ICES SGOA REPORT 2014

ICES ADVISORY COMMITTEE

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Report of the Joint OSPAR/ICES Ocean Acidification Study Group (SGOA)

6–9 October 2014

Copenhagen, Denmark

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Executive summary

The Joint OSPAR/ICES Study Group on Ocean Acidification (SGOA) held its third and final meeting in Copenhagen, Denmark from 6–9 October 2014. The meeting was hosted by the ICES Secretariat. The meeting was chaired by Evin McGovern (Ireland) and Mark Benfield (USA) and was attended by 25 scientists representing eleven countries, AMAP and the ICES DataCentre. Seven of the participants joined via WebEx conference.

The objective of the meeting was to address the Study Group's eight terms of reference (ToRs) as set for the group by OPSAR and to prepare a final consolidated report addressing these ToR. This report was completed during and after the meeting. The following annexes were also finalized:

- A draft ocean acidification (OA) monitoring strategy for consideration by OSPAR;
- Ocean acidification: an assessment of current and projected exposure of Cold Water Coral areas in the Northeast Atlantic;
- Long-term trends in ocean acidification in the OSPAR area;
- Chemical monitoring activities relevant to OA in the OSPAR and HELCOM areas.

Two additional tasks were added to the SGOA agenda arising from requests received prior to the meeting. One of these was a request for advice on inclusion of coccolithophorid phytoplankton (e.g. *Emiliania huxleyi*) in OSPAR Eutrophication Guidelines on Phytoplankton Species Composition for OA monitoring. SGOA does not recommend inclusion of *E. huxleyi*, or an alternative coccolithophore species, for OA monitoring within the guidelines based on current information.

The SGOA also discussed the potential future place for OA within ICES. The consensus of the group was that a Working Group on Ocean Acidification should be formed.

Opening of the meeting

The Joint OSPAR/ICES Study Group on Ocean Acidification (SGOA) met at ICES Headquarters in Copenhagen, Denmark from 6–9 October, 2014. The meeting was attended, in full or in part, by 25 scientists representing 11 countries, the Arctic Monitoring and Assessment Programme (AMAP) and the ICES DataCentre (ICES–DC), (Annex 1). Seven of the participants joined via WebEx conference.

The chairs of SGOA, Evin McGovern and Mark Benfield, opened the meeting at 10:00 am and welcomed the participants. Following a round of introductions, the chairs noted apologies received from members who were unable to attend.

1 Adoption of the agenda

1.1 Agenda

The agenda for the SGOA meeting (Annex 2) followed the Terms of Reference (ToR) adopted as a resolution by the ICES 2012 Annual Science Conference and Statutory Meeting, and agreed by OSPAR (Annex 3). The draft agenda had been circulated among the study group membership prior to the meeting and incorporated most suggestions and comments. The agenda was adopted unanimously.

Two further requests were received from ICES in advance of SGOA 2014 and are addressed in Section 3 of this report.

1) Advise on review of draft OSPAR JAMP Eutrophication Guidelines on phytoplankton species composition with respect to monitor effects of ocean acidification (OA) as, for example, on coccolithophorids (e.g. *Emiliania huxleyi*) in line with Descriptor 1 in MSFD. This was part of a broader requested directed to a number of working groups.

2) A further query to the ICES DataCentre from EMODNET on MSFD OA data requirements.

1.2 Feedback from OSPAR on SGOA 2013 report

Evin McGovern highlighted that OSPAR's Hazardous Substance and Eutrophication Committee (HASEC, 2014)[1] and Coordination Group (CoG 1, 2014)[2] had been updated on progress at SGOA 2013. HASEC noted the challenges with respect to data reporting as identified by SGOA 2013. HASEC also added discrete measurements of pH to the OSPAR Coordinated Environmental Monitoring Programme (CEMP) appendix on OA monitoring. An extract from the SGOA 2013 report specifically relating to development of the proposed OA monitoring strategy (ToR E) was presented to COG to solicit feedback on the direction proposed by SGOA. OSPAR Contracting Parties (CPs) were invited to provide feedback via the OSPAR Commission by 1 September, 2014. No comments were received from OSPAR CPs.

