon Project**, namely the **Global Carbon Budget** and **RECCAP2**. The Global Carbon Project provides annual updates of the global sources and sinks of carbon and the results of the working group will help to provide the best marine air- sea flux constraint and its variability in time.

Furthermore, we will closely collaborate with the existing surface ocean CO_2 data collection efforts, in particular the **Surface Ocean CO_2 Reference Observing Network (SOCONET),**

the **Surface Ocean CO_2 Atlas (SOCAT),** and the **Biogeochemical ARGO** projects. In particular, we will provide recommendations where additional observations will help to reduce future uncertainties.

We will collaborate with the **International Ocean Carbon Coordination Project (IOCCP)**, in particular relaying information on critical gaps in the existing pCO_2 network, to ensure that appropriate actions can be taken to improve this. We will also enlist IOCCP help in the planned training workshop.

We will communicate our findings and recommendations to the **Integrated Global Greenhouse Gas Information System (IG^{3}IS)**, which is a **World Meteorological Organisation** program that provides a bridge between science and policy for greenhouse gas monitoring and emissions. This will ensure uptake by relevant global, regional, and national research projects that seek to improve CO_2 emission and uptake estimates using atmospheric observations.

Providing crucial information regarding trends and variability of the ocean carbon as well as ocean pH content, in addition to progress in integrating CO_2 synthesis, will serve towards the achievement of both **United Nations Sustainable Development Goals 13 (Climate action) 14 (Life below water).**

We will be in direct interaction with the **WCRP grand challenge on Carbon Feedbacks in the Climate System.** Our Associate Member Tatiana Ilyina is co-lead of this WCRP project.

We will provide essential information in the area of "Constraining ocean carbon uptake and storage", highlighted in **CLIVAR**'s 2018 Science and Implementation Plan as a key component of its overarching goal: "Understanding the ocean's role in climate variability, change, and transient sensitivity".

Finally, we will work closely with global modelling groups to help improve future carbon cycle projections and decadal CO_2 predictions by adding the observation-based uncertainty, but also by providing an observation-based reference for model intercomparison projects such as **CMIP6**.

11. Key References

Canadell, J., Ciais, P., Gurney, K. & Le Quéré, C. An International Effort to Quantify Regional Carbon Fluxes. EOS **92,** 81–82, 2011

Gruber, N., Landschützer, P. & Lovenduski, N. S. The Variable Southern Ocean Carbon Sink. Annu. Rev. Marine. Sci. **11,** 159–186, 2019

Gruber, N. et al. Rapid Progression of Ocean Acidification in the California Current System. Science **337,** 220–223, 2012

Jacobson, A. R., Mikaloff Fletcher, S. E., Gruber, N., Sarmiento, J. L. & Gloor, M. A joint atmosphere-ocean inversion for surface fluxes of carbon dioxide: 1. Methods and global-scale fluxes. Global Biogeochem Cy **21,** 273, 2007

Lauvset, S. K., Gruber, N., Landschützer, P., Olsen, A. & Tjiputra, J. Trends and drivers in global surface ocean pH over the past 3 decades. Biogeosciences **12,** 1285–1298, 2015

Yasunaka, S. et al. Mapping of the air-sea CO2 flux in the Arctic Ocean and its adjacent seas: Basin-wide distribution and seasonal to interannual variability. Polar Science **10,** 323–334, 2016

Other references cited in the text are found in the next section.

12. Appendix

Full Member 5 Key Publications:

Peter Landschützer:

Landschützer, P., Gruber, N., Bakker, D. C. E., Stemmler, I. and Six. K. D.: Strengthening seasonal marine CO_2 variations due to increasing atmospheric CO_2. Nature Climate Change, 8, 146–150, doi: 10.1038/s41558-017-0057-x, 2018

Landschützer, P., Gruber, N. and Bakker, D. C. E.: Decadal variations and trends of the global ocean carbon sink, Global Biogeochemical Cycles, 30, 1396- 1417, doi:10.1002/2015GB005359, 2016

Landschützer, P., Gruber, N., Haumann, F. A. Rödenbeck, C. Bakker, D. C. E., van Heuven, S. Hoppema, M., Metzl, N., Sweeney, C., Takahashi, T., Tilbrook, B. and Wanninkhof, R: The reinvigoration of the Southern Ocean carbon sink, Science, 349, 1221-1224. doi: 10.1126/science.aab2620, 2015

Landschützer, P., Gruber, N., Bakker, D. C. E. and Schuster, U.: Recent variability of the global ocean carbon sink, Global Biogeochemical Cycles, 28, 927-949, doi: 10.1002/2014GB004853, 2014

Landschützer, P., Gruber, N., Bakker, D. C. E., Schuster, U., Nakaoka, S., Payne, M. R., Sasse, T., and Zeng, J.: A neural network-based estimate of the seasonal to inter-annual variability of the Atlantic Ocean carbon sink, Biogeosciences, 10, 7793-7815, doi:10.5194/bg- 10-7793-2013, 2013

Galen A. McKinley:

McKinley, G.A., Fay, A.R., Lovenduski, N.S. and Pilcher, D.J.: Natural Variability and Anthropogenic Trends in the Ocean Carbon Sink. Annu. Rev. Marine. Sci. 9, 125–150, 2017

Peters, G. P. C. LeQuere, R.M. Andrew, J.G. Canadell, P. Friedlingstein, T. Ilyina, R.B. Jackson, F. Joos, J.I. Korsbakken, **G.A. McKinley**, S. Sitch, and P. Tans. Towards real-time verification of CO2 emissions. *Nature Climate Change* **7,** 848–850, 2017

McKinley, G.A., Pilcher, D.J., Fay, A.R., Lindsay, K., Long, M.C. and Lovenduski, N.S.: Timescales for detection of trends in the ocean carbon sink. Nature 530, 469–472, 2016

Fay, A.R. & **McKinley, G.A.:** Global trends in surface ocean pCO2 from in situ data. Global Biogeochem Cycles 27, 1–17, 2013

McKinley, G.A., Fay, A.R., Takahashi, T. and Metzl, N., Convergence of atmospheric and North Atlantic carbon dioxide trends on multidecadal timescales. Nature Geoscience 4, 606– 610, 2011

Dorothee C.E. Bakker:

Bakker, D.C.E., Pfeil, B., Smith, K., Hankin, S., Olsen, A., Alin, S.R., Cosca, C., Harasawa, S., Kozyr, A., Nojiri, Y., O'Brien, K. M., Schuster, U., Telszewski, M., Tilbrook, B., Wada, C., Akl, J., Barbero, L., Bates, N. R., Boutin, J., Bozec, Y., Cai, W.-J., Castle, R.D., Chavez, F.P., Chen, L., Chierici, M., Currie, K., De Baar, H.J.W., Evans, W., Feely, R.A., Fransson, A., Gao, Z., Hales, B., Hardman-Mountford, N.J., Hoppema, M., Huang, W.-J., Hunt, C.W., Huss, B., Ichikawa, T., Johannessen, T., Jones, E.M., Jones, S., Jutterstrøm, S., Kitidis, V., Körtzinger, A., Landschützer, P., Lauvset, S.K., Lefèvre, N., Manke, A.B., Mathis, J.T., Merlivat, L., Metzl, N., Murata, A., Newberger, T., Omar, A.M., Ono, T., Park, G.-H., Paterson, K., Pierrot, D., Ríos, A. F., Sabine, C. L., Saito, S., Salisbury, J., Sarma, V.V.S.S., Schlitzer, R., Sieger, R., Skjelvan, I., Steinhoff, T., Sullivan, K.F., Sun, H., Sutton, A.J., Suzuki, T., Sweeney, C., Takahashi, T., Tjiputra, J., Tsurushima, N., Van Heuven, S.M.A.C., Vandemark, D., Vlahos, P., Wallace, D.W.R., Wanninkhof, R. and Watson, A.J.: An update to the Surface Ocean CO_2 Atlas (SOCAT version 2). Earth System Science Data 6: 69-90. doi:10.5194/essd-6-69-2014, 2014

Brévière, E.H.G., **Bakker, D.C.E.,** Bange, H.W., Bates, T.S., Bell, T.G., Boyd, P.W., Duce, R.A., Garçon, V., Johnson, M.T., Law, C.S., Marandino, C.A., Olsen, A., Quack, B., Quinn, P.K., Sabine, C.L., Saltzman, E.: Surface ocean - lower atmosphere study: Scientific synthesis and contribution to Earth System science. Anthropocene: 12:5468. doi: 10.1016/j.ancene.2015.11.001, 2015

Lenton, A., Tilbrook, B., Law, R.M., **Bakker, D.C.E**., Doney, S.C., Gruber, N., Ishii, M., Hoppema, M., Lovenduski, N.S., Matear, R.J., McNeil, B.I., Metzl, N., Mikaloff Fletcher, S.E., Monteiro, P.M.S., Rödenbeck, C., Sweeney, C. and Takahashi, T.: Sea-air CO_2 fluxes in the Southern Ocean for the period 1990-2009. Biogeosciences 10: 4037-4054. doi:10.5194/bg-10-4037-2013, 2013

Pfeil, B., Olsen, A., **Bakker, D.C.E.,** Hankin, S., Koyuk, H., Kozyr, A., Malczyk, J., Manke, A., Metzl, N., Sabine, C.L., Akl, J., Alin, S.R., Bates, N., Bellerby, R.G.J., Borges, A., Boutin, J., Brown, P.J., Cai, W.-J., Chavez, F.P., Chen, A., Cosca, C., Fassbender, A.J., Feely, R.A., González-Dávila, M., Goyet, C., Hales, B., Hardman-Mountford, N., Heinze, C., Hood, M., Hoppema, M., Hunt, C.W., Hydes, D., Ishii, M., Johannessen, T., Jones, S.D., Key, R.M., Körtzinger, A., Landschützer, P., Lauvset, S.K., Lefèvre, N., Lenton, A., Lourantou, A., Merlivat, L., Midorikawa, T., Mintrop, L., Miyazaki, C., Murata, A., Nakadate, A., Nakano, Y., Nakaoka, S., Nojiri, Y., Omar, A.M., Padin, X.A., Park, G.-H., Paterson, K., Perez, F.F., Pierrot, D., Poisson, A., Ríos, A.F., Santana-Casiano, J.M., Salisbury, J., Sarma, V.V.S.S., Schlitzer, R., Schneider, B., Schuster, U., Sieger, R., Skjelvan, I., Steinhoff, T., Suzuki, T., Takahashi, T., Tedesco, K., Telszewski, M., Thomas, H., Tilbrook, B., Tjiputra, J., Vandemark, D., Veness, T., Wanninkhof, R., Watson, A.J., Weiss, R., Wong, C.S., and Yoshikawa-Inoue, H.: A uniform, quality controlled Surface Ocean CO_2 Atlas (SOCAT). Earth System Science Data 5: 125-143. doi:10.5194/essd-5-125-2013, 2013

Watson, A.J.; Schuster, U.; **Bakker, D.C.E**.; Bates, N.R.; Corbière, A.; González-Dávila, M.; Friedrich, T.; Hauck, J.; Heinze, C.; Johannessen, T.; Körtzinger, A.; Metzl, N.; Olafsson, J.; Olsen, A.; Oschlies, A.; Padin, X.A.; Pfeil, B.; Santana-Casiano, J.M.; Steinhoff, T.; Telszewski, M.; Rios, A.F.; Wallace, D.W.R. & Wanninkhof, R. Tracking the variable North Atlantic sink for atmospheric CO_2, Science, 326, 1391-1393, 2009

Shin-Ichiro Nakaoka:

Le Quéré, C., Andrew, R.M., Friedlingstein, P., Sitch, S., Hauck, J., Pongratz, J., Pickers, P.A., Korsbakken, J.I., Peters, G.P., Canadell, J.G., Arneth, A., Arora, V.K., Barbero, L., Bastos, A., Bopp, L., Chevallier, F., Chini, L.P., Ciais, P., Doney, S.C., Gkritzalis, T., Goll, D.S., Harris, I., Haverd, V., Hoffman, F.M., Hoppema, M., Houghton, R.A., Hurtt, G., Ilyina, T., Jain, A.K., Johannessen, T., Jones, C.D., Kato, E., Keeling, R.F., Goldewijk, K.K., Landschützer, P., Lefèvre, N., Lienert, S., Liu, Z., Lombardozzi, D., Metzl, N., Munro, D.R., Nabel, J.E.M.S., **Nakaoka, S.-I.,** Neill, C., Olsen, A., Ono, T., Patra, P., Peregon, A., Peters, W., Peylin, P., Pfeil, B., Pierrot, D., Poulter, B., Rehder, G., Resplandy, L., Robertson, E., Rocher, M., Rödenbeck, C., Schuster, U., Schwinger, J., Séférian, R., Skjelvan, I., Steinhoff, T., Sutton, A., Tans, P.P., Tian, H., Tilbrook, B., Tubiello, F.N., van der Laan-Luijkx, I.T., van der Werf, G.R., Viovy, N., Walker, A.P., Wiltshire, A.J., Wright, R., Zaehle, S., and Zheng, B.: Global Carbon Budget 2018, Earth Syst. Sci. Data, 10, 2141-2194, https://doi.org/10.5194/essd-10-2141-2018, 2018

Hoshina, Y., Tohjima, Y., Katsumata, K., Machida, T., and **Nakaoka, S.-I.:** In situ observation of atmospheric oxygen and carbon dioxide in the North Pacific using a cargo ship, Atmos. Chem. Phys., 18, 9283-9295, https://doi.org/10.5194/acp-18-9283-2018, 2018

Ritter, R., Landschützer, P., Gruber, N., Fay, A.R., Iida, Y., Jones, S., **Nakaoka, S**., Park, G.-H., Peylin, P., Rödenbeck, C., Rodgers, K.B., Shutler, J.D. and Zeng, J.: Observation-based trends of the Southern Ocean carbon sink. Geophysical Research Letters, 44, doi:10.1002/2017GL074837, 2017

Rödenbeck, C., Bakker, D. C. E., Gruber, N., Iida, Y., Jacobson, A.R., Jones, S., Landschützer, P., Metzl, N., **Nakaoka, S**., Olsen, A., Park, G.-H., Peylin, P., Rodgers, K.B., Sasse, T.P., Schuster, U., Shutler, J.D., Valsala, V., Wanninkhof, R., and Zeng, J.: Data-based estimates of the ocean carbon sink variability – first results of the Surface Ocean pCO_2 Mapping intercomparison (SOCOM), Biogeosciences, 12, 7251-7278, https://doi.org/10.5194/bg-12-7251-2015, 2015

Nakaoka, S., Telszewski, M., Nojiri, Y., Yasunaka, S., Miyazaki, C., Mukai, H., and Usui, N.: Estimating temporal and spatial variation of ocean surface pCO_2 in the North Pacific using a self-organizing map neural network technique, Biogeosciences, 10, 6093-6106, https://doi.org/10.5194/bg-10-6093-2013, 2013

Sara Mikaloff-Fletcher:

Mikaloff-Fletcher, S.E.: Ocean carbon uptake driven by circulation. Nature, 542, 169–170, doi:10.1038/542169a, 2017

Mikaloff Fletcher, S.E., An increasing carbon sink? Science, 349, 1165, doi: 10.1126/science.aad0912, 2015

Rodgers, K.B., Aumont, O., **Mikaloff Fletcher, S.E.,** Iudicone, D., Bopp, L., Keeling, R.F., Madec, G., de Boyer Montégut, C., Plancherel, Y. and Wanninkhof, R., Strong sensitivity of Southern Ocean carbon uptake and nutrient cycling to wind stirring. 11, 4077-4098, doi:10.5194/bg-11-4077-2014, 2014

Mikaloff Fletcher, S.E., Gruber, N.,Jacobson, A.R., Doney, S.C., Dutkiewicz, S., Gerber, M., Follows, M., Joos, F., Lindsay, K., Menemenlis, D., Mouchet, A., Muller, S. A. and Sarmiento, J.L., Inverse estimates of anthropogenic CO_2 uptake, transport, and storage by the ocean. Global Biogeochem. Cycles, 20, GB2002, doi: 10.1029/2005gb002530, 2006

Mikaloff Fletcher, S.E., Gruber, N., Jacobson, A.R., Gloor, M., Doney, S.C., Dutkiewicz, S., Gerber, M., Follows, M., Joos, F., Lindsay, K., Menemenlis, D., Mouchet, A., Muller, S. A. and Sarmiento, J.L., Inverse estimates of oceanic sources and sinks of natural CO_2 and the implied oceanic carbon transport. Global Biogeochem. Cycles, 21, 21, GB1010, doi:10.1029/2006GB002751, 2007

Pedro M.S. Monteiro:

Gregor, L., Lebehot, A.D., Kok, S., and **Monteiro, P.**M.S. A comparative assessment of the uncertainties of global surfaceocean CO_2 estimates using a machine learning ensemble (CSIR ML6 version 2019a) – have we hit the wall?, Geosci. Model Dev. Discuss., https://doi.org/10.5194/gmd-2019-46, in review, 2019

Mongwe, N. P., Vichi, M., and **Monteiro, P. M.S**. The Seasonal Cycle of pCO_2 and CO_2 fluxes in the Southern Ocean: Diagnosing Anomalies in CMIP5 Earth System Models, Biogeosciences , https://doi.org/10.5194/bg-2017-361, 2018

Gregor, L., Kok, S., and **Monteiro, P. M. S.** Interannual drivers of the seasonal cycle of CO_2 in the Southern Ocean, Biogeosciences, 15, 2361-2378 doi.org/10.5194/bg-15-2361-2018, 2018

Monteiro, P. M. S., L. Gregor, M. Lévy, S. Maenner, C. L. Sabine, and S. Swart., Intraseasonal variability linked to sampling alias in air-sea CO_2 fluxes in the Southern Ocean, Geophysical Research Letters, 42, doi:10.1002/2015GL066009, 2015

Gregor, L and **Monteiro, P.M.S**, Seasonal cycle of N:P:TA stoichiometry as a modulator of CO_2 buffering in eastern boundary upwelling systems, Geophysical Research Letters : 40(20): 5429-5434 DOI: 10.1002/2013GL058036, 2013

Raphaëlle Sauzède:

Sauzède, R., Claustre, H., and Guinehut, S.: Towards the end-users: New three-dimensional biogeochemical products derived from machine learning-based methods. Oral presentation. 19th Argo Data Management Team meeting, La Jolla, CA, USA, December 2018

Sauzède, R.: Novel learning-based methods to derive biogeochemical parameters from profiling floats. Invited speaker. Gordon Research Conference on Ocean Biogeochemistry, Hong Kong, July 2018