1.3 Final SGOA Report to OSPAR

The SGOA chairs recalled that SGOA 2013 had agreed that a report would be prepared by SGOA 2014, consolidating the three-year SGOA output for presentation to OSPAR, and structured according to the Terms of Reference provided to the group. The proposed structure was agreed and completion of this report formed the primary task of SGOA 2014. The report was finalized subsequent to the SGOA 2014 meeting.

1.4 Links to other ICES working groups and activities

Evin McGovern presented the work of SGOA 2013 to a joint session of the working groups on Marine Chemistry (MCWG), Biological Effects of Contaminants (WGBEC) and Marine Sediments in Relation to Pollution (WGMS) in March 2014.

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[1] http://www.ospar.org/zip/SZ20150202-162400-5214/download.zip

[2] http://www.ospar.org/zip/SZ20150202-162110-6054/download.zip

Marine Chemistry Working Group (MCWG)

Katrin Vorkamp (Chair of MCWG) attended day 1 of the SGOA 2014 meeting. MCWG interest in the topic OA extends to reviewing analytical developments, advising on quality assurance/quality control (QA/QC) requirements and assisting in elaboration of reporting requirements with respect to chemical parameters. MCWG 2014 had addressed two aspects of relevance to SGOA (ICES 2014) in accordance with the request of SGOA 2013.

a) MCWG addressed outstanding reporting issues to facilitate reporting of OSPAR CEMP OA data to the ICES DOME (Marine Environment database) using Environmental Reporting Format (ERF) 3.2. Specifically, this involved finalizing the reporting fields, units and defining DATSU screening protocols which generate warnings, errors and critical errors.

b) MCWG also progressed plans for the proposed OA QA workshop as discussed in Section 2.4.

Working Group on Biological Effects of Contaminants (WGBEC)

Kris Cooreman reported on WGBEC's interest in the topic of OA. WGBEC has proposed undertaking the following tasks (ICES 2014b):

1) To review the existing literature for recommendations on suitable species/ endpoints for monitoring.

2) To focus efforts on those parameters relating to the expertise of WGBEC (endpoint measurements in individuals/ populations rather than, for example, e.g. biogeographic trends, etc.).

3) To account for in-combination effects with other climate change variables (e.g. carbonate chemistry changes and temperature).

4) A subgroup led by Kris will produce a review for publication including monitoring recommendations.

SGOA welcomed these WGBEC activities request that any follow-on group to SGOA that may be formed is updated on progress.

ICES Annual Science Congress (ASC) 2015

WGBEC with SGOA and MCWG put forward a theme session entitled Ocean Acidification: Understanding chemical, biological and biochemical responses in marine ecosystems for ASC 2015, 21–25 September 2015, in Copenhagen. Kris Cooreman reported that this had been accepted. Silvana Birchenough (UK WGBEC), Pam Walsham (UK SGOA/MCWG) and Klaas Kaag (The Netherlands WGBEC) were nominated as conveners. Researchers are encouraged to submit papers for this theme session, noting the abstract submission deadline is 30 April 2015.

2 Main Terms of Reference

The meeting focused on preparing the final consolidated report to OSPAR addressing the eight ToRs. The information was gleaned from SGOA 2012 and 2013 reports and new information provided at SGOA 2014.

2.1 ToR A: Collate chemical data and information on ocean acidification in the OSPAR Maritime Area

During SGOA 2014, new information on national monitoring activities from the Faroe Islands (Maria Chun Nielsdóttir), Sweden (Anna Willstrand Wranne) and Belgium (Kris Cooreman) as well as updated information from the Iceland (Sólveig Ólafsdóttir), Ireland (Evin McGovern) and the USA (Richard Feely). These activities are described in Sections 2.1–2.14 of the final report to OSPAR.

SGOA members also presented information on a number of national research initiatives. The information on these programmes is incorporated into Section 2 of the Final SGOA Report to OSPAR as shown in Table 1.

Table 1. Presentations at SGOA 2014 on relevant national research.

Presentation	Final SGOA Report Section
BIOACID project (Hans Otto Portner, DE)	2.15.2
UK Shelf Seas Biogeochemistry Project (Caroline Kivimae, UK)	2.15.3
OA Research at Cefas –PLACID, MINERVA and IFMA projects (Dave Pearce, UK)	2.15.4
4DEMON project (Kris Cooreman, BE)	2.15.1

2.2 ToR B: Seek information from relevant international initiatives on ocean acidification; as listed in OSPAR MIME 11/3/3 (e.g. EU, Arctic Council)

Presentations on various international projects and activities of relevance to SGOA's work were given by SGOA participants during the 2014 meeting. The information was incorporated into Section 3 of the Final SGOA Report to OSPAR as indicated in Table 2.

Table 2. Presentations at SGOA 2014 on relevant international activities.

PRESENTATION	FINAL SGOA REPORT SECTION
AMAP Update (Jan Rene Larson, AMAP)	3.1
CarboChange (Toste Tanhua, DE)	3.4.3
OA in IPCC AR5 (WGII report) (Hans Otto Pörtner, DE) (Pörtner *et al*., 2014)	5.4
Convention on Biological Diversity (CBD) Updated Synthesis of the Impacts of Ocean Acidification on Marine Biodiversity (Phil Williamson, UK) CBD 2014	3.3
Global OA – Observing Network (Phil Williamson, UK) Newton *et al*., 2014	6.2

2.3 ToR D: Collect and exchange information on biological effects [of ocean acidification] on plankton, and macrozoobenthos

SGOA 2014 discussed biological impacts of OA following the presentations on the IPCC Working Group II AR5 (Pörtner *et al.,* 2014), CBD synthesis on the impacts of OA on marine biodiversity (CBD 2014) and findings of the BIOACID project. In light of these discussions SGOA decided that, rather than update the table of likely effects of OA on different groups of marine organisms as prepared initially by SGOA 2012 (Table 3), Table 6.2 from IPCC WGII report summarizing the tolerances to OA of marine taxa should be reproduced in the Final SGOA Report to OSPAR.

Although the topic area is relatively new, a substantial body of literature already exists on the potential biological effects of ocean acidification. This is a highly active area of research that is producing new publications with high frequency (>200 per annum; Gattuso and Hansson, 2011). It should be noted here that the taxonomic scope of ToR D ("… on plankton, and macrozoobenthos") seems unnecessarily restrictive, since a much wider range of marine organisms are potentially directly impacted, both negatively and positively, with others indirectly affected through interspecific interactions, affecting ecosystem function and ecosystem services.

A summary of the sensitivity of major marine groups to pH and associated carbonate chemistry parameters has been synthesized by the Intergovernmental Panel on Climate Change (IPCC) and this information has been reproduced here as Table 3. Although broad differences in sensitivity to OA are apparent, measured responses can show high variability at both inter- and intraspecific levels (Kroeker *et al*., 2010; Barry *et al*., 2011; Riebesell and Tortell, 2011; Wicks and Roberts, 2012). This variability is partly due to different experimental manipulations of different carbonate chemistry parameters (increased dissolved CO_2; increased H^+/ decreased pH; decreased CO_3^{2-}; increased HCO_3^-), and partly due to biological factors; thus response may vary markedly according to life stages, duration of experiment, food availability (for animals), nutrient availability (for phytoplankton, macroalgae and seagrasses), temperature, and genetic strain.