Bittig, H. C., Steinhoff, T., Claustre, H., Fiedler, B., Williams, N. L., **Sauzède, R.,** Körtzinger, A., and Gattuso, J.-P: An Alternative to Static Climatologies: Robust Estimation of Open Ocean CO_2 Variables and Nutrient Concentrations From T, S, and O_2 Data Using Bayesian Neural Networks. Frontiers in Marine Science, 5:328, ISSN 2296-7745. 10.3389/ fmars.2018.00328. 2018

Sauzède, R., Bittig, H., Claustre, H., de Fommervault, O., Gattuso, J.-P., Legendre, L., and Johnson, K: Estimates of water-column nutrient concentrations and carbonate system parameters in the global ocean: A novel approach based on neural networks. Frontiers in Marine Science, 4(128), ISSN 22967745. 10.3389/fmars.2017.00128. 2017

Sauzède, R., Claustre, H., Uitz, J., Jamet, C., Dall'Olmo, G., D'Ortenzio, F., Gentili, B., Poteau, A., and Schmechtig, C: A neural network-based method for merging ocean color and Argo data to extend surface bio-optical properties to depth: Retrieval of the particulate backscattering coefficient. Journal of Geophysical Research: Oceans, 121(4). ISSN 21699291. 10.1002/2015JC011408. 2016

Goulven Laruelle:

Laruelle, G.G., Cai, W.J., Hu, X., Gruber, N., Mackenzie, F.T. and Regnier, P.: Continental shelves as a variable but increasing global sink for atmospheric carbon dioxide, Nature communications 9 (1), 454, 2018

Laruelle, G.G., Goossens, N., Arndt, S., Cai, W.J., Regnier, P.: Air–water CO_2 evasion from US East Coast estuaries, Biogeosciences 14, 2441-2468, 2017

Laruelle, G.G., Landschützer, P., Gruber, N., Tison, J.L., Delille, B., Regnier, P.: Global high-resolution monthly pCO_2 climatology for the coastal ocean derived from neural network interpolation, Biogeosciences 14 (19), 4545, 2017

Laruelle, G. G., Lauerwald, R., Pfeil, B., Regnier, P.: Regionalized global budget of the CO_2 exchange at the air-water interface in continental shelf seas, Global biogeochemical cycles 28 (11), 1199-1214, 2014

Regnier,P., Friedlingstein, P., Ciais, P., Mackenzie, F.T., Gruber, N., Janssens, I.A., **Laruelle, G.G.**, Lauerwald, R., Luyssaert, S., Andersson, A.J., Arndt, S., Arnosti, C., Borges, A.V., Dale, A.W., Gallego-Sala, A., Goddéris, Y., Goossens, N., Hartmann, J., Heinze, C., Ilyina, T., Joos, F, LaRowe, D.E., Leifeld, J., Meysman, F.J.R., Munhoven, G., Raymond, P.A., Spahni, R., Suntharalingam, P. and Thullner, M.: Anthropogenic perturbation of the carbon fluxes from land to ocean, Nature geoscience, 6, 8, 597, 2013

Leticia Cotrim da Cunha:

Perretti, A.R., de Albergaria-Barbosa, A.C.R., Kerr, R., and **da Cunha, L.C**. Ocean acidification studies and the uncertainties relevance on measurements of marine carbonate system properties. Brazilian J. Oceanogr. 66, 234–242. doi:10.1590/s1679-87592018000706602, 2018

da Cunha, L. C., Hamacher, C., Farias, C. de O., Kerr, R., Mendes, C.R.B., and Mata, M.M. Contrasting end-summer distribution of organic carbon along the Gerlache Strait, Northern Antarctic Peninsula: Bio-physical interactions. Deep Sea Res. Part II Top. Stud. Oceanogr. 149, 206–217. doi:10.1016/j.dsr2.2018.03.003, 2018

Kerr, R., Orselli, I.B.M., Lencina-Avila, J.M., Eidt, R.T., Mendes, C.R.B., **da Cunha, L.C**., et al. Carbonate system properties in the Gerlache Strait, Northern Antarctic Peninsula (February 2015): I. Sea–Air CO_2 fluxes. Deep Sea Res. Part II Top. Stud. Oceanogr. 149, 171–181. doi:10.1016/j.dsr2.2017.02.008, 2018

Kerr, R., Goyet, C., **da Cunha, L.C**., Orselli, I.B.M., Lencina-Avila, J.M., Mendes, C.R.B., et al. Carbonate system properties in the Gerlache Strait, Northern Antarctic Peninsula (February 2015): II. Anthropogenic CO_2 and seawater acidification. Deep Sea Res. Part II Top. Stud. Oceanogr. 149, 182–192. doi:10.1016/j.dsr2.2017.07.007, 2018

Kerr, R., **da Cunha, L.C**., Kikuchi, R.K.P., Horta, P.A., Ito, R.G., Müller, M.N., et al. The Western South Atlantic Ocean in a High-CO_2 World: Current Measurement Capabilities and Perspectives. Environ. Manage. 57, 740–752. doi:10.1007/s00267-015-0630-x, 2016

Laure Resplandy:

Resplandy, L., Keeling, R.F., Rödenbeck, C., Stephens, B.B., Khatiwala, S., Rodgers, K.B., Long, M.C., Bopp, L., Tans, P.P., Revision of global carbon fluxes based on a reassessment

of oceanic and riverine carbon transport. Nature Geoscience 1. doi.org/10.1038/s41561-018-0151-3. 2018

Resplandy, L., Keeling, R.F., Eddebbar, Y., Brooks, M.K., Wang, R., Bopp, L., Long, M.C., Dunne, J.P., Koeve, W., Oschlies, A., Quantification of ocean heat uptake from changes in atmospheric O_2 and CO_2 composition. Nature 563, 105–108. doi.org/10.1038/s41586-018-0651-8. 2018

Resplandy, L., Séférian, R. and L. Bopp. Natural variability of CO_2 and O_2 fluxes: what can we learn from centuries-long climate models simulations? J. Geophys. Res, 120, doi:10.1002/2014JC010463. 2015

Resplandy, L., Boutin J. and Merlivat L. Observed small spatial scale and seasonal variability of the CO_2-system in the Southern Ocean. Biogeosciences, 11, 75-90, doi:10.5194/bg-11-75- 2014. 2014

Resplandy, L., M. Lévy, F. d'Ovidio and L. Merlivat, Impact of submesoscale variability in estimating the air-sea CO_2 exchange: Results from a model study of the POMME experiment, Glob. Biogeo. Cyc., 23, GB1017, doi:10.1029/2008GB003239. 2009

CBIOS

Changing Biotic-Sediment Interactions in the Ocean Seabed

Rapidly Changing Biotic-Sediment Interactions in the Ocean Seabed – Biogeochemical Consequences in the 21st Century

1. Summary/Abstract

The activities of macrobenthos (animals > 500 μm living in or on sediments) significantly alter organic carbon (OC) storage and cycling within the seafloor. However, the lack of validated conceptual models and paucity of integrated datasets limit accurate and appropriately scaled predictions of benthic community response to global warming, acidification, and deoxygenation, and subsequent alterations in carbon cycling. We propose a working group (WG) to coordinate internationally among research disciplines, spanning climate science, organic geochemistry, paleoecology, benthic ecology, and evolutionary genetics. This WG, *Changing Biotic-Sediment Interactions in the Ocean Seabed (CBIOS)*, will enhance understanding of global benthic- sediment dynamics. We will review current science on biotic-sediment interactions to develop a conceptual model(s) informed by paleo records of global change and contemporary benthic community functional traits, evaluate non-carbon ecosystem services that changing biotic- sediment interactions may alter, and develop an open-access database that supports cross- disciplinary investigations into altered macrobenthos communities, OC cycling and carbon sequestration. CBIOS products will include three annual WG meetings, a training workshop hosted by the University of the West Indies in collaboration with SpeSeas (Trinidad and Tobago), a new conceptual model, an open-access CBIOS dataset, and a perspectives article synthesizing working group findings. This WG will include several members from, and will build on, a previously SCOR-sponsored workshop on benthic systems.[1]

2. Scientific Background and Rationale

2.1 Importance

Documented poleward shifts of many benthic taxa in response to climate warming and potential changes in vertical exchange of materials (including living biota) due to changes in climate- related water-column productivity has sparked growing interest in how these shifts interactively influence biogeochemical processing. Such global changes in species distribution influence the geochemical properties of sediments, and their role as global carbon sources and sinks.[2] Ocean sediments represent Earth's largest interactive landscape for OC storage. An estimated 16% of the global seabed lies on continental shelves and margins which, along with other contiguous nearshore regions, account for ca. 75% of total ocean carbon burial. Several reviews have discussed marine megafaunal effects on carbon processes, but do not detail the specific influence of benthic metazoans on biogeochemical processes.[3] For example, while

much attention has been directed towards understanding the role of vegetation in blue carbon habitats, the influence of metazoans has been largely ignored.
CBIOS will explore direct effects of carbon consumption/uptake by macrobenthos, indirect effects via grazing on microbes, modification of the environment (i.e., bioturbation, including particle reworking, solute exchange during bio-irrigation and burrowing, and biodeposition), and linkages with phylogenetic diversity of carbon-processing pathways. We will consider linkages with environmental heterogeneity to both the distribution of macrobenthos and to changes in biogeochemical cycling, noting direct ties to nitrogen and phosphorus cycling. We will also scale up this relationship to evaluate its regional and global significance, which is particularly timely given that state-of-the-art Earth System Models (ESMs), such as those used for the IPCC AR5 report,[4] still rely on rudimentary sediment models[5] (e.g., Hülse et al., 2018 for a recent overview) and none consider the potential effects of benthic ecosystem changes on coupled biogeochemical cycles and the climate system. Due to differences in shallow (photic) habitats and deep-sea environments, CBIOS will calibrate our model(s) for each of these environments.

These changes will likely include poleward shifts in species, reshuffling of community compositions (taxonomic and functional groups), and alteration of biomass/body size distributions, mortality, and behavioral/physiological adaptations. Informed environmental and management decisions, the development of mitigation strategies, and prediction of the global capacity to cycle carbon all require understanding the role natural communities play in sedimentary OC accumulation and long-term C sequestration (burial). This working group will explore biogeochemical pathways and associated organismal change in low- and high-carbon deposition/burial (hot spots) spanning across oxic and anoxic regions. These regions range from shallow (intertidal) to deep waters and span latitudinal gradients and we predict they will respond differently to climate-related changes in ocean ecosystems.

Past climate shifts have resulted in many large-scale redistributions and extinctions of marine organisms. We will therefore use the fossil record of marine macrobenthic fauna to better understand how to predict adaptive responses or extinctions of different taxa. Similarly, we will synthesize the current literature that explores adaptive phenotypic and genotypic variation and change in macrobenthos across different latitudes and water depths, and incorporate them into the CBIOS conceptual model(s). Understanding carbon cycle-climate feedbacks across terrestrial and marine pelagic ecosystems has motivated major research efforts over the past two decades, in part to improve predictions from ESMs. CBIOS will examine how changes in the attributes and distribution of macrobenthic fauna could impact biogeochemical cycling in ocean sediments, and how these impacts may result in additional positive or negative feedbacks in the coupled ocean-atmosphere system. More specifically we will work within the following core topics: 1) *Carbon Dynamics, Marine Benthos, and a Changing Marine Climate*; 2) *Long-Term Evolution of Marine Benthos and Impacts on Sediment Chemistry*; and 3) *Modeling "Transient" Carbon Cycling in a Rapidly Warming Climate.*

2.2 Challenges

Ultimately, integrating the (generally poleward) redistribution of benthos and associated impacts on carbon cycling via changes in sediment oxygenation across a spectrum of global

carbon (i.e., from high OC deposition/burial hotspots to low OC supply zones in the deep-ocean) and climatic (i.e., latitudinal gradients in temperature across a species range) gradients presents a major challenge that will be addressed by CBIOS. The WG also seeks to address glaring gaps in knowledge on the global carbon budget as it relates to ocean sediments, diagenetic models, benthic-pelagic coupling in ocean biogeochemical models and, ultimately, ESMs. In particular, we plan to identify knowledge gaps (e.g. regional gaps) that require more data collection. While we have some understanding of changes in microbial carbon cycling and changes in benthos because of global warming, the integrated response is largely unknown. Additionally, CBIOS will examine one of the complicating factors when considering poleward redistribution of a particular species, which is the changing nature of shallow water deposits latitudinally resulting from increased dominance of relict (glacial) deposits in the < 200 m depth range towards the poles. We will also address the complicating factors of changing sea levels, their impact on intertidal sedimentary habitats, and how inundation of shallow sediments affects carbon deposition/burial.

2.3 Justification for SCOR working group

A subset of our proposed members are currently developing a *Nature Reviews* article that will synthesize the current state of the science on animal-sediment interactions in the face of global change. The review article will provide a foundation for the proposed WG and identify knowledge gaps that CBIOS will address. The scope of past and future animal-sediment interactions is a topic that lies within SCOR's mission, was identified as a key gap in a previously funded SCOR workshop,[1] and is not being addressed by any current SCOR-sponsored large-scale research projects. The lack of conceptual models and integrated datasets limits current research on benthic-sediment interactions - a need our proposed WG will address. The development of an international open-source database will unite disparate research groups and address a need recognized by previous WGs[6] by allowing the ocean research community to better access data regarding past changes in benthic communities composition/function to predict future benthic community changes and alterations in C cycling. In addition to addressing current knowledge gaps, the proposed WG will also promote capacity building in the ocean sciences by supporting early career scientists and underrepresented groups, promoting a training workshop led by early career scientists, and encouraging international collaboration with members spanning a diversity of backgrounds, career stages, and institutions.

3. Terms of Reference

1. To evaluate the state of the science of animal-sediment interactions, their response to a changing climate, subsequent alterations in metazoan community composition and function, and the consequences for carbon cycling.
2. To create a conceptual model(s) that integrates ancient ocean macrobenthic fauna and their adaptive response to past climate change with modern benthic communities to predict future alterations in animal-sediment interactions, their effects on carbon cycling, and how Earth System Models, such as those used by the IPCC, can best incorporate this information.
3. To assess the mechanisms by which climate change impacts on animal-

sediment interactions may alter non-carbon ecosystem services.

4. To develop an open-access database that integrates paleo records (using museum databases) with modern benthic community data, including information on phenotypic and genotypic variation within and among species, to support cross-disciplinary investigations into animal-sediment interactions and to identify knowledge gaps for future studies.
5. To foster international collaborations across transdisciplinary research groups and promote capacity building in the ocean sciences through the involvement of early-career scientists from a diversity of countries, backgrounds and institutions.

4. Working Plan

CBIOS will develop a series of meetings to achieve the goals described in the WG's terms of reference (ToR), with products including a conceptual model, a perspectives article, an open-source database, and model outputs under climate scenarios for use in climate assessments (IPCC). Prior to WG initiation, a subset of members will attend a workshop hosted by Utah State University (application submitted for Summer 2019), and WG members will apply for an OCB workshop at WHOI (application to be submitted December 2019).

The main work plan activities are:

(1) Creation of a conceptual model describing past, current, and future changes to benthic-sediment interactions

We will develop a conceptual model that will inform database and model development. As needed, working sub-groups will be developed for specific research areas. The conceptual model will incorporate the following:

(a) review of current spatial patterns of global sediment carbon sequestration and stocks. We will summarize recent estimates of the amount of carbon stored in the continental margin and deep ocean sediments (hadal zone and abyssal plains) and polar, temperate, and tropical marine sediments, and how those link to extant animals and their activities.
(b) examine mechanisms linking adaptive responses to the distributions of marine benthos, underpinned by both inter- and intra-specific diversity.[7,8] We will explore how evolutionary innovations established novel burrow architectures and feeding guilds, and how the emergence of bioturbation acted as a major player on geobiologic feedbacks and geochemical cycles and how this can inform carbon cycling models.

(c) consider the influence of continental margin type (e.g., passive or active, seasonal or aseasonal) on benthic community composition via different input rates, timing, and types of sediment and organic matter, and how these gradients, from natural and human drivers, create critical zones that influence productivity, distribution, phenotypic plasticity, and/or evolution that offer an opportunity to advance our understanding of seafloor carbon cycling.[9]

(d) predict the effect of projected changes to climate variables at the seafloor (T, O_2, pH, and aragonite saturation) and to particulate organic carbon (POC) flux, sources of uncertainty, time of signal emergence, and the expected nature of metazoan faunal responses with respect to carbon dynamics.

(e) assess the impacts of redistribution and general poleward expansion of benthos on carbon cycling via changes in sediment oxygenation across a spectrum of global carbon (i.e., from coastal hotspots to low C supply zones in the deep-ocean) and climactic (i.e., latitudinal gradients in temperature across a species range) gradients.

(2) Development of an open-access CBIOS database that will incorporate paleoenvironmental and modern data

The conceptual model developed in Activity 1 (ToR #2) *will identify current critical gaps* in knowledge on the global carbon budget as it relates to ocean sediments, diagenetic models, benthic-pelagic coupling in ocean biogeochemical models and, ultimately, ESMs. To address these gaps, *we will develop a database* to compile the necessary data to understand how the redistribution of benthos may impact carbon cycling via changes in sediment oxygenation across a spectrum of global carbon (i.e., from coastal hotspots to low C supply zones in the deep-ocean) and climatic (i.e., latitudinal gradients in temperature across a species range) gradients.

(3) Development of a perspective article(s) on the fate of benthic-sediment interactions

As mentioned previously, a subset of the CBIOS group is writing an article for *Nature Reviews* which will provide a foundation for the SCOR WG. The SCOR WG will work from this document to *develop a perspective article* for a high-impact journal that challenges the evolutionary, ecological, and marine science communities with questions that go beyond those covered in the *Nature Review* on the following core topics: (1) Carbon Dynamics, Marine Benthos, and a Changing Marine Climate; (2) Long-Term Evolution of Marine Benthos and Impacts on Sediment Chemistry; and (3) Modeling "Transient" Carbon Cycling in a Rapidly Warming Climate. This perspective article will synthesize the findings of the WG and highlight future research needs.

Year 1:

First WG Meeting, Conceptual Model and CBIOS Database
At the first CBIOS meeting, members and attendees will discuss the structure and implementation of CBIOS, agree on rules and norms for collaborative work, develop the conceptual model (ToR #1-3), and begin the open-access database plan (ToR #4). Working sub- groups will be created to discuss areas of need within the different aspects of CBIOS to develop the conceptual model. These sub-groups will also identify the type of data needed to understand how marine benthos respond to changing climatic gradients with the ultimate goal of incorporating them into regional biogeochemical cycles in ESMs.