Table 3. Tolerances to ocean acidification in marine taxa, assessed from laboratory and field studies of species in the pCO_2 range from <650 to >10 000 µatm, compared to present day atmospheric levels of 400 µatm. (It should be noted that anthropogenic CO_2 emissions add to the natural variability of CO_2 concentrations in marine environments, which can reach much higher than atmospheric levels). Variables studied include growth, survival, calcification, metabolic rate, immune response, development, abundance, behaviour and others. Neither all life stages, nor all variables, including the entire range of CO_2 concentrations, were studied in all species. Confidence is based on the number of studies, the number of species studied and the agreement of results within one group. +: denotes that possibly more species or strains (genetically distinct populations of the same species) were studied, as only genus or family were specified; beneficial: most species were positively affected; vulnerable: more than 5% of species in a group will be negatively affected by 2100; tolerant: more than 95% of species will not be affected by 2100. RCP 6.0: representative concentration pathway with projected atmospheric pCO_2 = 670 µatm; RCP 8.5: pCO_2 = 936 µatm in 2100 (Meinshausen *et al.*, 2011). Confidence is limited by the short- to medium-term nature of various studies and the lack of sensitivity estimates on evolutionary time-scales, i.e. across generations (see separate reference list, online supplementary material). Note that the assessment of variability between species from the same animal phylum has revealed an increase in the fraction of sensitive species with rising CO_2 levels. (Reproduced from Table 6_2 IPCC, 2014).

Taxon	No. of studies	No. of parameters studied	Total no. of species studied	pCO_2 where the most vulnerable species is negatively affected or investigated pCO_2 range[a] (µatm)	Assessment of tolerance to RCP 6.0 (*confidence*)	Assessment of tolerance to RCP 8.5 (*confidence*)
Cyanobacteria	17	5	9+	180–1250[a]	Beneficial (*low*)	Beneficial (*low*)
Coccolithophores	35	6	7+	740	Tolerant (*low*)	Vulnerable (*medium*)
Diatoms	22	5	28+	150–1500[a]	Tolerant (*low*)	Tolerant (*low*)
Dinoflagellates	12	4	11+	150–1500[a]	Beneficial (*low*)	Tolerant (*low*)
Foraminifers	11	4	22	588	Vulnerable (*low*)	Vulnerable (*medium*)
Seagrasses	6	6	5	300–21,000[a]	Beneficial (*medium*)	Beneficial (*low*)
Macroalgae (non-calcifying)	21	5	21+	280–20,812[a]	Beneficial (*medium*)	Beneficial (*low*)
Macroalgae (calcifying)	38	10	36+	365	Vulnerable (*medium*)	Vulnerable (*high*)
Warm-water corals	45	13	31	467	Vulnerable (*medium*)	Vulnerable (*high*)
Cold-water corals	10	13	6	445	Vulnerable (*low*)	Vulnerable (*medium*)
Annelids	10	6	17+	1200	Tolerant (*medium*)	Tolerant (*medium*)
Echinoderms	54	14	35	510	Vulnerable (*medium*)	Vulnerable (*high*)
Mollusks (benthic)	72	20	38+	508	Vulnerable (*medium*)	Vulnerable (*high*)
Mollusks (pelagic)	7	8	8	550	Vulnerable (*low*)	Vulnerable (*medium*)
Mollusks (cephalopods)	10	8	5	2200 (850 for trace elements)	Tolerant (*medium*)	Tolerant (*medium*)
Bryozoans	7	3	8+	549	Tolerant (*low*)	Vulnerable (*low*)
Crustaceans	47	27	44+	700	Tolerant (*medium*)	Tolerant (*low*)
Fish[b]	51	16	40	700	Vulnerable (*low*)	Vulnerable (*low*)

[a]Rather than a sensitivity threshold the entire range of investigated pCO_2 values is given for groups of photosynthetic organisms. In all studies photosynthetic rates are stimulated to different, species-specific degrees by elevated pCO_2, indicating low vulnerability. Coccolithophores and calcifying algae are assessed as being more sensitive than other photosynthetic organisms due to reduced calcification and shell dissolution. NA, not available.
[b]Confidence levels for fishes were converted from medium to low, in light of uncertainty on the long-term implications of behavioral disturbances.

Because of the rapid developments in this field, and complexity of the interactions of OA with other factors, it would be a major undertaking for this Study Group to undertake a comprehensive and up-to-date literature review and synthesis of all potentially relevant direct and indirect effects of OA on marine organisms. The numbers of published studies on the potential impacts of OA on marine organisms continue to increase each year. While it is not the intention of this document to provide a comprehensive list or review of the recent literature, readers are directed to recent reviews on the subject (Andersson *et al.*, 2011; Barry *et al.*, 2011; Byrne, 2011; Byrne and Przeslawski, 2013; Dupont *et al.*, 2010; Gazeau *et al.*, 2013; Harvey *et al.*, 2013; Hendriks *et al.*, 2010; Hofmann *et al.*, 2010; Koch *et al.*, 2013; Kroeker *et al.*, 2010, 2013; Pörtner *et al.*, 2011; Riebesell and Tortell, 2011; Ross *et al.*, 2011; Weinbauer *et al.*, 2011). Furthermore, there are a number of summary reports on OA impacts by reputable bodies and organizations that are in progress, planned or have recently been

completed, and that together provide a relatively thorough overview of the current state of knowledge in this area. These include:

- The Arctic Ocean Acidification Assessment, by the Arctic Council's Arctic Monitoring and Assessment Programme (AMAP, 2013);
- Working Group 2 (Chapters 5, 6, 19 and 30) of the 5th Assessment of the International Panel on Climate Change (IPCC, 2014);
- A new synthesis of OA impacts on marine and coastal organisms and systems by the Convention on Biological Diversity (Secretariat of the Convention on Biological Diversity, 2014);
- An in-preparation report from the 2nd International Workshop on Ocean Acidification Impacts on Fisheries, Aquaculture, Economics and Industry held in Monaco, Nov 11–13, 2012, which examined impacts by FAO fishing areas (http://www.iaea.org/ocean-acidification/page.php?page=2229); and
- The Washington State Blue Ribbon Panel Report on Ocean Acidification (Adelsman and Whitely Binder, 2012), which focuses on impacts on mariculture and fisheries in the NE Pacific.

2.4 ToR E: Consider the strategy that would be required for an assessment framework appropriate to long-term assessment of the intensity/severity of the effects of ocean acidification, including any assessment criteria required

SGOA 2013 outlined the key elements of a proposed monitoring strategy for consideration by OSPAR and OSPAR Contracting Parties were invited by OSPAR CoG 2014 to comment on the outline. No comments were received. SGOA 2014 further developed this draft. See Section 5 and Annex 5 of the Final SGOA Report to OSPAR.

Quality assurance

SGOA were updated on progress with the proposed QA/QC workshop as discussed at SGOA 2013.

MCWG 2014 was informed by Quasimeme that they would now be willing to host the proposed workshop under the Quasimeme banner. This decision was welcomed by both MCWG 2014 and SGOA. Intersessionally Caroline Kivimae (UK NOC) and Pam Walsham (Marine Scotland) have been working on progressing the QA/QC workshop and have identified topics to be covered and key speakers. The workshop is now planned for May 2015 with Andrew Dickson (Scripps Institute of Oceanography US) attending as a key invited speaker.

SGOA 2014 identified the need to include discussions on uncertainty of measurements in the workshop, these should include uncertainty in sampling, analysis and data calculations. SGOA has now completed its three-year term and recommends that the QA/QC workshop and any reports/technical annex guidance documents should be progressed as a ToR by ICES MCWG.