This first meeting will coincide with the 2020 Ocean Sciences Meeting in San Diego, CA to maximize attendance and visibility of the CBIOS working group. If selected, an additional meeting would gather any WG members attending the Summer 2020 Ocean Carbon and Biogeochemistry (OCB) workshop.

Year 2:

Second WG Meeting, Training Workshop, Finalize Conceptual Model
At the second WG meeting, each sub-group will present their portions of the conceptual model, and members will integrate each component and finalize the conceptual model developed in Year 1 (ToR #2). Development of the open-access database will continue, and final decisions regarding database development (i.e., data accessibility, usage, long-term hosting and maintenance) will be agreed upon (ToR #4). This WG meeting will coincide with the 2021 Aquatic Sciences Meeting in Palma de Mallorca, Spain.

In addition to the second WG meeting, early career scientists will organize a training workshop hosted by the University of the West Indies, in collaboration with SpeSeas (Trinidad and Tobago), with mentorship from more established researchers (ToR #5). This workshop will cover benthic-sediment interactions and global change, data standardization and database implementation.

Year 3:

Third WG meeting, Finalize CBIOS Database, Perspectives Article
The third workshop will draft the perspectives article that synthesizes the findings of the WG, highlights remaining knowledge gaps, and outlines a way forward for future research in the field of benthic-sediment interactions (ToR #1, 3). Additional development of the database will be included as needed (ToR #4). This WG workshop will coincide with the 2022 Ocean Sciences Meeting in Honolulu, Hawaii.

5. Deliverables

We will develop a conceptual model (Year 1-2; ToR #2) to describe past animal-sediment interactions, and their response to past global change, to assess how the modern response of benthos compares to previous global change, and to lay a framework for future predictions of altered benthic-sediment interactions.

After developing the conceptual model, we will generate an open-access database (Year 2; ToR #4) to incorporate paleo-environmental data and modern data on benthos distribution, functional guilds, phenotypic and genotypic data, as well as organic geochemical data relating to OC and other elemental cycling. The database will conform to Biological and Chemical Oceanography Data Management Office (BCO-DMO) best management practices. We will investigate BCO-DMO or OBIS (Ocean Biogeographic Information System) as a potential host for the database. All data and associated metadata will be organized, validated for QA/QC, and made available according to the data management practices described by BCO-DMO and OBIS.

The WG will produce a perspective article to evaluate the ramifications of changes in zoogeochemistry of ocean seafloor in response to global change/mass migration and/or adaptive change (phenotypic/genotypic) (Year 3; ToR #1, 3). This perspective article will address questions such as: *what are implications of changing biotic-sediment interactions for carbon cycling and ESMs?* These specific deliverables will be developed through SCOR WG meetings, which will be further leveraged by an OCB workshop to be held at WHOI and a training workshop to enhance capacity building for our international partners (Year 2; ToR #5).

6. Capacity Building

The database and conceptual model produced by the S WG will promote the synthesis and preservation of data and concepts related to benthic-sediment interactions. The long-term storage and open-access nature of the CBIOS database will promote international collaborations, standardized data collection, and increase data accessibility for the ocean science research community. The CBIOS database will be accessible according to the data management practices described by OBIS, BCO-DMO, the Intergovernmental Oceanographic Commission (IOC) Ocean Data and Information System (ODIS) or equivalent data management center.

CBIOS will promote open-access documentation whenever possible. This WG is a transdisciplinary group that can go beyond "business-as-usual" to look at interconnections and bio-geo-chemical processes over multiple spatial and temporal scales to highlight underlying mechanisms driving sediment-benthos processes. Moreover, the WG will promote systems- thinking and connect multiple highly technical disciplines at multiple scales of research.

The proposed WG members (full and associate) come from a diversity of institutions and countries, as well as a variety of career stages, which will promote capacity building within the ocean sciences. To further build capacity for ocean sciences, CBIOS will develop a training workshop on benthic-sediment interactions and global change hosted by the University of the West Indies, in collaboration with SpeSeas (Trinidad and Tobago). The training workshop will be organized by early-career scientists with advice from more established WG members. Early career scientists, post-doctoral research associates, and graduate students will be encouraged to attend the training workshop. We will promote further capacity building by seeking collaborations and funding with other national and international groups, including the U.S. Ocean Carbon and Biogeochemistry program, to support meeting costs.

7. Working Group Composition

The proposed WG is comprised of world-renowned scientists that represent a diverse range of career stages, institutions, and countries.

7.1 Full members

Name	Gender	Place of work	Expertise relevant to proposal
Thomas S. Bianchi (co-chair)	Male	Professor, Department of Geological Sciences, University of Florida, Gainesville, FL, **USA**	Global carbon cycling, chemical biomarkers, benthic biogeochemistry
Luis Buatois	Male	Professor, Department of Geological Sciences, University of Saskatchewan, **Canada**	Animal-substrate interactions through geologic time
Judith Gobin	Female	Senior Lecturer, Department of Life Sciences, The University of The West Indies, St. Augustine, **Trinidad and Tobago**	Marine benthos in soft sediments, rocky shores, deep-sea environments and climate change impacts across these habitats (and over time)
Agnes Karlsson	Female	Assistant Professor, Dept. of Ecology, Environment, and Plant Sciences, Stockholm University, Stockholm, **Sweden**	Integrating stress responses at sub-cellular level with higher biological levels, benthos-based indicators of ecological status
Lisa A. Levin	Female	Professor Center for Marine Biodiversity and Conservation Scripps Institution of Oceanography, UC San Diego, **USA**	Benthic community structure and function, global climate projections to the seafloor, and carbon cycling
Jack J. Middelburg	Male	Professor, Earth Sciences, Utrecht University, **The Netherlands**	Inorganic and organic geochemistry, benthic ecology, and earth system science
Pierre Regnier	Male	Professor, Université Libre de Bruxelles, Brussels, **Belgium**	Biogeochemistry with model-data fusion approaches and advanced statistical methods

Natasha Karenyi	Female	Lecturer, Dept. of Biological Sciences, University of Cape Town, **Republic of South Africa**	Marine biodiversity, ecosystem classification, benthic ecology
Paul V.R. Snelgrove (co-chair)	Male	Professor, Dept. of Ocean Sciences and Biology Department, Memorial University of Newfoundland, **Canada**	Marine biodiversity, food quality, and ecosystem functioning
Hong Zhou	Female	Professor, Dept. of Environmental Ecology College of Marine Life Sciences, Ocean University of **China**	Modern benthic community data collection including phenotypic and genotypic variation

7.2 Associate members

Name	Gender	Place of work	Expertise relevant to proposal
Diva Amon	Female	Visiting Curie Fellow, Natural History Museum, **UK**; Director, SpeSeas, **Trinidad and Tobago**	Deep sea biology, human impacts on the deep sea, caribbean, and chemosynthetic environments
Sandra Arndt	Female	Professor, Department of Geosciences, Environment and Society, Université Libre de Bruxelles, Brussels, **Belgium**	Biogeochemistry, diagenesis, land-ocean interactions, paleoclimate
Trisha Atwood	Female	Assistant Professor, Watershed Sciences, Utah State University **USA**	Response of aquatic ecosystems to global change; effects of disturbance on aquatic biogeochemistry, including carbon cycling and storage
Erik Kristensen	Male	Professor, Dept. of Biology, Southern University of Denmark, Odense, **Denmark**	Biodiversity, biogeochemistry, bioturbation, benthic fauna

Alf Norkko	Male	Professor, Tvärminne Zoological Station, University of Helsinki, Helsinki, **Finland**	Ecology of seafloor habitats; environmental mediation of biodiversity and ecosystem function
Deena Pillay	Male	Lecturer, Department of Zoology University of Cape Town Rondebosch, **Republic of South Africa**	Bioturbation, benthic ecology, ecosystem engineers, anthropogenic effects on estuarine systems.
Candida Savage	Female	Assistant Professor, Dept. of Marine Science, University of Otago, Dunedin, **New Zealand**	Marine ecology, nutrient cycling, systems ecology, and paleoecology
Erik E. Sotka	Male	Professor, College of Charleston, Department of Biology, Grice Marine Laboratory, SC, **USA**	Marine and molecular ecology, evolutionary ecology
Ryan Stanley	Male	Research Scientist, Bedford Institute of Oceanography, Fisheries and Oceans Canada, Dartmouth, Nova Scotia, **Canada**	Cryptic intraspecific diversity associated with climatic variation
Simon Thrush	Male	Professor, The University of Auckland, Inst. Of Marine Science, Auckland, **New Zealand**	Organism-sediment interactions; effects of disturbance on populations, communities and recovery processes

8. Working Group Contributions

Dr. Thomas S. Bianchi has studied biogeochemical cycling in marine sediments, more specifically sources and decay dynamics of sedimentary organic matter, and hotspots of carbon burial in the coastal ocean for over 30 years.

Dr. Luis Buatois focuses on animal-substrate interactions through geologic time. He characterizes secular changes in types of bioturbation in different environmental settings as a result of the interplay of evolutionary radiations and mass extinctions. The long-term goal of his research program is to understand the role bioturbation may have played in macroevolution and evolutionary paleoecology.

Dr. Judith Gobin brings a wealth of marine benthic ecological experience to the team and especially from the SIDs perspective. Her expertise covers soft sediments, rocky shores as well as deep-sea environments and her understanding of climate change impacts across these habitats (and over time), is of great importance to her geographic study area of the Caribbean territory.

Dr. Natasha Karenyi is a benthic ecologist with a particular interest in developing a conceptual framework for the ecology of subtidal sediment ecosystems. She has a focus on marine biodiversity and ecosystem classification research.

Dr. Agnes Karlson studies biodiversity and ecosystem functioning as well as adaptive capacity of individuals and populations to environmental changes in the species-poor system of the Baltic Sea, which is also the fastest warming sea area in the world. She is particularly interested in how to interpret stable isotope data in archived samples of consumers from e.g. long-term monitoring.

Dr. Lisa A. Levin will contribute expertise on the effects of climate change, particularly oxygen loss and ocean acidification, on benthic community structure and function. She brings experience with infaunal lifestyles, bioturbation, global climate projections to the seafloor and assessments of their consequences for carbon cycling and the climate. She has participated in the IPCC AR 5 as contributing author, in the IPCC Special Report on Oceans and Cryosphere, served on the Ocean Carbon Biogeochemistry Program steering committee, and serves as co-lead of the Deep Ocean Observing Strategy and Deep-Ocean Stewardship Initiative.

Dr. Jack J. Middelburg is a biogeochemist with expertise in inorganic and organic geochemistry, benthic ecology, stable isotopes and earth system science, including paleoceanography.

Dr. Pierre Regnier is leading the research group 'Biogeochemistry & Modeling of the Earth System' at the Université Libre de Bruxelles. His research focuses on the biogeochemistry of carbon and nutrients in terrestrial, freshwater and marine ecosystems including the seafloor, global greenhouse gas (CO_2, N_2O, CH_4) cycling, geomicrobiology, and modeling of land-ocean interactions. He combines model-data fusion approaches and advanced statistical methods, as well as reactive-transport and Earth system modeling.

Dr. Paul V.R. Snelgrove brings 30 years of research experience in seafloor ecosystems and has published widely on questions relating to marine biodiversity, food quality, and ecosystem functioning.

Dr. Hong Zhou studies modern benthic community data collection from Chinese continental shelf and coastal habitats, including information on phenotypic and genotypic variation within and among species (e.g. Chinese polychaetes and other macrobenthic invertebrates, Chinese free- living marine nematodes in Barcode of Life Data System).

9. Relationship to other international programs and SCOR Working groups

CBIOS strongly relates to current and past SCOR WGs, as well as other international programs. Specifically, the objectives and scope of CBIOS will complement current SCOR WGs such as **Changing Ocean Biological Systems (COBS; SCOR WG#149)**, which is investigating the effects of oceanic conditions on marine organisms and ecosystems. CBIOS also builds off of past working groups, such as **WG#62: Carbon Budget of the Ocean**; and **WG#76: Ecology of the Deep Sea Floor**, and other large-scale research projects that have been co-sponsored by SCOR, such as the **Global Ocean Ecosystem Dynamics (GLOBEC)** which focused on the impacts of climate change on marine ecosystems and fisheries. Additionally, CBIOS complements the work conducted by SCOR **WG#128 Natural and Human-Induced Hypoxia and Consequences for Coastal Areas**, and two members of WG#128 are proposed members of CBIOS. This WG would also build on the foundation provided by the SCOR-sponsored workshop on benthic systems and several participants in that workshop are proposed as members of this group. CBIOS further complements these current and previously supported SCOR programs by investigating the impacts of climate change on benthic community dynamics and carbon cycling. Members of CBIOS have also been involved in a Pegasus/ Future Earth/ NCEAS workshop to advance the Global Ocean Observing System (GOOS).

CBIOS is currently seeking support from Utah State University to fund a workshop on marine animal-sediment interactions in Summer/Fall 2019 and will also seek support from **Ocean Carbon and Biogeochemistry (OCB)**, by applying for a Summer 2020 workshop (deadline December 2019) to be held at Woods Hole, MA.

April 15, 2019

Dear Dr. Thomas Bianchi and SCOR Working Group Proposal Review Committee:

I am writing on behalf of the Ocean Carbon & Biogeochemistry (OCB) Project Office to express our great interest in the proposed SCOR Working Group "*CBIOS (Changing Biotic-Sediment Interactions in the Ocean Seabed) - Rapidly Changing Biotic-Sediment Interactions in the Ocean Seabed – Biogeochemical Consequences in the 21st Century*." OCB is a network of scientists who work across disciplines to understand the ocean's role in the global carbon cycle and the response of marine ecosystems and biogeochemical cycles to environmental change. The proposed working group is highly relevant to the scientific goals of OCB and would help characterize and quantify processes involved in carbon transformation by the macrobenthos, which remains a key unknown in the ocean carbon cycle and has important implications for ocean carbon uptake and sequestration. Furthermore, earth system models currently lack the necessary information to effectively parameterize processes mediated by the macrobenthos, which limits our predictive understanding of how biogeographic and compositional shifts in these communities will impact global marine biogeochemical cycles.

As part of this activity, I understand that the investigators plan to submit an activity proposal on the macrobenthos to the next OCB solicitation, which will be of great interest to the OCB Scientific Steering Committee. The proposed working group, along with an associated OCB activity represent an important opportunity to build and strengthen this community of researchers and build awareness in the broader OCB community about the role of the macrobenthos and associated sedimentary processes in the ocean carbon budget.

We look forward to hearing more about this activity and are hopeful for a positive outcome.

Sincerely yours,

Heather M. Benway

Heather Benway
Executive Officer, OCB Project Office

10. Key References

1. Snelgrove, P. V. R. *et al.* Global Carbon Cycling on a Heterogeneous Seafloor. *Trends in Ecology and Evolution* (2018). doi:10.1016/j.tree.2017.11.004
2. Schmitz, O. J. *et al.* Animals and the zoogeochemistry of the carbon cycle. *Science (80-.).* (2018). doi:10.1126/science.aar3213
3. Atwood, T. B. *et al.* Predators help protect carbon stocks in blue carbon ecosystems. *Nature Climate Change* (2015). doi:10.1038/nclimate2763
4. Ciais, P. *et al. Carbon and Other Biogeochemical Cycles. In: Cli- mate Change 2013: The Physical Science Basis. Climate Change 2013 - The Physical Science Basis* (2013). doi:10.1017/CBO9781107415324.015
5. Hülse, D., Arndt, S., Daines, S., Regnier, P. & Ridgwell, A. OMEN-SED 1.0: A novel, numerically efficient organic matter sediment diagenesis module for coupling to Earth system models. *Geosci. Model Dev.* (2018). doi:10.5194/gmd-11-2649-2018
6. Boyd, P. W. *et al.* Experimental strategies to assess the biological ramifications of multiple drivers of global ocean change—A review. *Global Change Biology* (2018). doi:10.1111/gcb.14102
7. Sotka, E. E. Natural selection, larval dispersal, and the geography of phenotype in the sea. in *Integrative and Comparative Biology* (2012). doi:10.1093/icb/ics084
8. Stanley, R. R. E. *et al.* A climate-associated multispecies cryptic cline in the northwest Atlantic. *Sci. Adv.* (2018). doi:10.1126/sciadv.aaq0929
9. Snelgrove, P. V. R., Thrush, S. F., Wall, D. H. & Norkko, A. Real world biodiversity-ecosystem functioning: A seafloor perspective. *Trends in Ecology and Evolution* (2014). doi:10.1016/j.tree.2014.05.002

11. Appendix - 5 publications for full members

Thomas S. Bianchi

Bianchi, T.S., Blair, N., Burdige, D., Eglinton, T.I., Galy, V. (2018) Centers of organic carbon burial at the land-ocean interface. *Org. Geochem.* 115: 138-155.

Shields, M.R., Bianchi, T.S., Mohrig, D., Hutchings, J.A., Kenney, W.F., Kolker, A.S., Curtis, J.H., 2017. Carbon storage in the Mississippi River delta enhanced by environmental engineering. Nat. Geosci. 10, 846–851. https://doi.org/10.1038/ngeo3044.

Smith, R.W., Bianchi, T.S., Allison, M.A., Savage, C., Galy, V. (2015) The Role of Fjords as Major Oceanic Sites of Marine Organic Carbon Burial. *Nat. Geosci.* 8: 450–453.

Bauer, J.E., Cai, W.J., Raymond, P., Bianchi, T.S., Hopkinson, C.S., Regnier, P. (2013) The Coastal Ocean as a Key Dynamic Interface in the Global Carbon Cycle. *Nature* 504 (7478): 61-70.

Bianchi, T.S., Allison, M.A. (2009) Large-river delta-front estuaries as natural "recorders" of global environmental change. *Proc. Nat. Acad. Sci*. 106 (20): 8085-8092.

Luis Buatois

Buatois, L.A., Almond, J., Mángano, M.G., Jensen, S., Germs, G.J. (2018) Sediment disturbance by Ediacaran bulldozers and the roots of the Cambrian explosion. *Nat. Sci. Reports* 8: 4514.

Buatois, L.A., Mángano, M.G. (2018) The other biodiversity record: Innovations in animal-substrate interactions through geologic time. *GSA Today* 28:4-10.

Mángano, M.G., Buatois, L.A. (Eds.) (2016) The trace-fossil record of major evolutionary events. Volume 1: Precambrian and Paleozoic. *Topics Geobiol.* 39. Springer, 358 pp.

Mángano, M.G., Buatois, L.A. (Eds.) 2016. The trace-fossil record of major evolutionary events. Volume 2: Mesozoic and Cenozoic. *Topics Geobiol*. 40. Springer, 486 p.

Buatois, L.A., Mángano, M.G., Olea, R.A., Wilson, M.A. (2016) Decoupled evolution of soft and hard substrate communities during the Cambrian Explosion and Great Ordovician Biodiversification Event. *Proc. Nat. Acad. Sci.* 113: 6945–6948.

Judith Gobin

Amon, D.J., Gobin, J., Van Dover, C.L., Levin, L.A., Marsh, L., Raineault, N.A. (2017) Characterization of Methane-Seep Communities in a Deep-Sea Area Designated for Oil and Natural Gas Exploitation Off Trinidad and Tobago. *Front. Mar. Sci.* 4:1-16.doi: 10.3389/fmars.2017.00342.

Levin, L.A., Baco, A.R., Bowden, D., Colaço, A., Cordes, E., Cunha, M.R., Demopoulos, A., Gobin, J., Grupe, B., Le, J., Metaxas, A., Netburn, A., Rouse, G.W., Thurber, A.R., Tunnicliffe, V., Van Dover, C., Vanreusel, A., Watling., L. (2016) Hydrothermal Vents and Methane Seeps: Rethinking the Sphere of Influence. *Front. Mar. Sci*., section Deep- Sea Environments and Ecology. Front 3:72, pp 1-23.doi: 10.3389/fmars.2016.00072.

Cordes, E., Jones, D., Schlacher, T., Amon, D., Bernardino, A., Brooke, S., Carney, R., DeLeo, D., Dunlop, K., Escobar-Briones, E., Gates, A., Genio, L., Gobin, J., Henry, L., Herrera, S., Hoyt, S., Joye, M., Kark, S., Mestre, N., Metaxas, A., Pfeirfe, S., Sink, K., Sweetman, A., Witte, U. (2016) Environmental Impacts of the Deep-Water Oil and Gas Industry: A Review to Guide Management Strategies. Frontiers in Marine Science, section Deep-Sea

Environments and Ecology. *Front. Environ. Sci*., 4:58, pp, 1-26.doi: 10.3389/fenvs.2016.00058.

Miloslavich, P., Webb, T., Snelgrove, P., Vanden Berghe, E., Kaschner, K., Halpin, P.N., Reeves, R.R., Lascelles, B., Tarzia, M., Wallace, B.P., Dulvy, N., Simpfendorfer, C.A., Schillinger, G., Boustany, A., Collette, B.B., Graves, J.E., Obura, D., Edwards, M., Clark, M., Stocks, K., Morato, T., Tunnicliffe, V., Hopcroft, R., Archambault, P., Pepin, P., Tunnell, J.W., Moretzsohn, F., Escobar-Briones, E., Ojaveer, H., Gobin, J., Nakaoka, M., Fujikura, K., Yamano, H., Li, X., Venkataraman, K., Raghunathan, C., Griffiths, C.L., Bax, N.J., Butler, A.J., Brandt, A., Griffiths, H.J., Rice, J. (2016) World Oceans Assessment. Chapter 35. Extent of Assessment of Marine Biological Diversity, pp 1-58.

Sharkey, P.M., Merrick, J., Gobin, J. (2016) Chapter 3: Benthic Assemblages in South American Intertidal Rocky Shores: Biodiversity, Services and Threats, pp 83-137, *In* Marine Benthos, Biology, Ecosystem Functions and Environmental Impact. Editors: Rafael Riosmena-Rodríguez (The Autonomous University of Baja California Sur, Marine Biology Department and Marine Botany Research Program, Mexico).

Sharkey, P.M., Merrick, J., Gobin, J. (2016) Chapter 5: Environmental Impacts on Marine Benthic Communities in an Industrialized Caribbean Island- Trinidad and Tobago, pp169-179. *In* Marine Benthos, Biology, Ecosystem Functions and Environmenta Impact. Editors: Rafael Riosmena-Rodríguez (The Autonomous University of Baja California Sur, Marine Biology Department and Marine Botany Research Program, Mexico).

Natasha Karenyi

Karenyi, N., Sink, K., Nel, R., Clark, A.E., Altwegg, R. (2018) Imperfect detection distorts depth-related trends in marine macrofaunal species richness. *Ecography*. 41(10): 1698-1706.

Karenyi, N., Sink, K., Nel, R. (2016) Defining seascapes for marine unconsolidated shelf sediments in an eastern boundary upwelling region: the southern Benguela as a case study. *Estuar. Coast. Shelf Sci.* 169: 195-206.

Karenyi, N., Nel, R., Altwegg, R., Sink, K. (2016) Incorporating species detectability into conservation targets based on the species–area relationship. *Divers. Distrib.* 22: 758–769.

Kruger, N., Branch, G.M., Griffiths, C.L., Field. J.G. (2005) Changes in the benthos of Saldanha Bay (1960s-2001): an analysis based on dredge samples. *African J. Mar. Sci.* 27(2): 471- 477.

Griffiths, C.L., Van Sittert, L., Best, P.B., Brown, A.C., Clark, B.M., Cook, P.A., Crawford, R.J.M., David, J.H.M., Davies, B.R., Griffiths, M.H., Hutchings, K., Jerarddino, A., Kriger, N., Lamberth, S., Leslie, R.W., Melville-Smith, R.W., Tarr, R., Van der Lingen, C.d. (2004) Impacts of human activities on marine animal life in the Benguela: a historical overview. *Oceanogr. Mar. Biol.: An Ann. Rev.* 42: 303-392

Agnes Karlson

Ek, C., Holmstrand, H., Mustajärvi, L., Garbaras, A., Barisevičiū te, R., Šapolaitė, J., Sobek, A., Gorokhova, E., Karlson, A.M.L. (2018) Using Compound-Specific and Bulk Stable Isotope Analysis for Trophic Positioning of Bivalves in Contaminated Baltic Sea Sediments. *Environ. Sci. Technol. 52(8)* DOI: 10.1021/acs.est.7b05782.

Karlson, A.M.L., Niemand, C., Savage, C., Pilditch, C.A. (2016) Density of key-species determines efficiency of macroalgal uptake by intertidal benthic communities *PLos ONE* 11, e0158785.

Karlson, A.M.L., Gorokhova, E., Elmgren, R. (2015) Do deposit-feeders compete? Isotopic niche analysis of an invasion in a species-poor system. *Sci. Reports* 5: *9715. DOI: 10.1038/srep09715.*

Karlson, A.M.L., Gorokhova, E., Elmgren, R. (2014) Nitrogen fixed by cyanobacteria is utilized by deposit-feeders. *PLoS ONE* 9(8): e104460.

Karlson, A.M.L., Nascimento, F.J.A., Näslund, J., Elmgren, R. (2010) Higher diversity of deposit-feeding macrofauna enhances phytodetritus processing. *Ecology* 91: 1414-1423.

Lisa A. Levin

Sweetman, A.K., Thurber, A.R., Smith, C.R., Levin, L.A., Mora, C. Wei, C.L., Gooday, Jones, D.O.B., Rex, M. Yasuhara, M., Ingels, J., Ruhl, H.A., Frieder, C.A., Roberto, D., Wurzberg, L., Baco, A. Grupe, B.M., Pasulka, A. Meyer, K.S., Dunlop, K.M., Henry, L.A., Roberts, J.M. (2017) Major impacts of climate change on deep seafloor ecosystems. *Elementa* DOI: https://doi.org/10.1525/elementa.203.

Sperling, E.A., Frieder, C.A., Levin, L.A. (2016) Biodiversity response to natural gradients of multiple stressors on continental margins. *Proceeding Royal Society B.* 283: 20160637. http://dx.doi.org/10.1098/rspb.2016.0637.

Levin, Lisa A., Le Bris, N. Deep oceans under climate change (2015) *Science* 350: 766-768. (2015)

Levin, L.A., Sibuet, M. (2012) Understanding Continental Margin Biodiversity: A New Imperative. *Ann. Rev. Mar. Sci.* doi: 10.1146/annurev-marine-120709-142714

Levin, L.A., Ekau, W., Gooday, A., Jorrisen, F., Middelburg, J., Neira, C., Rabalais, N., Naqvi, S.W.A., Zhang, J. (2009) Effects of natural and human-induced hypoxia on coastal benthos. *Biogeosciences* 6: 2063-2098.

Jack J. Middelburg

Middelburg, J.J. (2019) Ocean carbon biogeochemistry: *A primer for Earth System Scientists*. Springer International Publishing, 118 pp. 10.1007/978-3-030-10822-9 (open access book)

Middelburg, J.J. (2018) Reviews and synthesis: to the bottom of carbon processing at the seafloor. *Biogeosciences* 15(2): 413-427.

Woulds, C., Bouillon, S., Cowie, G.L., Drake, E., Middelburg, J.J., Witte, U. (2016) Patterns of carbon processing at the seafloor - the role of faunal and microbial communities in moderating carbon flows. *Biogeosciences* 13: 4343-4357.

Meysman, F.J.R., Boudreau, B.P., Middelburg, J.J. (2010) When and why does bioturbation: lead to diffusive mixing. *J. Mar. Res*. 68: 891-920.

Meysman, F.J.R., Middelburg, J.J., Heip, C.H.R. (2006) New insights into Darwin's last idea: bioturbation. *Trends Ecol. Evol* 21: 688-695.

Pierre Regnier

Arndt, S., Jørgensen, B. B., LaRowe, D. E., Middelburg, J. J., Pancost, R. D. and Regnier, P. (2013) Quantifying the degradation of organic matter in marine sediments: A review and synthesis. (2013) *Earth Sci. Rev.* 123 : 53-86.

Bauer, J.E., Cai, W-J, Raymond, P., Bianchi, T., Hopkinson, C. and Regnier P. (2013) The changing coastal carbon cycle. (2013) *Nature* 504 : 61–70.

Hülse, D., Arndt, S., Daines, S., Regnier, P., and Ridgwell, A. (2018) OMEN-SED 1.0: a novel, numerically efficient organic matter sediment diagenesis module for coupling to Earth system models. *Geoscient. Model Develop*. 11: 2649-2689, doi: 10.5194/gmd-11-2649.

Regnier, P., Friedlingstein, P., Ciais, P., Mackenzie, F.T., Gruber, N. et al. (2013) Anthropogenic perturbation of the carbon fluxes from land to ocean. *Nature Geosci.*, 6 (8) : 597-607.

Thullner M., Dale, A.W. and Regnier P. (2009) Global scale quantification of organic carbon degradation pathways in marine sediments: a reactive transport modeling approach. Geochem. Geophys. Geosyst. 10:1, doi:10.1029/2009GC002484.

Paul V.R. Snelgrove

Stanley, R.R.E., DiBacco, C., Lowen, B., Bieko, R., Wyngaarden, M., Jeffery, N.W., Bentzen, P., Bernatchez, L., Gosselin, T., Johnson, C., Snelgrove, P.V.R., Wringe, B.F., Bradbury, I.R. (2018) A climate-associated multi-species cryptic genetic cline in the northwest Atlantic. *Sci. Adv.* 4, eaaq0929 (2018).

Snelgrove, P.V.R., Soetaert, K., Solan, M., Thrush, S., Wei, C.-L., Danovaro, R, Fulweiler, R.W., Kitazato, H., Ingole, B., Norkko, A., Parkes, R.J., Volkenborn, N. (2018) Contrasting biogeochemical and biological estimates of carbon turnover on the global seafloor. *Trends Ecol. Evol.* 33: 96-105.

Belley, R., Snelgrove, P.V.R (2017) The role of infaunal functional groups in short-term response of contrasting benthic communities to an experimental food pulse. *J. Exp. Mar. Biol. Ecol.* 491: 38-50.

Belley, R., Snelgrove, P.V.R. (2016) Relative contributions of biodiversity and environment to benthic ecosystem functioning. *Front. Mar. Sci.* 3, 10.3389/fmars.2016.00242

Snelgrove, P.V.R. Thrush, S.F., Wall, D.H., Norkko, A. (2014) Biodiversity - ecosystem functioning for the real world: A seafloor perspective. *Trends Ecol. Evol.* 29: 398-405.

Hong Zhou

Sun, X.Y., Zhou, H., Hua, E., Xu, S.H., Cong, B.Q., Zhang, Z.N. (2014) Meiofauna and its sedimentary environment as an integrated indication of anthropogenic disturbance to sandy beach ecosystems. *Mar. Poll. Bull.* 88: 260-267.

Zhou, H., Zhang, Z.N., Liu, X.S., Hua, E. (2012) Decadal change in sublittoral macrofaunal biodiversity in the Bohai Sea, China. *Mar. Poll. Bull.* 64: 2364-2373.

Zhou, H., Fend, S.V., Gustafson, D.L., Wit, P.D., Erséus, C. (2010) Molecular phylogeny of Nearctic species of *Rhynchelmis* (Annelida). *Zool. Scr.* 39: 378-393.

Zhou, H., Zhang, Z.N., Chen, H.Y., Sun, R.H., Wang, H., Guo, L., Pan, H.J. (2010) Integrating a DNA barcoding project with an ecological survey: a case study on temperate intertidal polychaete communities in Qingdao, China. *Chin. J. Oceanol. Limnol.* 28: 899-910.

Zhou, H., Zhang, Z.N., Liu, X.S., Tu, L.H., Yu, Z.S. (2007) Changes in the shelf macrobenthic community over large temporal and spatial scales in the Bohai Sea, China. *J. Mar. Syst.* 67: 312-321.

C-GRASS: Coordinated Global Research Assessment Of Seagrass Systems

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1. Summary

Seagrasses provide the foundation of submerged coastal grassland ecosystems around the world but are threatened by human activities, with substantial declines in global cover over the last century. Seagrasses provide multiple valuable ecosystem services, particularly in the developing world. Yet obtaining an accurate understanding of seagrass status, trends, and responses to global change has been challenging due to the fragmented nature of available data. The time is opportune to solve these problems. Building on a recently completed Community White Paper and initial workshops to organize global seagrass researchers, we propose a series of SCOR workshops to collate and analyze existing data toward a scientific synthesis of the drivers and trajectories of seagrass ecosystems under global change, and to provide a framework for future coordinated observation and research on seagrass systems. Our Working Group (WG) engages a diverse community, spanning the globe and fields of technical expertise to: (1) collate and analyze existing data to publish an open-access scientific synthesis of current status, trends, and drivers of change in global seagrass systems; (2) establish common protocols and best practices for seagrass data collection, curation, and sharing, collated in a multi-media handbook of accepted protocols and best practices; (3) integrate seagrass data collection into international, open-access portals, with common frameworks for data vocabulary, metadata, management, and service to stakeholders; and (4) integrate ongoing seagrass monitoring and research into a global community of practice that incorporates diverse data types and informs diverse end users.

2. Scientific Background and Rationale

2.1. Global status of seagrass ecosystems

Seagrasses provide the foundation of submerged coastal grassland ecosystems around the world. They are among the most productive natural habitats on land or sea (1), store substantial quantities of carbon, and provide humanity with fishery habitat, coastal protection,

erosion control, and other services (2). Seagrass nutrient cycling services alone have an estimated value of nearly $2 trillion per year (3), and Indonesian seagrass meadows provide fishery nursery areas that contribute an estimated 54% to 99% of daily protein intake for local communities (4).
Seagrasses also serve as early warning indicators of anthropogenic perturbations in the coastal zone due to their sensitivity to changing water quality and fishing activities (5).

Seagrass habitats are threatened worldwide by human activities: a recent synthesis estimates that almost 30% of seagrass global cover has been lost over the last century (6) and 22 of the world's 72 seagrass species (31%) are in decline (2, 7), a trend widely considered a global crisis (8).
Recognizing this, the Global Ocean Observing System (GOOS) has proposed seagrass cover and composition as one of seven Essential Ocean Variables (EOVs) defined by societal importance as reflected in reporting requirements for numerous international conventions and agreements that shape policy responses to global change (9).

Despite their importance, developing coordinated systems for observing seagrass status and trends has been challenging for several reasons. First is the fragmented nature of available in situ data. Data on seagrass systems are collected by numerous local and regional monitoring programs, and by two global programs: Seagrass-Watch (10, 11), SeagrassNet (12). These networks, together with the Smithsonian's newer MarineGEO program, have engaged hundreds of scientists and thousands of citizens in collecting data. But such programs often have different objectives, methods, and target variables, making inter-comparison and synthesis difficult. A second challenge is that field sampling is biased geographically, concentrated in North America and western Europe around major scientific organizations. As a result, syntheses of seagrass occurrence rely heavily on interpolation of expert knowledge and low-resolution point-based occurrence sampling, whereas seagrass extent is difficult to quantify and resolution is low in the regions where seagrasses are most diverse such as the western Pacific.

2.2. New opportunities in seagrass science and conservation

We are now poised to overcome these historical challenges, as illustrated by several recent developments. These include production of a consensus Community White Paper outlining criteria for a coordinated global seagrass observing system (13), convening of the International Seagrass Experts Network (ISEN),[3] an upcoming GOOS workshop to draft implementation plans for seagrass and mangrove observing, and participation in this WG of leaders of the two major global seagrass networks, Seagrass-Watch (WG member McKenzie) and SeagrassNet (WG member Short). Recent field initiatives have focused on seagrasses in the rich and understudied territories of southeast Asia and the coral triangle, including by members of this Working Group: Ambo-Rappe, Cullen-Unsworth, Fortes, Nordlund, Prathep, and Unsworth. While Africa remains poorly documented, WG member Uku is an authority in that region. This work promises to significantly expand geographic coverage of seagrass knowledge in understudied areas.

[3] See: http://unseagrass.org/

Additional opportunities to assemble a geographically comprehensive and well resolved understanding of global seagrass systems come from innovations in remote sensing; engagement of citizen scientists in field data collection; and community consensus around the need for standardization of protocols and data management (13). Our proposed working group (WG) aims to integrate and coordinate remote sensing and in situ sampling programs toward a more powerful scientific synthesis of global seagrass distribution and ecosystem characteristics. The WG will then extend this synthesis by coordinating seagrass ecosystem researchers worldwide toward consensus on comparable approaches for collecting and organizing data on seagrass cover, composition, and ecosystem characteristics. The WG will have the secondary benefit of providing a scientific and operational foundation to advance seagrass cover and composition as an Essential Ocean Variable (1).

2.3. Rationale for a SCOR working group

We propose a series of SCOR workshops that engage a diverse community of scientists and stakeholders to achieve the following goals: (1) collate and analyze data to produce a synthesis of the current status, trends, and drivers of change in global seagrass systems; (2) establish common protocols and best practices for seagrass data collection, curation, and sharing; (3) integrate existing and ongoing seagrass data collection into open-access portals, using a common schema; and (4) integrate existing seagrass monitoring and analysis into a unified, global community of practice. The proposed workshops will establish the community to continue the process into the future, and several participating institutions are committed to supporting achievement of the long-term goals.

Over the last few years seagrass researchers around the world have recognized the need for a more coordinated global response to understanding and publicizing seagrass degradation and have begun to coalesce around a shared vision for achieving this (8, 13). The time is ripe for a new global assessment of seagrass ecosystems. Achieving such a synthesis requires engaging expertise in seagrass physiology, field ecology, biogeochemistry, remote sensing, database architecture, geospatial science and mapping, social science, and digital knowledge product development and service. The proposed WG, and our large network of collaborators, spans this expertise. Foundations have been laid by incorporating seagrass cover as an Essential Ocean Variable by the Global Ocean Observing System (9), engaging the global community in the consensus Community White Paper (13), and formation of the ISEN.

The primary bottlenecks to a global seagrass database are comparability of protocols and accessibility of data. We will make rapid progress on the first of these as leaders of both major seagrass networks and the MarineGEO program are full members of this group (McKenzie, Short, Duffy). An achievable first step is to establish a public metadata portal to summarize what seagrass data exist and who holds them. We will then work to make as much of this data as possible accessible and will incorporate new data as they become available.

Candidate protocols and best practices have been developed, vetted, and formalized by Seagrass- Watch, SeagrassNet, the *Zostera* Experimental Network (14), MarineGEO,[4] and

[4] Available at: https://marinegeo.github.io/seagrass.html

other programs, providing a foundation for a global community of practice. Under the right conditions, satellite remote sensing (15) and lightweight drone technology (16) can obtain high-resolution maps of seagrass distribution and resolve variation in abundance, offering promise in linking regional and global-scale cover mapping, and validating these with strategically sited *in situ* measurements.
We will evaluate the capabilities of remote sensing to conduct regional assessments on the health and cover of seagrass communities. Satellite images collected over the past 30 years provide an basis for evaluating change, yet it is not clear how this technology can be leveraged with new unmanned airborne systems and field efforts. WG Members Muller-Karger and Dierssen bring experience in these areas to the WG.

The accessibility of shallow-water seagrass meadows and their importance to local fisheries and ecosystems makes seagrass systems prime targets for application of citizen science monitoring, as done by Seagrass-Watch and the Seagrass Spotter phone app,[5] co-developed by WG Member Unsworth. There is considerable potential to expand and integrate these activities. Through all these approaches, we are poised to achieve a previously unavailable synthesis of the changing distribution of global seagrass habitat, and the drivers of these trends. This process will also advance implementation of the seagrass EOV envisioned as part of GOOS.

3. Terms of Reference

The objectives of the SCOR C-GRASS Working Group are:

Objective 1: Produce a scientific synthesis of status and trends in global seagrasses and the systems they support, via a comprehensive review of peer-reviewed and gray literature, and unpublished data, on seagrass occurrence, ecosystem characteristics, and benefits to human well- being.

Objective 2: Produce a handbook of standard protocols and best practices for collecting, curating, and sharing data on seagrass ecosystems among scientists and stakeholder groups, building on existing experience of scientists and end-users in management and conservation, and contributed to the Ocean Data Standards and Best Practices Project of IODE.

Objective 3: Promote development of standardized vocabularies for variables and data schemas specific to seagrass ecosystems, and integration of existing and new data into the Ocean Biodiversity Information System (OBIS) using the EVENT-DATA schema (17).

Objective 4: Organize an interdisciplinary community of practice to synthesize data on status, trends, and drivers of global change in seagrass ecosystems, building on and integrating existing resources.

[5] Available at: https://seagrassspotter.org/

4. Working plan

4.1. Objective 1: Produce a scientific synthesis of status and trends in global seagrass systems

The centerpiece of the Working Group will be assembling the existing global seagrass data into an updated scientific assessment, building on previous assessments of global seagrass occurrence (18). Collaboration of major global seagrass networks (WG members Short, McKenzie, Duffy) will achieve an unprecedented coordination and integration of data, knowledge, and practice.
The data will be analyzed with ocean environmental data layers and data on human activities to quantify drivers of change in global seagrass systems. The results will be published in peer-reviewed paper(s), and integrated into the UNEP-WCMC Ocean+ initiative, which maintains a database of seagrass cover and produces maps and knowledge products that directly inform decision-making (available through Ocean Data Viewer[6]), including the *Global Distribution of Seagrasses*.[7] The synthesis will also link in situ seagrass data to remote sensing approaches (19) and quantification of seagrass ecosystem services (WG members Cullen-Unsworth and Nordlund) (20, 21).

4.2. Objective 2: Produce a handbook of standard protocols and best practices

Agreement on comparable protocols and best practices is key to coordinating monitoring across a distributed network and ensuring that data are comparable across space and time. We will assemble and analyze core measurements and protocols for in situ survey methods (22), remote- sensing approaches (15), and sampling designs, focusing on those that are fit to purpose, i.e., selected to provide information of appropriate resolution, quality, and scale to capture seagrass trends relevant to reporting requirements of nations and decision-makers. This process is facilitated because only two large networks dominate the field and leaders of both (McKenzie, Short) are members of our WG. The Working Group will produce a multi-media handbook, linked to training videos and online resources facilitating field data collection, data management, and curation methods accepted by community consensus. These products will accelerate data collection and integration across networks by making protocols and data more accessible, and by building capacity to collect and contribute data, also adding value to existing networks (as confirmed by participation of Short and McKenzie).

4.3. Objective 3: Promote development of standardized vocabularies and data schemas

Rigorous comparison of data among programs requires a common language. The recently developed EVENT-DATA OBIS schema uses a standard Darwin Core set of terms and accommodates sampling descriptions, environmental data, and biodiversity records. The WG will develop and compile a standardized vocabulary for seagrass systems via established OBIS collaborations developed by the MBON (WG member Muller-Karger) and Smithsonian MarineGEO (WG co-lead Duffy). We will integrate a substantial body of records of seagrass cover and species composition into OBIS, notably from SeagrassNet representing 33

[6] Available at: http://data.unep-wcmc.org
[7] Available at: http://data.unep-wcmc.org/datasets/7

countries, Seagrass-Watch representing 26 countries, and the 13 sites in the MarineGEO program.

Data access and ownership are key issues in the emerging networked data ecosystem. A key first step will be a metadata portal. We will promote availability of as much seagrass data as possible, building on the Seagrass-Watch model, which involves a tiered system of data sharing that respects the ownership of raw data, while making detailed summaries available via open access portals.

Objective 4: Organize an interdisciplinary community of practice

A dynamic observing system for seagrasses requires a coordinated effort, structures to manage ongoing data input and access to maintain inter-comparability, and engagement of diverse partners across the world, disciplinary expertise, and knowledge of the needs of policy- and decision-makers. We will focus on linking the web portals and protocols of the Seagrass-Watch, SeagrassNet, the Ocean Data Viewer, and MarineGEO programs, leveraging resources already invested in them and the continuing support of their secretariat institutions. Working Group members, including the UN Environment World Conservation Monitoring Centre (UNEP- WCMC, with leadership from co-chair Weatherdon) and GRID-Arendal (Maria Potouroglou
) will assist in engaging end-users of the information products from the policy community, and in developing a communications strategy. UNEP-WCMC's existing seagrass layer has been used for environmental sensitivity mapping, marine spatial planning, high-level screening of biodiversity risk, and blue carbon assessments, and its application to ecosystem-based adaptation to climate change is in progress. We expect rapid uptake of our findings in development and refinement of global blue carbon inventories and development of blue carbon markets as several WG members play advisory roles in International Blue Carbon Partnership (collaborator Peter Macreadie), the IUCN Blue Carbon Initiative (Fourqurean, Fortes, Marba), the IPCC Guidelines for National Greenhouse Gas Inventories (Macreadie), and the Coastal Carbon Research Coordination Network (Duffy).

4.4. Timeline

Working Group meetings will be held in association with international conferences and we will work to leverage other funds to cover costs of participants; several participating institutions have offered financial or in-kind support. Likely venues for meetings include the 14th International Seagrass Biology Workshop (2020, Washington DC); and international Ocean Science meetings.

Month 1: Working Group meeting 1. Hone goals, assign subgroups with leads for each of the four objectives. Begin to identify data sources and tractable synthesis goals, and to assemble data and metadata (Objective 1). Draft outline of best practices (Objective 2) and data schema (Objective 3).

Month 1-12: Subgroups work on collating data, integrating into the developing data schema (Objectives 1,3), and converge on best practices for handbook (Objective 2). Integrate sample data sets into OBIS using draft schema (Objectives 1,3).

Month 12: WG meeting 2. Present draft of best practices document (Objective 2) and data schema (Objective 3) for discussion by WG. Review data assembled, outline synthesis papers, and begin intensive data analysis (Objective 1).

Month 12-24: Continue work on best practices (Objective 2) and synthesis paper(s) (Objective 4). Introduce drafts to policy end-users and incorporate feedback.

Month 24: WG meeting 3. Complete best practices handbook (Objective 2) and synthesis papers (Objective 4). Report on data integration (Objectives 1, 3), challenges, and plans.

Month 24-36: Subgroups finish work on all four objectives.

Month 36: Meeting of selected WG members, lead authors, and data architects, to synthesize results toward the Objectives, finish products, and develop plans for long-term advancement. Official launch of products.

5. Deliverables

(1) Hold a town hall meeting at the 2020 Ocean Sciences meeting (and potentially others) to announce the Working Group effort and solicit broad input. Contributes to delivering all Objectives.
(2)
(3) Produce a peer-reviewed scientific synthesis of status, trends, and environmental and anthropogenic drivers of change in global seagrasses and the systems they support, based on a comprehensive review of peer-reviewed and gray literature and unpublished data available in major seagrass network databases. Delivers Objective 1.

(4) Integrate existing seagrass data, and ongoing monitoring data, into the Ocean Biodiversity Information System (OBIS) using a common data schema. Contributes to delivering Objectives 1 and 3.

(5) Produce a peer-reviewed handbook of inter-comparable protocols and best practices for seagrass field measurements and data management, published and contributed to the Ocean Data Standards and Best Practices Project of IODE. Delivers Objective 2.

6. Capacity Building

The community of practice built through this series of working groups will be advanced into the future in several ways. First, we engage seagrass researchers and stakeholders from a diverse range of backgrounds, geographic regions, and disciplines in this common,

collaborative effort. Second, we intend to develop courses with support from IODE Ocean Teacher Global Academy (OTGA) of the International Oceanographic Data and Information Exchange (IODE) to spread the protocols, best practices and synthesis tools in seagrass research to a global community. We will liaise with the OTGA program to propose an OBIS course tailored for the seagrass community, and seek support from OTGA. Third, the several seagrass observation programs, including Seagrass-Watch (McKenzie), SeagrassNet (Short), the MarineGEO program (Duffy), and the MBON (Muller-Karger) conduct training and outreach activities that will promote the best practices developed by the WG. Finally, development of the handbook and other products will also focus on feeding information into international targets such as the UN Sustainable Development Goals and Aichi Targets, as well as the post-2020 biodiversity agenda, with leadership by UNEP-WCMC (Weatherdon) and GRID-Arendal (Potouroglou).

7. Working Group Composition

Our Working Group brings together ten Full Members (6 female, 4 male), representing 9 countries, and a range of career stages and disciplinary expertise from seagrass biology to biogeochemistry, remote sensing, fisheries, social science, and global conservation. Several Full and Associate Members are leaders in existing synthesis and coordination efforts in coastal marine and seagrass science. This diversity will help ensure that interdisciplinary products of the working group are effectively communicated to a wide audience and translated into practical applications.

7.1. Full Members

Name	**Gender**	**Place of Work**	**Expertise**
Emmett Duffy (co-chair)	M	Smithsonian Institution, USA	Marine ecology and biodiversity
Lauren Weatherdon (co-chair)	F	UN Environment World Conservation Monitoring Centre, UK	digital knowledge products, ocean biodiversity and spatial data
Rohani Ambo Rappe	F	Universitas Hasanuddin, Indonesia	Seagrass ecology, ecosystem services, seagrass restoration
Leanne Cullen-Unsworth	F	Cardiff University, Wales	Coupled social-ecological systems, seagrass ecosystem services
Miguel Fortes	M	University of the Philippines	Seagrass & mangrove ecology, blue carbon, policy & coastal resilience

Núria Marbà	F	Consejo Superior de Investigaciones Científicas, Spain	Seagrass ecology, global change
Len McKenzie	M	James Cook University, Australia	Seagrass status, management and sustainable use, founder Seagrass-Watch
Maria Potouroglou	F	GRID Arendal, Norway	Seagrass mapping, monitoring and ecosystem services assessment, coastal and marine policy
Fred Short	M	University of New Hampshire, USA	Seagrass ecology and restoration, founder SeagrassNet
Jacqueline Uku	F	Kenya Marine and Fisheries Research Institute	Seagrass physiology, ecology, community development

7.2. Associate Members

Name	**Gender**	**Place of Work**	**Expertise**
Rod Connolly	M	Griffith University, Australia	Seagrass ecosystem resilience, carbon pathways, fisheries food web
Maricela de la Torre Castro	F	Stockholm University, Sweden	Social-ecological systems analysis, governance, gender, sustainable resource use, resilience
Heidi Dierssen	F	University of Connecticut, USA	Remote sensing of seagrass extent, leaf area index, carbon
Carlos Duarte	M	King Abdullah University of Science and Technology, Saudi Arabia	Marine ecology and oceanography, expertise in all aspects of seagrass ecology
James W. Fourqurean	M	Florida International University, USA	Ecosystem ecology, biogeochemistry of seagrass systems

Margot Hessing-Lewis	F	Hakai Institute, Canada	Coastal marine ecology, focusing on seagrass systems
Frank Muller-Karger	M	University of South Florida, USA	Biological oceanography, remote sensing, global change
Masahiro Nakaoka	M	Hokkaido University, Japan	Coastal ecosystem dynamics, seagrass ecology
Anchana Prathep	F	Prince of Songkla University, Thailand	Seaweed and seagrass biodiversity and ecology; coastal climate change
Richard Unsworth	M	Swansea University, Wales	Seagrass ecology, conservation, and ecosystem services, co-founder Project

8. Working Group contributions

Rohani Ambo Rappe is a seagrass ecologist, studying ecosystem services and seagrass restoration, with expertise in the seagrass systems of the coral triangle region, the most diverse marine systems in the world.

Leanne Cullen-Unsworth is a coupled social-ecological systems analyst focusing on seagrass ecosystem services, in particular seagrass fisheries and associated food security.

Emmett Duffy is a biodiversity scientist who founded the *Zostera* Experimental Network (ZEN) and is the first Director of the Smithsonian's Tennenbaum Marine Observatories Network and MarineGEO program. He is a member of MBON, the GOOS Biology and Ecosystem panel, and is lead development of specification sheet and implementation plan for the GOOS seagrass EOV.

Miguel D. Fortes is a coastal Ecologist, and specialist on Biodiversity, ICZM and Blue Carbon, focusing on seagrasses and mangroves. His works are major additions to seagrass science and policy in the tropics and are having major impacts in applications and in development of coastal resilience in the face of climate change and other environmental uncertainties.

Núria Marbà is a seagrass ecologist focusing on assessing sustainability and integrity of coastal ecosystems and ecosystem services as well as the impact of global change.

Len McKenzie is a seagrass and coastal ecosystems ecologist working to facilitate the protection, conservation, biological diversity, rehabilitation, management and sustainable development of seagrass resources. His research focuses on status and condition of seagrass

resources, the role of disturbance, and identifying thresholds of concern and investigating resilience of seagrass ecosystems. Len directs the Seagrass-Watch program, one of the two major global seagrass observing networks.

Maria Potouroglou is a biologist with extensive experience in seagrass ecosystems science and policy in several Regional Seas programmes, including the Eastern Africa, Mediterranean, North-West Pacific, Western Africa and ROPME Sea regions. She leads the scientific strategy of the first ever seagrass project in West Africa, and co-ordinates the UN Environment/GRID-Arendal convened International Seagrass Experts Network.

Fred Short is a seagrass ecologist with expertise in restoration, global seagrass mapping and monitoring, eelgrass stressors including nitrogen loading, physical impacts and climate change. He established the global seagrass monitoring program SeagrassNet and co-edited the seminal book *Global Seagrass Research Methods* (2001).

Jacqueline Uku is a marine ecologist working on seagrass systems in Kenya and recently engaged in community development projects along the Kenyan Coast. She is current President and member of the Western Indian Ocean Marine Science Association (WIOMSA), providing linkage to the member countries of the Western Indian Ocean.

Lauren Weatherdon leads development of digital knowledge products that contribute to a step- change in global access to, and use of, ocean biodiversity information and spatial data. These products help to support the delivery of global ocean goals and targets, and to support marine spatial planning, conduct environmental impact assessments, produce ecosystem assessments, and enhance ocean literacy; she is also a member of MBON.

9. Relationship to other international programs and SCOR Working groups

This project builds on and synergizes with two initiatives already underway. First, in May 2019, UN Environment/GRID Arendal will convene an International Seagrass Experts Network to produce a report, led by member Potouroglou, highlighting the current state and threats to seagrass systems and their ecosystem services with relevance to policy. Second, in June 2019, Co-chair Duffy will co-lead a NASA-funded workshop to develop implementation plans for the GOOS seagrass and mangrove Essential Ocean Variables (EOVs). These two activities, which involve several of our members, will lay a strong foundation by identifying available data sources, conducting a qualitative review, and articulating a plan for coordinating seagrass research globally. Our proposed SCOR project will advance to the next, quantitative step by picking up where those efforts leave off: assembling, harmonizing, and analyzing the metadata and available data to produce a quantitative picture of global seagrass status, and the rates and drivers of change. A second major product will be an agreement among key seagrass constituencies around the world on terms of coordination, protocol comparability, and data sharing in future research. Together, these activities will facilitate rigorous global analyses of seagrass distribution, change, and responses to environmental and anthropogenic forcing.

The proposed WG has important relevance to several other interdisciplinary global change science efforts, and to the science-policy-society interface and communication initiatives. These other efforts are not specifically focused on seagrasses and would benefit from the research advanced by this SCOR WG on seagrasses. Among these are the following. The OceanObs Research Coordination Network is an NSF-sponsored effort to advance the integration of biological observations into ocean observing systems for societal benefit, co-led by WG member Muller-Karger. We have already submitted a Community White Paper on seagrasses to the OceanObs'19 meeting in Honolulu, Hawaii, September 2019. The Marine Biodiversity Observation Network (MBON, with WG members Muller-Karger and Duffy) is a thematic program under the Group on Earth Observations Biodiversity Observation Network or GEO BON to strengthen understanding of marine biodiversity and coordinate monitoring of associated changes over time by defining marine Essential Biodiversity Variables or EBVs. The Global Ocean Observing System (GOOS) Bio-Eco Panel (WG members Muller-Karger and Duffy) seeks to improve the availability of existing core biological variables and identify and prioritize additional cross-cutting biological and ecosystem observation needs by defining Essential Ocean Variables or EOVs for biology and to integrate these with physical and biogeochemical EOV and observing programs. Several members of the proposed C-GRASS WG are closely involved in each of these efforts and will work to integrate the WG's activities with their goals.

10. Key References

1. Duarte C, Chiscano C (1999) Seagrass biomass and production: a reassessment. *Aquatic Botany* 65(1–4):159–174.
2. West JA, Calumpong HP, Martin G, Gaever S van (2016) Kelp Forests and Seagrass Meadows. *United Nations World Ocean Assessment*, eds Inniss L, Simcock A, pp 1–13.
3. Costanza R, et al. (1997) The value of the world's ecosystem services and natural capital. *Nature* 387(6630):253–260.
4. Unsworth R, Hinder SL, Bodger OG, Cullen-Unsworth LC (2014) Food supply depends on seagrass meadows in the coral triangle. *Environ Res Lett* 9(094005). doi:10.1088/1748-9326/9/9/094005.
5. Dennison W, et al. (1993) Assessing water quality with submersed aquatic vegetation. *BioScience* 43(2):86–94.
6. Waycott M, et al. (2009) Accelerating loss of seagrasses across the globe threatens coastal ecosystems. *Proceedings of the National Academy of Sciences* 106(30):12377–12381.
7. Short FT, et al. (2011) Extinction risk assessment of the world's seagrass species. *Biological Conservation* 144(7):1961–1971.
8. Orth R, et al. (2006) A global crisis for seagrass ecosystems. *BioScience* 56(12):987–996.
9. Miloslavich P, et al. (2018) Essential ocean variables for global sustained observations of biodiversity and ecosystem changes. *Global Change Biology* 105(6332):10456–18.
10. McKenzie LJ, Long L, marina RCB, 2000 (2000) Seagrass-Watch: Community based monitoring of seagrass resources. *Biol Mar Medit* 7(2):393–396.
11. Jones BL, Unsworth RKF, McKenzie LJ, Yoshida RL, Cullen-Unsworth LC (2017)

Crowdsourcing conservation: The role of citizen science in securing a future for seagrass. *Mar Pollut Bull*:1–0.
12. Short FT, et al. (2006) SeagrassNet monitoring across the Americas: case studies of seagrass decline. *Marine Ecology* 27(4):277–289.
13. Duffy JE (2019) Toward a coordinated global observing system for seagrasses and marine macroalgae. *Frontiers in Marine Science* in press.
14. Ruesink JL, et al. (2017) Form-function relationships in a marine foundation species depend on scale: a shoot to global perspective from a distributed ecological experiment. *Oikos* 127(3):364–374.
15. Muller-Karger FE, et al. (2018) Satellite sensor requirements for monitoring essential biodiversity variables of coastal ecosystems. *Ecological Applications* in press. doi:10.1002/eap.1682.
16. Duffy JP, Pratt L, Anderson K, Land PE, Shutler JD (2018) Spatial assessment of intertidal seagrass meadows using optical imaging systems and a lightweight drone. *Estuarine coastal and Shelf Science* 200:169–180.
17. De Pooter D, et al. (2017) Toward a new data standard for combined marine biological and environmental datasets - expanding OBIS beyond species occurrences. *BDJ* 5:e10989.
18. Green EP, Short FT (2003) *World atlas of seagrasses* (University of California Press) Available at: http://books.google.com/books?hl=en&lr=&id=dHV0NA3m2AIC&oi=fnd&pg=PA1&dq=w orld+atlas+of+seagrasses+short&ots=wxBQHQxIJP&sig=U3kliAAUH0Jf4H-yDtfsLZ5PLzw.
19. Wabnitz CC, Andréfouët S, Torres-Pulliza D, Muller-Karger FE, Kramer PA (2008) Regional-scale seagrass habitat mapping in the Wider Caribbean region using Landsat sensors: Applications to conservation and ecology. *Remote Sensing of Environment* 112(8):3455–3467.
20. Nordlund LM, Koch EW, Barbier EB, Creed JC (2016) Seagrass Ecosystem Services and Their Variability across Genera and Geographical Regions. *PLoS ONE* 11(10):e0163091-23.
21. Nordlund LM, et al. (2017) Seagrass ecosystem services – What's next? *Mar Pollut Bull*:in press.
22. Short FT, Coles RG (2001) Global seagrass research methods. 33. Available at: http://www.worldcat.org/title/global-seagrass-research-methods/oclc/935245623.

11. Appendix—5 key publications for full members

Emmett Duffy

Miloslavich, P. N. Bax, S. Simmons, E. Klein, W. Appeltans, O. Aburto-Oropeza, M. Anderson-García, S. Batten, L. Benedetti-Cecchi, D. Checkley, S. Chiba, E. Duffy, D. Dunn, A. Fischer, J. Gunn, R. Kudela, F. Marsac, F. Muller-Karger, D. Obura, Y.-J. Shin. 2018. Essential Ocean Variables for global sustained observations of biodiversity and ecosystem changes. Global Change Biology doi.org/10.1111/gcb.14108.

Duffy, J.E., C.M. Godwin, B.J. Cardinale. 2017. Biodiversity effects in the wild are as strong as global change drivers of productivity. Nature 549:261-264.

Naeem, S., R. Chazdon, J.E. Duffy, C. Prager, B. Worm. 2016. Biodiversity and human wellbeing: an essential link for sustainable development. Proceedings of the Royal Society of London B 283(1844): 20162091.

Stuart-Smith, R.D., G.J Edgar, N.S. Barrett, A.E. Bates, S.C. Baker, N. Bax, M. Becerro, J. Blanchard, D.J. Brock, G.F. Clark, T.R Davis, P.B. Day, J.E. Duffy, T. Holmes, E. Johnston, A. Jordan, N. Knott, J. Lefcheck, S.D. Ling, S. Kininmonth, A. Parr, E. Strain, H. Sweatman, R. Thomson. 2017. Assessing national trends in biodiversity indicators for rocky and coral reefs through integration of citizen science and scientific monitoring programs. BioScience, 67:134- 146.

Duffy, J.E. and 27 others. 2015. Biodiversity mediates top-down control in eelgrass ecosystems: A global comparative-experimental approach. Ecology Letters 18:696–705.

Lauren Weatherdon

Weatherdon LV, Appeltans W, Bowles-Newark N, Brooks TM, Davis FE, Despot-Belmonte K, Fletcher S, Garilao C, Hilton-Taylor C, Hirsch T, Juffe-Bignoli D, Kaschner K, Kingston N, Malsch K, Regan EC, Kesner-Reyes K, Rose DC, Wetzel FT, Wilkinson T, Martin CS. (2017). Blueprints of effective biodiversity and conservation knowledge products that support marine policy. *Frontiers in Marine Science* 4(96). Doi: 10.3389/fmars.2017.00096.

Weatherdon LV, Mcowen C, Martin CS, Thomas H. (2015). Marine and coastal data requirements to achieve Sustainable Development Goals. In: The Oceans and Us. Neumann C, T Bryan, L Pendleton, A Kaupo, J Glavan (eds.). Arendal, Norway: GRID-Arendal. Pp. 32-35. URL: http://wcmc.io/OceanAndUs.

Weatherdon LV, Fletcher R, Jones MC, Kaschner K, Sullivan E, Tittensor DP, Mcowen C, Geffert JL, van Bochove JW, Thomas H, Blyth S, Ravilious C, Tolley M, Stanwell-Smith D, Fletcher S, Martin CS. (2015). Manual of marine and coastal datasets of biodiversity importance. December 2015 edition. Cambridge (UK): UNEP World Conservation Monitoring Centre. 30 pp. (+4 annexes totalling 221 pp. and one e-supplement). URL: http://wcmc.io/MarineDataManual.

Bird K, Mcowen C, Weatherdon LV, Crooks S, Holmquist, J. (in production) Status of Tidal Marsh Mapping for Blue Carbon Inventories. In: A Blue Carbon Primer: The State of Coastal Wetland Carbon Science, Practice, and Policy. CRC Press. 350 pp.

Brummitt N, Regan EC, Weatherdon LV, Martin CS, Geijzendorffer IR, Rocchini D, Gavish Y, Haase P, Marsh CJ, Schmeller DS. (2017). Taking stock of nature: Essential biodiversity variables explained. *Biological Conservation* 213 (Part B): 252-255. Doi: 10.1016/j.biocon.2016.09.006.

Rohani Ambo Rappe

Unsworth, R.K., Ambo-Rappe, R., Jones, B.L., La Nafie, Y.A., Irawan, A., Hernawan, U.E., Moore, A.M. and Cullen-Unsworth, L.C., 2018. Indonesia's globally significant seagrass meadows are under widespread threat. Science of The Total Environment 634: 279-286.

Williams, S.L., Ambo-Rappe, R., Sur, C., Abbott, J.M. and Limbong, S.R., 2017. Species richness accelerates marine ecosystem restoration in the Coral Triangle. Proceedings of the National Academy of Sciences of the United States of America 114:11986-

11991.
Ambo-Rappe, R., 2016. Differences in Richness and Abundance of Species Assemblages in Tropical Seagrass Beds of Different Structural Complexity. Journal of Environmental Science and Technology 9:246. DOI: 10.3923/jest.2016.Ambo-Rappe, R., 2014. Developing a methodology of bioindication of human-induced effects using seagrass morphological variation in Spermonde Archipelago, South Sulawesi, Indonesia. Marine pollution bulletin, 86: 298-303.
Ambo-Rappe, R., Nessa, M.N., Latuconsina, H. and Lajus, D.L., 2013. Relationship between the tropical seagrass bed characteristics and the structure of the associated fish community. Open Journal of Ecology 3(05): 331-342.

Leanne Cullen-Unsworth

Nordlund LM, RKF Unsworth, M Gullstron, LC Cullen-Unsworth (accepted, October 2017) Global significance of seagrass fishery activity. *Fish & Fisheries* 2017; 00:1-14.
LC Cullen-Unsworth, RKF Unsworth (2016). Strategies to enhance the resilience of the world's seagrass meadows. *Journal of Applied Ecology*53, 967-972. doi:10.1111/1365- 2664.12637.
RKF Unsworth, SL Hinder, OG Bodger & LC Cullen-Unsworth (2014) Food supply depends on seagrass meadows in the Coral Triangle *Environmental Research Letters* 9: 094005 doi:10.1088/1748-9326/9/9/094005.
LC Cullen-Unsworth, L Mtwana Nordlund, J Paddock, S Baker, LJ McKenzie & RKF Unsworth (2014) Seagrass meadows globally as a coupled social-ecological system: implications for human well-being, *Marine Pollution Bulletin*, 83 (2): 387-397.
RKF Unsworth & LC Cullen (2010) Recognising the Necessity for Seagrass Conservation. *Conservation Letters*, 3 (2): 63-73.

Miguel Fortes

Fortes MD. 2018. Seagrass ecosystem conservation in Southeast Asia needs to link science to policy and practice, Ocean and Coastal Management. https://doi.org/10.1016/j.ocecoaman.2018.01.028 (Available on line)
Fortes MD and Salmo III SD. 2017. Mangroves in the Philippines: Responding to Change. Lambert Academic Publishing. Germany. 312 p.
Quiros TEAL, Croll D, Tershy B, Fortes MD, Raimondi P. 2017. Land use is a better predictor of tropical seagrass condition than marine protection. Biological Conservation 209: 454–463.
Short FT, Coles R, Fortes MD, Victor S, Salik M, Isnain I, Andrew J, Seno A. 2014. Monitoring in the Western Pacific region shows evidence of seagrass decline in line with global trends
Fortes MD. 2013. A Review: Biodiversity, Distribution and Conservation of Philippine Seagrasses, Philippine Journal of Science, 142: 95-111, Special Issue. ISSN 0031 – 7683

Núria Marbà

Roca, G., TAlcoverro, T., Krause-Jensen, D., Balsby, T.J.S., van Katwijk, M.M., Marbà, N., Santos, R., Arthur, R., Mascaró, O., Fernández-Torquemada, Y., Pérez, M., Duarte, C.M., Romero, J. 2016. Response of seagrass indicators to shifts in environmental stressors: a

global review and management synthesis. Ecological Indicators. 63: 310–323. http://dx.doi.org/10.1016/j.ecolind.2015.12.007

Marbà, N., Arias-Ortiz, A., Masqué, P., Kendrick, G.A., Mazarrasa, I., Bastyan, G.R., Garcia-Orellana, J., Duarte, C.M. 2015. Impact of seagrass loss and subsequent revegetation on carbon sequestration and stocks. Journal of Ecology, 103: 296–302. doi: 10.1111/1365-2745.12370.

Marbà, N., Díaz-Almela, E., Duarte, C.M. 2014. Mediterranean seagrass (Posidonia oceanica) loss between 1842 and 2009. Biological Conservation 176: 183–190. DOI: 10.1016/j.biocon.2014.05.024

Duarte, C.M., Losada, I.J., Hendriks, I.E., Mazarrasa I., Marbà N. 2013. The Role of Coastal Plant Communities for Climate Change Mitigation and Adaptation. Nature Climate Change 3: 961–968. DOI: 10.1038/NCLIMATE1970

Marbà N., Duarte C.M. 2010. Mediterranean Warming Triggers Seagrass (Posidonia oceanica) Shoot Mortality. Global Change Biology 16: 2366-2375

Len McKenzie

Unsworth, R.K., McKenzie, L.J., Collier, C.J., Cullen-Unsworth, L.C., Duarte, C.M., Eklöf, J.S., Jarvis, J.C., Jones, B.L. and Nordlund, L.M. 2018. Global challenges for seagrass conservation. Ambio 2018:1-15.

Jones, B.L., Unsworth, R.K., McKenzie, L.J., Yoshida, R.L. and Cullen-Unsworth, L.C., 2018. Crowdsourcing conservation: The role of citizen science in securing a future for seagrass. *Marine pollution bulletin*, *134*, pp.210-215.

Kilminster, K., McMahon, K., Waycott, M., Kendrick, G.A., Scanes, P., McKenzie, L., O'Brien, K.R., Lyons, M., Ferguson, A., Maxwell, P. and Glasby, T., 2015. Unravelling complexity in seagrass systems for management: Australia as a microcosm. Science of the Total Environment 534:97-109.

McKenzie LJ, Long L, marina RCB, 2000 (2000) Seagrass-Watch: Community based monitoring of seagrass resources. Biol Mar Medit 7(2):393–396.

McKenzie, L.J., Finkbeiner, M.A. and Kirkman, H., 2001. Methods for mapping seagrass distribution. Global seagrass research methods. Pp.101-121.

Maria Potouroglou

Potouroglou, M., Bull, J.C., Krauss, K.W., Kennedy, H.A., Fusi, M., Daffonchio, D., Mangora, M.M., Githaiga, M.N., Diele, K. and Huxham, M., 2017. Measuring the role of seagrasses in regulating sediment surface elevation. Scientific reports 7(1):11917.

Olsen, Y.S., Potouroglou, M., Garcias-Bonet, N. and Duarte, C.M., 2015. Warming reduces pathogen pressure on a climate-vulnerable seagrass species. *Estuaries and coasts*, *38*(2), pp.659- 667.

Potouroglou, M., Kenyon, E.J., Gall, A., Cook, K.J. and Bull, J.C., 2014. The roles of flowering, overwinter survival and sea surface temperature in the long-term population dynamics of Zostera marina around the Isles of Scilly, UK. Marine pollution bulletin 83(2):500-507.

Malea, P., Kevrekidis, T. and Potouroglou, M., 2013. Seasonal variation of trace metal (Mn, Zn, Cu, Pb, Co, Cd) concentrations in compartments of the seagrass Cymodocea nodosa. Botanica Marina 56(2):169-184.

Fred Short

Neckles, H.A., Kopp, B.S., Peterson, B.J. and Pooler, P.S., 2012. Integrating scales of seagrass monitoring to meet conservation needs. Estuaries and Coasts 35(1): 23-46.

Coles, R., Grech, A., Rasheed, M., McKenzie, L., Unsworth, R. and Short, F., 2011. Seagrass ecology and threats in the tropical Indo-Pacific bioregion. *Seagrass: Ecology, Uses and Threats.* Hauppauge: Nova Science Publishers. Pp.225-240.

Short, F.T., Polidoro, B., Livingstone, S.R., Carpenter, K.E., Bandeira, S., Bujang, J.S., Calumpong, H.P., Carruthers, T.J., Coles, R.G., Dennison, W.C. and Erftemeijer, P.L., 2011. Extinction risk assessment of the world's seagrass species. Biological Conservation 144(7): 1961-1971.

Short, F., Carruthers, T., Dennison, W. and Waycott, M., 2007. Global seagrass distribution and diversity: a bioregional model. Journal of Experimental Marine Biology and Ecology 350(1-2):3-20.

Green, E.P., Short, F.T. and Frederick, T., 2003. *World atlas of seagrasses*. University of California Press.

Jacqueline Uku

Aura, C.M., Hassan, F., Osore, M.K., Musa, S., Morara, G. and Uku, J., 2015. A comprehensive public-private partnership concept for resources sustainability from a mega- project management multi-level perspective. International Journal of Management and Sustainability, 4(11): 218-236.

Eklöf, J.S., Fröcklin, S., Lindvall, A., Stadlinger, N., Kimathi, A., Uku, J.N. and McClanahan, T.R., 2009. How effective are MPAs? Predation control and 'spill-in effects' in seagrass–coral reef lagoons under contrasting fishery management. Marine Ecology Progress Series, 384: 83-96.

Uku, J. and Björk, M., 2005. Productivity aspects of three tropical seagrass species in areas of different nutrient levels in Kenya. Estuarine, Coastal and Shelf Science, 63(3): 407-420.

Uku, J., Beer, S. and Björk, M., 2005. Buffer sensitivity of photosynthetic carbon utilisation in eight tropical seagrasses. Marine Biology, 147(5): 1085.

Björk, M., Uku, J., Weil, A. and Beer, S., 1999. Photosynthetic tolerances to desiccation of tropical intertidal seagrasses. Marine Ecology Progress Series 191:121-126.

2.2.6 Integration of international ocean acidification research at CO_2 seeps (InterSEEP) *Myers*

Title: Integration of international ocean acidification research at CO_2 seeps.

Acronym: InterSEEP

Summary
Ocean acidification (OA) is caused by the uptake of anthropogenic carbon dioxide (CO_2) and its effects on ocean chemistry are well understood. Most OA research has been conducted in laboratories and mesocosms, which isolate organisms from their environment, so the effects of OA on marine communities, species interactions, food web structure, and on ecosystem services are poorly known. Over the past 10 years, the study of shallow marine CO_2 seeps has emerged as a powerful tool to address this knowledge gap, to assess effects of OA on coastal ecosystems. This research community remains fragmented internationally, with a lack of capacity to study CO_2 seep systems in developing nations, so the time is right to form an international forum to exchange knowledge and coordinate efforts.

This working group will coordinate interdisciplinary international studies using natural CO_2 gradients on seeps worldwide to analyse current data available, plan *in situ* observations, agree a set of standard techniques for work in seeps, and establish a foundation for long-term capacity building. A new global research community will be formed for the exchange of scientific information, to share new technologies/facilities, and to coordinate programs that no single nation can achieve alone. InterSEEP will also strengthen the voice of shallow CO_2 seep researchers worldwide, providing syntheses for policy makers and a legacy through training scientists worldwide.

Scientific Background and Rationale

Atmospheric pCO_2 will almost certainly double from pre-industrial levels by 2100, higher than at any time during the past few million years.[1] CO_2 emissions have caused a 26% increase in [H+] in surface ocean waters since the early 1900s, with a projected drop in seawater pH of up to 0.5 units by 2100.[1] Additionally, increased air-sea heat flux and altered circulation patterns have led to significant warming of the global ocean, while extreme warming of seeps has also intensified in many regions.[1,2] The combined stressors of ocean acidification (OA) and warming are a major threat to marine ecosystems and the goods and services they provide (e.g., food provision and security, coastal defence, mitigation of climate change-blue carbon).[3] However, current understanding of how marine ecosystems will respond to climate change remains severely limited, which restricts our ability to predict and manage for further change.[4] Currently, the only forum that attracts OA scientists to meet on a regular basis are the symposia

on The Ocean in a High-CO_2 World every four years, and that this frequency of meeting is not often enough to achieve needed planning and coordination in the CO_2 seep community. This proposal aims to bring together the resources of the global community of CO_2 seep scientists to address important OA research issues, and is explicitly linked to the UN Sustainable Development Goal (# 14.3), which aims to better understand the impacts of climate change on marine ecosystems.

The vast majority of our current understanding of how marine biota will respond to climate change stems from experiments conducted in tanks and mesocosms.[5,6] While these controlled manipulations are useful, they suffer from a lack of realism, as natural populations are influenced by abiotic and biotic processes that operate over multiple spatial and temporal scales.[5] Conversely, the majority of research on the impacts of climate change stems from long-term time series, which document ecological change, but do not generally elucidate underlying causative mechanisms.

Researchers around the globe have begun utilizing existing natural gradients in climate variables to conduct 'space for time' substitution experiments[7-9] to examine how increased temperature and pCO_2 will likely influence ecological structure and functioning. This approach offers increased realism and inference because (i) marine communities found under the different environmental conditions are naturally assembled, complex and shaped by species interactions; (ii) environmental variables (both climate and non-climate related) exhibit 'real' variability patterns; and (iii) populations and communities have been exposed to the different environmental conditions for periods of time (decades to many centuries) that far exceed that of laboratory experiments. Recent work using spatial gradients (usually latitudinal) in temperature has shown that continued ocean warming will likely lead to changes in primary productivity, decreased resilience to physical disturbance and increased grazing pressure within many habitat types.[10] Similarly, research using CO_2 seeps as natural analogues has shown that OA will likely cause shifts in the relative abundance of calcifying organisms and changes in community structure and biodiversity.[7-9] Furthermore this kind of ecosystem can be found around the globe (Fig. 1).

Of the research focused on CO_2 seeps so far, there have been several high-impact publications.[9,11,12] We feel the time is ripe to create a holistic global synthesis of lessons learned to date and to map future strategies to maximize the use of natural analogues for ocean acidification. Therefore, we propose the creation of a global network of researchers working on CO_2 seeps to create open-access data resources, synthesize the impacts of variability in carbon chemistry, design global joint experiments, develop internationally agreed best practices for data acquisition and build capacity internationally, with an emphasis on developing countries. This proposal is designed to provide a unified forum for shallow CO_2 seeps researchers worldwide.

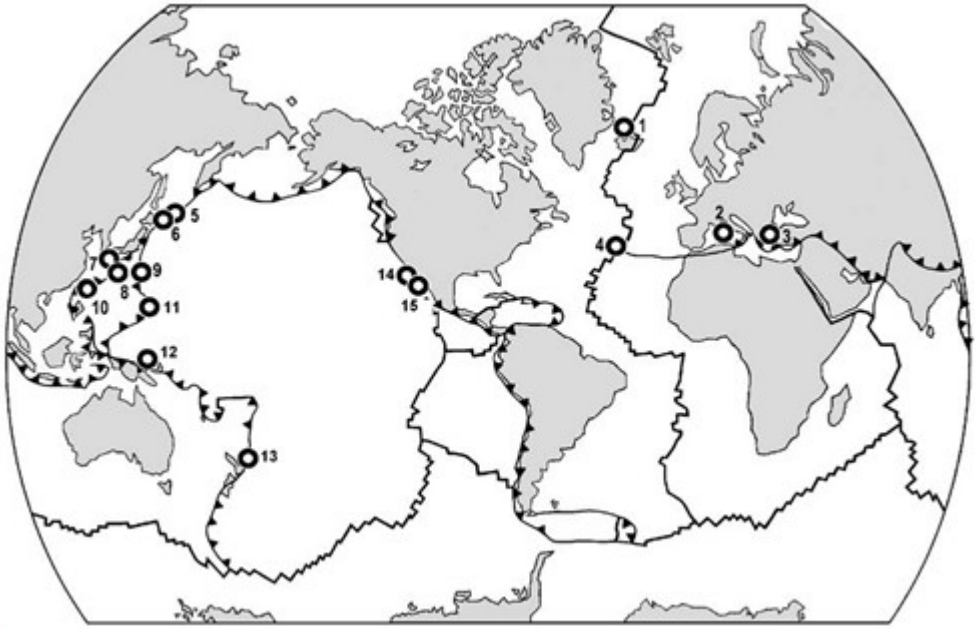

Figure 1. Areas of shallow-water (<200 m) hydrothermal seeping with known data on biota up to 2005 (in several cases one symbol shows more than one closely located areas). 1 - Kolbeinsey, 2 - Tyrrhenian Sea (Capes Palinuro and Messino, Baia Pozzuoli, Aeolian Islands), Columbretes Islands (NW Mediterranean Sea) 3 - Aegean Sea (Islands Santorini and Milos), 4 - D. Joao de Castro Bank, Azores, 5 - Kraternaya Bight, Ushishir Island, Kuril Islands, 6 - Kunashir Island, Kuril Islands, 7 - Kagoshima Bay, 8 - Tokora and Iwo Islands (Kita-Iwo-jima and Akuseki-jima), 9 - Nishino-shima Sintoh, Ogasawara Islands, 10 - Kueishan Is., Taiwan, 11 - Esmeralda Bank, Mariana Islands, 12 - Matupi Harbour, New Britain Island and Tutum Bay, Ambitle Island, Papua New Guinea, 13 - Bay of Plenty, New Zealand, 14 - White Point, Palos Verdes, California, 15 - Punta Banda and Punta Mita, Baja California. From Tarasov[13]

Terms of Reference (ToR)

1. To create an open-access data resource based on observations made at CO_2 seep sites globally.
2. To produce a new synthesis of the impacts of the variability in carbon chemistry on marine ecosystems and the goods and services they provide.
3. To produce a peer-reviewed perspectives article on future seep research, identifying what kind of research is needed and in which locations. Emphasis will be given to a) benthic and fish diversity, abundance and biomass; b) sea food quality; and c) resilience of coastal habitats to ocean acidification and temperature increases.
4. To share knowledge and transfer skills for surveys and experiments, laboratory analysis and data management, in order to build capacity in developing countries.
5. To develop a document of internationally agreed best practices for data acquisition, standardized output formats and archiving for surveys and experiments at CO_2 seep sites.

Working plan (logical sequence of steps to fulfil terms of reference, with timeline)

Year 1 - February 2020

A kick-off meeting will be held in Ecuador to begin addressing TORs 1-5.

Goal for ToR 1 at this meeting - Determine what data are currently available in what format, propose how to structure data, determine what data can be uploaded into the database, and design a Data Team.

One-day session. Participants will be contacted before the workshop and asked to complete a survey where they will state which data they could contribute and its structure.

The working methodology is:

1) Presentation of the Sustainable Development Goal 14.3.1 in order to have all participants aware of expected data quality and format to be used.
2) Presentation of the results of the survey of WG members on available data.
3) Form small groups, based on the expertise of the Working Group members, which will focus on each kind of data in order to propose specifics ways to structure the data.
4) Each group will present in 15 minutes their proposal for the data structure and will receive comments of all participants.
5) Designation of a Data Team within the members of the working group, which will be in charge of developing the dataset.
6) A summary of the proposed methodology.
7) Design a follow-up plan to develop the database.

Goal for ToR 2 at this meeting.- To create a draft with the structure of a synthesis paper.

One-day session. Before the Workshop, all participants will be asked to create a 10-minute presentation with their current work and results. The presentations will be held at the beginning of the day in order to show the state of the science on CO_2 seeps. The working methodology is:

1) Presentation of participant's research and results.
2) Presentation of general guidelines of the content of the synthesis paper.
3) Separate in work groups to modify/improve the proposed guidelines.
4) Presentation of work groups' ideas.
5) Brainstorming to define the structure and content of the synthesis paper.
6) Designation of a Synthesis Paper Coordinator.
7) Design a follow-up plan to develop the paper.

Goal for ToR 3 at this meeting.- Design research strategies, with general and specific objectives, plus methodology, for a peer-reviewed perspectives article.

One-day session. Based on the expertise and interest of each participant, the attendees will be separated in small work groups to design research strategies and perspectives with emphasis on each of the ToR's scopes. The working methodology is:

1) Separate in work groups to design research strategies for each experimental focus.
2) Presentation of work groups ideas.
3) Brainstorming to define final content of each approach.
4) Designation of 3 Research Strategy coordinators, one per topic.
5) Define collaborators for each Research Strategy.
6) Design a follow up plan to develop each Research Strategy.

Goal for ToR 4 at this meeting.- Planning of Capacity building event.
One-half day will be devoted to this goal, discussing the following topics:

1) Decide what capacity will be built at the following year's meeting.
2) How it will be test/use the best practices manual.
3) How funding will be raised for the event.

Goal for ToR 5 at this meeting.- To create a draft with the structure of the Best Practices handbook.

One-day session. Before the Workshop, all participants will receive a document with bullet points and a tentative structure of a Best Practices handbook, plus reference material. The working methodology is:

1) Presentation of general guidelines of the content of the Best Practices handbook.
2) Separate in work groups to modify/improve the proposed guidelines.
3) Presentation of work groups ideas.
4) Brainstorming to define final content of the Best Practices handbook.
5) Designation of Best Practices handbook chapter leaders and teams.
6) Design a follow-up plan to develop the Best Practices handbook.

Year 2 - February 2021
The second meeting of the group will be held in Dominica in February 2021. The meeting will address ToRs 2, 4, and 5. In particular, ToR 4 will be addressed through a special capacity building event to be done at the same time (see capacity building section below).

Goal for ToR 2 at this meeting - Finalise the synthesis paper.

The document started during the previous year will be approved by all Working group members and submitted for review. A half-day session will be devoted to a final check of the synthesis paper.

Goal for ToR 4 at this meeting - Conduct a training activity focused on the use of CO_2 seeps for ocean acidification studies (see capacity building section below).

Goal for ToR 5 at this meeting - Review, based on field activities, the Best Practices handbook.

Two sessions, one before and one after the capacity building event, will be carried out to discuss the methods and content of the document. The Best Practices Handbook Chapter leaders and teams will review the work carried out and will propose improvements on the document.

Year 3 - February 2022

The closing meeting of the group will be held in Barcelona. The meeting will address ToR 5 in detail.

Goal for ToR 5 at this meeting - Final review of the content, structure and final agreement on the Best Practices handbook.

Two and a half day session. Before the Workshop, all participants will receive the latest draft of the Best Practices handbook. The working methodology is:

Day 1 - Mini symposia

1) Presentation of the current content of the Best Practices handbook.
2) Presentation of research results of the "road test" of the Best Practices handbook done at the Capacity building event, as well as research conducted by the participants in the previous 2 years.

Day 2 - Work groups and brainstorming

1) Separate in work groups to modify/improve the proposed methodologies.
2) Presentation of work groups' ideas in a plenary session.
3) Brainstorming to define final content of the Best Practices handbook.

Day 3 - Half day

4) Summary of the 2 previous days' work.
5) Discussion of a potential follow-up plan of InterSEEP.
6) Closing remarks of the Working Group.

Deliverables.

1. ToR 1

Open-access resource of temporal-space data variability, created in the Pangea database, including gas parameters, water parameters, substratum parameters, bacteria, meiofauna, macroalgae, sessile and mobile macrobenthos, and demersal and pelagic fish.

2. ToR 2.

- Synthesis paper to be published in a peer-reviewed journal: reanalysis of datasets mentioned above, focusing on the most relevant aspect (e.g., effects on ecosystem functioning and services).

3. ToR 3.

- A peer-reviewed perspectives article on future seep research with conceptual models of key future global experiments. A key legacy of this Working Group will be to create a roadmap of globally replicated experiments at CO_2 seeps a reality, focused on socially and economically important aspects of coastal services to mankind. The OA research community can use these perspectives as a basis to design and submit new research projects to funding agencies as Horizon Europe, a €100 billion research and innovation programme that will succeed Horizon 2020, the Environmental Restoration and Conservation Agency from Japan (ERCA), the Japan International Cooperation Agency and NOAA's Ocean Acidification Program, if possible.

4. ToRs 4-5.

- Road test our draft of the Best Practices Handbook during the Capacity Building activity in 2021. Then with input of all the participants finalize a guide of best practices on Ocean Acidification research in CO_2 seeps.

Capacity Building

Our training activity will focus on the use of CO_2 seeps for ocean acidification studies, and will be held in February 2021.

The aim of the workshop is to provide an opportunity for training as well as data collection. A major goal of the workshop will be to educate a new cohort of young scientists from developing countries to the opportunities available to apply their techniques to natural CO_2 gradients to scale-up from laboratory studies and improve predictions about the long- term effects of CO_2 on coastal ocean system functioning.

The training activity will consist on theoretical and review lectures in the mornings about the chemical and physical effects of volcanic marine seeps, the use of natural analogues for high-CO_2 conditions, physiological experiments at CO_2 seeps and work to date on the use of low pH/low saturation states in natural settings. These will be followed by practical field sessions in the afternoons on the intertidal and subtidal coastal ecological shifts along CO_2 gradients, physiological in situ experimentation, pelagic sampling and boat- based water chemistry monitoring plus the deployment of a range of loggers to monitor the system. A total of 12 early-career scientists willing to work on those ecosystems back at their home countries are expected to participate.

During this training course the participants will be trained in different aspects of OA research as:

- Standard measurements for carbon system parameters, including analytical chemistry techniques,
- The use of stable isotopes as a major tool in food web analysis in the framework of OA research,
- In-situ sample collection in a CO_2 seep for chemical and biological analysis,
- And the study of benthic community structure and functioning under the influence of high CO_2 conditions.

Upon completion of the training course, participants will have gained increased knowledge in the different issues involved in the training and experimental activities, and they will be able to:

1. Monitor basic carbonate chemistry, including detailed methodology for collecting samples, measurements of potentiometric pH and total alkalinity (TA), the use of certified reference materials, and specific challenges related to each method.
2. Understand what ancillary seawater measurements are needed, and at what accuracy to calculate all the parameters of the carbonate system in seawater (i.e., temperature, salinity, nutrients, barometric pressure), as well as to know what algorithms can be used as proxies for aragonite and calcite saturation state in field studies.
3. Collect and pre-treat seawater samples and biological samples for isotopic analysis, explore data management and interpretation.
4. Analyse the relationship between seawater carbonate chemistry and benthic community structure in enriched-CO_2 sites, in order to evaluate potential impact of high pCO_2 conditions on ecosystem functioning.

To fund this activity support proposals will be submitted to The Ocean Foundation (TOF), and to the International Atomic Energy Agency (IAEA) Technical Cooperation project INT7019 "Supporting a Global Ocean Acidification Observing Network – towards Increased Involvement of Developing States"; both of which support training initiative in OA research.

Working Group composition

Full Members

Name	Gender	Place of work	Expertise relevant to proposal
1 Cristina Linares	Female	Associate Professor at the Department of Evolutionary Biology, Ecology and Environmental Sciences, University of Barcelona, Spain	Her research focuses on the study of the structure and dynamics of coastal benthic communities and their response to global change
2 Jason Hall-Spencer CO-CHAIR	Male	Professor of Marine Biology. School of Biological and Marine Sciences, Faculty of Science and Engineering. UK.	Seamount ecology, fisheries ocean acidification, aquaculture and conservation. Fieldwork sites are currently at volcanic CO_2 seeps in the Mediterranean and off Japan.
3 Katharina Fabricius	Female	Senior Principal Research Scientist, Australian Institute of Marine Science (AIMS), Australia.	Coral reefs processes (ranging from ecophysiology to macro-ecology), understanding the effects of cumulative impacts from chronic and acute disturbances, CO_2 seeps, ecosystem resilience.
4 Haruko Kurihara	Female	Assistant Professor, Department of Chemistry, Biology, and MarineScience, University of the Ryukyus, Japan.	Research focus on risk assessment and managementof ocean acidification impacts on Japan's coastal habitats and fisheries
5 Rafael Bermúdez CO-CHAIR	Male	Researcher- Lecturer at Galapagos Marine Research and Exploration Program (GMaRE), Ecuador.	Research focus on the effect of Ocean Acidification in the biomolecular composition of primary producers and its concomitant influence in food webs.

6 Riccardo Rodolfo Metalpa	Male	Researcher at ENTROPIE - Écologie marine tropicale des océans Pacifique et Indien, Institute of Research for Development, France.	Research focus on coral reefs, global change, ocean acidification, coral calcification, coral physiology,
7 Salvatrice Vizzini	Female	Professor of Ecology, Università degli Studi di Palermo, Consorzio Nazionale Interuniversitario per le Scienze del Mare-CoNISMa, Italy.	Research activity is focused on the ecology of coastal environments with particular attention on trophic ecology using stable isotopes and fatty acids as trophic markers
8 Sam Rastrick	Male	Associate Research Professor, Research Group of Benthic Habitats and Shellfish, Institute of Marine Research, Norway.	Research focus on the use of physiology to explain the ecological distribution, both temporal and spatial, of species important to both ecosystem function and services.
9 Sylvain Agostini	Male	Assistant Professor. Shimoda Marine Research Center, University of Tsukuba, Japan.	Research activity is focused on the eco physiology of hermatypic corals in temperate and tropical zones.
10 Vanessa Yepes-Narvaez	Female	Marine and Coastal Research Institute INVEMAR, Santa Marta, Colombia.	Ecology, taxonomy, distribution and population genetics of marine deep and shallow bryozoans in the Atlantic Ocean

Associate Members

Name	**Gender**	**Place of work**	**Expertise relevant to proposal**
1 Christopher Cornwall	Male	Victoria Wellington University, Wellington, New Zealand	Research focus on examine how macroalgal dominated ecosystems function today and how this will be altered by future ocean acidification in the context of variability in the environment (e.g. pH, water motion and light)

2 Derek Manzello	Male	Researcher, Ocean Chemistry and Ecosystems Division, NOAA's Atlantic Oceanographic and Meteorological Laboratory, USA	Research focus on how climate change and ocean acidification will, and already are, affecting the construction (coral growth, calcification) and breakdown (bioerosion, dissolution) of coral reefs, as well as the associated ramifications this has for ecosystem function
3 Marco Milazzo	Male	Professor of Ecology, Università degli Studi di Palermo, Italy	Research interests on impacts of humans on marine ecosystems, biological invasions, and marine reserves.
4 Lucia Porzio	Female	PostDoc at Stazione Zoologica Anton Dohrn, Italy	Research focus on the study of anthropogenic pressures and the impacts they cause on macrophytes and on their biodiversity.
5 Yu-Shih Lin	Female	Assistant professor, Department of Oceanography, National Sun Yat- Sen University	Biogeochemistry and isotope geochemistry in CO_2 vents

Working Group contributions

Cristina Linares - Associate professor from a developed country. Expertise on the study of the structure and functioning of temperate benthic ecosystems and their response to global change and CO_2 seep research affecting mesophotic communities in Columbretes Islands (NW Mediterranean Sea)

Jason Hall-Spencer - Senior researcher from a developed country. Expertise on laboratory studies, mesocosms and CO_2 seep research in the Mediterranean, the Azores, Papua New Guinea, China and Japan. Helped organise a previous training workshop on seeps in Italy
Katharina Fabricius - Senior researcher from a developed country, ongoing collaborative research in developing countries. Coral reef ecologist, with strong focus on using field settings as natural laboratories. Her interdisciplinary CO_2 seeps project in Papua New Guinea has involved ~50 collaborators from over 20 nations to date.

Haruko Kurihara - Assistant professor from a developed country. Research focus on risk assessment and management of ocean acidification impacts on Japan's coastal habitats and fisheries.

Rafael Bermúdez.- Junior Professor from a developing country. Expertise on food webs under ocean acidification conditions. Researcher at the newly found seep at Galapagos. organized previous training on seeps in Ecuador.

Riccardo Rodolfo Metalpa - Researcher from a developing country. Working on coral reefs and other calcifier organisms at CO_2 seep from 2008. Laboratory mesocosms, CO_2 seep and extreme environments in the Med, Papua New Guinea and New Caledonia.

Salvatrice Vizzini - Senior researcher from a developed country. Expertise on effects of ocean acidification on trophic interactions and benthic communities and processes in CO_2 seeps. Organised previous training on seeps in Italy.

Samuel Rastrick - Associate research professor in marine ecophysiology form a developed country. Expertise in laboratory, mesocosm and natural analogue studies e.g. CO_2 seeps in Mediterranean, Japan and the Caribbean. Develops traditionally laboratory based methods for use in the field. Chairs an international WG exploring using natural analogies to investigate CC in Arctic ecosystems. Organised previous training on seeps in Dominica.

Sylvain Agostini - Assistant professor from a developed country in Asia. Expertise on the ecological and physiological effects of ocean acidification on corals and other marine organisms. Researcher at the CO_2 seeps in Japan.

Vanessa Yepes-Narvaez - Junior researcher from a developing country. Research focus on ecology, taxonomy, distribution and population genetics of marine deep and shallow bryozoans in the Atlantic Ocean with emphasis in seep sites in the Caribbean sea.

Relationship to other international programs and SCOR Working groups (max. 500 words)

The Ocean Foundation (TOF) is a community foundation with a mission to support, strengthen, and promote organizations dedicated to reversing the trend of destruction of ocean environments around the world. In parallel, the International Atomic Energy Agency (IAEA) has the Technical Cooperation project INT7019 “Supporting a Global Ocean Acidification Observing Network – towards Increased Involvement of Developing States”; InterSEEP aims to partner with TOF and the IAEA in order to promote Ocean Acidification research on natural CO_2 seep systems on developing countries as a model for predictive future ocean scenarios. InterSEEP also aspires to become a Special Hub (in contrast to Regional Hubs) within the Global Ocean Acidification Observing Network (GOA-ON) in order to promote OA research in Seep sites around the globe.

This proposed group fits perfectly within SCOR’s scope on Ocean Carbon Working Groups. It is novel as it focuses on observations of biological responses of Ocean Acidification using the complex marine communities found around natural seeps. InterSEEP is also a timely update to the Working Group 104 “Coral Reef Responses to

Global Change: The Role of Adaptation" which published its last report 20 years ago. Additionally, InterSEEP will potentially expand the application of the newly developed tool, created by the Working Group 149, for experiments related to Ocean Acidification and multi-stress factors in laboratory experiments, in order to use it in natural field seep conditions. Furthermore, following the steps of SCOR/InterRidge Working Group 135 on Deep Sea Hydrothermal systems, InterSEEP will bring together CO_2 seep researchers worldwide to address important issues to improve and coordinate global research.

Key References

1. Boyd, P. W. *et al.* IPCC WGII AR5 Chapter 6. (2014).
2. Oliver, E. C. J. *et al.* Longer and more frequent marine heatwaves over the past century. *Nat. Commun.* 1–12 (2018).
3. Gattuso, J.-P. *et al.* Contrasting futures for ocean and society from different anthropogenic CO_2 emissions scenarios. *Science (80-.).* 349, aac4722 (2015).
4. Riebesell, U. & Gattuso, J. Lessons learned from ocean acidification research. *Nat. Clim. Chang.* 5, 12–14 (2015).
5. Wernberg, T. *et al*. A decade of climate change experiments on marine organisms: Procedures, patterns and problems. *Glob. Chang. Biol.* 18, 1491– 1498 (2012).
6. Kroeker, K. *et al*. Meta-analysis reveals negative yet variable effects of ocean acidification on marine organisms. *Ecol. Lett.* 13, 1419–34 (2010).
7. Agostini, S. *et al*. Ocean acidification drives community shifts towards simplified non-calcified habitats in a subtropical − temperate transition zone. 5–10 (2018).
8. Pessarrodona, A. *et al*. Carbon assimilation and transfer through kelp forests in the NE Atlantic is diminished under a warmer ocean climate. *Glob. Chang. Biol.* 24, 4386–4398 (2018).
9. Hall-Spencer, J.M. & Harvey, B.P. Ocean acidification impacts on coastal ecosystem services due to habitat degradation. *Emerging Topics in Life Sciences* DOI: 10.1042/ETLS20180117(2019)
10. Vergés, A. *et al.* Long-term empirical evidence of ocean warming leading to tropicalization of fish communities, increased herbivory, and loss of kelp. *Proc. Natl. Acad. Sci.* 113, 13791–13796 (2016).
11. Fabricius, K. E. *et al.* Losers and winners in coral reefs acclimatized to elevated carbon dioxide concentrations. *Nat. Clim. Chang.* 1, 165–169 (2011).
12. Munday, P. *et al*. Behavioural impairment in reef fishes caused by ocean acidification at CO_2 seeps. *Nat. Clim. Chang.* 4, 487–492 (2014).
13. Tarasov, V. G., *et al*. Deep-sea and shallow-water hydrothermal seep communities : Two different phenomena ? *Chem. Geol*. 224, 5–39 (2005).

ANNEX 1.- Five more relevant publications of the Full Members

Cristina Linares

Exploring the oxygen and carbon isotopic composition of the Mediterranean red coral (Corallium rubrum) for seawater temperature reconstruction (2016) S Chaabane, ML Correa, P Montagna, N Kallel, M Taviani, C Linares, *et al.* Marine Chemistry 186, 11-23

Experimental evidence of the synergistic effects of warming and invasive algae on a temperate reef-builder coral (2015) DK Kersting, E Cebrian, C Casado, N Teixidó, J Garrabou, C Linares Scientific reports 5, 18635

Persistent natural acidification drives major distribution shifts in marine benthic ecosystems (2015) C Linares, M Vidal, *et al.* Proc. R. Soc. B 282 (1818), 20150587

Harvesting effects, recovery mechanisms, and management strategies for a long-lived and structural precious coral (2015) I Montero-Serra, C Linares, M García, *et al.* PloS one 10 (2), e0117250.

Rapid recovery from injuries in the temperate long-lived coral *Cladocora caespitosa* (2015) C Casado, DK Kersting, E Cebrian, N Teixidó, J Garrabou, C Linares Marine Biodiversity 45 (1), 135-137

Jason Hall-Spencer

Responses of marine benthic microalgae to elevated CO2 (2011) VR Johnson, C Brownlee, REM Rickaby, M Graziano, M Milazzo, JM Hall- Spencer, *et al.* Marine Biology, 1-12

Effects of ocean acidification on macroalgal communities (2011) L Porzio, MC Buia, JM Hall-Spencer Journal of experimental marine biology and ecology 400 (1-2), 278-287

Effects of ocean acidification on invertebrate settlement at volcanic CO2 vents (2010) M Cigliano, MC Gambi, R Rodolfo-Metalpa, FP Patti, JM Hall-Spencer Marine Biology, 1-14

Volcanic carbon dioxide vents show ecosystem effects of ocean acidification (2008) JM Hall-Spencer, R Rodolfo-Metalpa, *et al.* Nature 454 (7200), 96-99

Ocean acidification impacts on coastal ecosystem services due to habitat degradation. (2019) JM Hall-Spencer, BP Harvey. Emerging Topics in Life Sciences DOI: 10.1042/ETLS20180117

Katharina Fabricius

Classification and regression trees: a powerful yet simple technique for ecological data analysis (2000) G De'ath, KE Fabricius. Ecology 81 (11), 3178-3192

Losers and winners in coral reefs acclimatized to elevated carbon dioxide concentrations (2011) KE Fabricius, C Langdon, *et al.*. Nature Climate Change 1 (3), 165

Declining coral calcification on the Great Barrier Reef (2009) G De'ath, JM Lough, KE Fabricius Science 323 (5910), 116-119

Declining coral calcification in massive Porites in two nearshore regions of the northern Great Barrier Reef (2008) TF Cooper, G De'Ath, KE Fabricius, JM Lough Global Change Biology 14 (3), 529-538

Changes in algal, coral and fish assemblages along water quality gradients on the inshore Great Barrier Reef (2005) K Fabricius, G De'ath, *et al.* Marine pollution bulletin 51 (1-4), 384-398

Haruko Kurihara

Ocean acidification impacts in select Pacific Basin coral reef ecosystems (2019) M Lebrec, S Stefanski, R Gates, S Acar, Y Golbuu, A Claudel-Rusin, H Kurihara, *et al*. Regional Studies in Marine Science, 100584

Effects of CO2-driven ocean acidification on the early developmental stages of invertebrates (2008) H Kurihara Marine Ecology Progress Series 373, 275-284

Effects of increased seawater pCO_2 on early development of the oyster *Crassostrea gigas* (2007) H Kurihara, S Kato, A Ishimatsu Aquatic Biology 1(1), 91-98

Effects of increased atmospheric CO2 on sea urchin early development (2004) H Kurihara, Y Shirayama Marine Ecology Progress Series 274, 161-169

Sub-Lethal Effects of Elevated Concentration of CO2 on Planktonic Copepods and Sea Urchins (2004) H Kurihara, S Shimode, Y Shirayama Journal of Oceanography 60 (4), 743-750

Rafael Bermúdez

Phytoplankton blooms at increasing levels of atmospheric carbon dioxide: experimental evidence for negative effects on prymnesiophytes and positive on small picoeukaryotes (2017) KG Schulz, LT Bach, RGJ Bellerby, R Bermúdez, *et al.* Frontiers in Marine Science 4, 64

Ocean acidification reduces transfer of essential biomolecules in a natural plankton community (2016) JR Bermúdez, U Riebesell, *et al.*Scientific reports 6, 27749

Effect of ocean acidification on the structure and fatty acid composition of a natural plankton community in the Baltic Sea (2016) JR Bermudez, M Winder *et al.* Biogeosciences (BG) 13 (24), 6625-6635

Long-term conditioning to elevated pCO_2 and warming influences the fatty and amino acid composition of the diatom *Cylindrotheca fusiformis* (2015) R Bermudez, Y Feng, *et al*. PLoS One 10 (5), e0123945

Ocean acidification-induced food quality deterioration constrains trophic transfer (2012) D Rossoll, R Bermúdez, *et al*. PloS one 7 (4), e34737

Riccardo Rodolfo Metalpa

Coral and mollusc resistance to ocean acidification adversely affected by warming (2011) R Rodolfo-Metalpa, F Houlbrèque, *et al.* Nature Climate Change 1 (6), 308

Response of the temperate coral *Cladocora caespitosa* to mid-and long- term exposure to pCO_2 and temperature levels projected for the year 2100 AD (2010) R Rodolfo-Metalpa, S Martin, *et al.* Biogeosciences 7 (1), 289-300

Effects of ocean acidification and high temperatures on the bryozoan *Myriapora truncata* at natural CO_2 vents (2010) R Rodolfo-Metalpa, C Lombardi, *et al.* Marine Ecology 31 (3), 447-456

Volcanic carbon dioxide vents show ecosystem effects of ocean acidification (2008) JM Hall-Spencer, R Rodolfo-Metalpa, *et al.* Nature 454 (7200), 96

Effects of naturally acidified seawater on seagrass calcareous epibionts (2008) S Martin, R Rodolfo-Metalpa, E Ransome, *et al*. Biology letters 4 (6), 689-692

Salvatrice Vizzini

Plant and sediment properties in seagrass meadows from two Mediterranean CO2 vents: Implications for carbon storage capacity of acidified oceans (2019) S Vizzini, ET Apostolaki, E Ricevuto Marine Environmental Research, Available online 18 March 2019

The influence of high *p*CO2 on otolith shape, chemical and carbon isotope composition of six coastal fish species in a Mediterranean shallow CO2 vent (2017) AM irasole · BM Gillanders · P Reis-Santos · F Grassa · S Vizzini Marine Biology 164(9):191

Ocean acidification as a driver of community simplification via the collapse of higher-order and rise of lower-order consumers S Vizzini, B Martínez-Crego *et al.* Scientific Reports 7(1):4018

Altered epiphyte community and sea urchin diet in *Posidonia oceanica* meadows in the vicinity of submarine volcanic CO2 vents (2017) P Nogueira, MC Gambi, S Vizzini, *et al.* Marine environmental research 127

Ocean acidification effects on stable isotope signatures and trophic interactions of polychaete consumers and organic matter sources at a CO2 shallow vent system (2015) E Ricevuto, S Vizzini, *et al.* Journal of Experimental Marine Biology and Ecology 468

Samuel Rastrick

Using natural analogues to investigate the effects of climate change and ocean acidification on Northern ecosystems (2018) S Rastrick, H Graham, *et al.* ICES Journal of Marine Science 75(7)

Feeding plasticity more than metabolic rate drives the productivity of economically important filter feeders in response to elevated CO2 and reduced salinity (2018) S Rastrick, V Collier, *et al.* ICES Journal of Marine Science 75(6)

Natural acidification changes the timing and rate of succession, alters community structure, and increases homogeneity in marine biofouling communities (2017) NE Brown, M Milazzo, S Rastrick, *et al.* Global Change Biology 24(1)

The impact of ocean acidification and warming on the skeletal mechanical properties of the sea urchin *Paracentrotus lividus* from laboratory and field observations (2016) M Collard, S Rastrick, *et al.* ICES Journal of Marine Science 73(3)

Individual and population-level responses to ocean acidification (2016) BP Harvey, NJ Mckeown, S Rastrick, *et al*. Scientific Reports 6, 20194.

Sylvain Agostini

Geochemistry of two shallow CO_2 seeps in Shikine Island (Japan) and their potential for ocean acidification research (2015) S Agostini, S Wada, *et al.* Regional Studies in Marine Science 2, 45-53

Bacterial enhancement of bleaching and physiological impacts on the coral *Montipora digitata* (2013) T Higuchi, S Agostini, BE Casareto, K Yoshinaga, T Suzuki, Y Nakano, *et al*. Journal of experimental marine biology and ecology 440, 54-60

The effects of thermal and high-CO_2 stresses on the metabolism and surrounding microenvironment of the coral *Galaxea fascicularis* (2013) S Agostini, H Fujimura, *et al.* Comptes rendus biologies 336 (8), 384-391

Respiratory electron transport system activity in symbiotic corals and its link to calcification (2013) S Agostini, H Fujimura, *et al*. Aquatic Biology 18 (2), 125-139

Biological and chemical characteristics of the coral gastric cavity (2012) S Agostini, Y Suzuki, *et al*. Coral Reefs 31 (1), 147-156

Vanessa Yepes-Narvaez

Habitat-forming bryozoans in the Colombian Caribbean Sea: a possible hotspot of biodiversity? (2016) P Flórez, E Montoya-Cadavid, V Yepes-Narváez, A Polanco, A Gracia. International Bryozoology Association 44 p.

Recruitment dynamics of sessile organisms is shallow benthic habitats in the Sanctuary of Wildlife Malpelo (2013) V Yepes-Narvaez, L Chasqui-Velasco, et al. Technical document. Marine and Coastal Research Institute, Invemar. 40 pp.

Four new records of ascidians (Ascidiacea: Tunicata) in Colombian Caribbean (2014) V Yepes-Narvaez, K Carreño, M Santos-Acevedo, C Puentes, J Gómez- León. Zootaxa

Thirteen new registers of bryozoans in Colombian Caribbean (2016) V Yepes-Narvaez, P Florez, *et al*. Boletin de Investigaciones marinas y costeras

Offshore exploration in Colombia: Situation, methodologies, challenges and resources for a sustainable utilization (2015) M Garrido-Linares, F Dorado-Roncancio, C Cedeño-Posso, V Yepes- Narváez, *et al*. XVI Seminario Nacional de Ciencias y Tecnologías del Mar. Santa Marta, Colombia. 176 p.