There is no routine proficiency testing scheme available for the carbonate chemistry parameters. There was, however an ad-hoc intercalibration exercise organized by Andrew Dickson's laboratory in 2013.

2.5 ToR F: Inform the development of biological effects indicators for ocean acidification, including the identification of suitable species and key areas

Anna de Kluijver (NL) presented a project report (Landman, 2014) that had carried out a review of indicator organisms based on the table of potential indicator organisms prepared by SGOA 2013 and considering the approach for further selection as outlined in the SGOA 2013 report. The review focused on coccolithophores, foraminfera and pteropods although for most species considered there was insufficient information on the sensitivity to OA expected over the coming decades and/or limited distribution in the OSPAR area. The report suggests, and SGOA concurred, that the organism of most promise for monitoring in the arctic region is the pteropod *Limacina helicina* due its occurrence, its sensitivity to OA, the rapid acidification expected in the arctic, and the work done to date on preservation and analytical techniques (Bednaršek *et al*., 2012). This comprehensive review examined the potential utility of a number of other taxa belonging to groups that might be sensitive to OA due to calcifying structures. In particular, the sensitivity of the coccolithophore *E. huxleyi* was found to be highly strain-specific, with only a few strains showing a negative response to OA. Given the near-impossibility of identifying the strain of a cell without molecular techniques, it is not practical to collect and archive specimens of the appropriate strain. Thus we do not recommend that *E. huxleyi* be used as an indicator.

SGOA recommends that WGZE should encourage and summarize development of protocols for the collection and preservation of thecosomate pteropod shells for future evaluation of OA-driven changes in morphological characteristics.

Cold-water corals

NOAA have recently produced a series of habitat suitability index models predicting where cold-water corals such as *Lophelia pertusa* and others would likely occur along the US Atlantic and Gulf Coasts. An example map was shown and discussed with respect to the potential implementation of these models within the OSPAR region as a means of identifying areas where corals might have a higher probability of occurrence.

2.6 ToR G: Elaborate reporting requirements to ICES (taking account of the information in table at OSPAR MIME 2011 SR Annex 6)

SGOA 2012 and 2013 had detailed discussions on OA data management and reporting to the ICES DataCentre as well as the compatibility of reporting formats across international data centres. At SGOA 2014, Liqing Jiang gave an invited presentation on developments in the US with respect to OA data. SGOA 2014 also received an update on progress OA data reporting by the ICES DataCentre.

2.6.1 NOAA OA Data Stewardship and Update on CDIAC data management (Liqing Jiang, US)

Liqing Jiang from the US National Oceanographic Data Center (NODC) presented the National Oceanic and Atmospheric Administration (NOAA)'s OA data management activities. Established in 2012, the Ocean Acidification Scientific Data Stewardship (OADS) Project's near term goal is to manage datasets that are generated from NOAA Ocean Acidification Program funded projects. Liqing demonstrated the main components of the OADS data management (Figure 1). This includes a new OA metadata template that can document various types of OA dataset (including physio-

logical response OA datasets), an envisioned OA data submission interface, and a newly launched data search portal. Liqing also talked about the exchange of ocean carbon data with the Carbon Dioxide Information Analyses Center (CDIAC). The long-term vision of the Project is to build a US national OA data exchange service, with the goal of providing dedicated OA data discovery and access to both modern and historical OA datasets that are collected worldwide. Liqing made the following recommendations in his presentation:

For researchers

1) Whenever possible, the calibration of carbon related instruments should be done with independent standards. The Certificated Reference Materials should only be used to check the system.

2) It is advised to estimate uncertainties by randomly taking duplicate samples and calculate their standard deviations.

3) WOCE data quality flags should be used to indicate the quality of the measurement.

4) When direct submission of ocean carbon data to CDIAC is not possible, it is highly recommended to notify CDIAC of the new data submission, so that the carbon data can be incorporated into their global synthesis products.

For data managers to

5) Consider to build an automation program which could enable instant data archival for data that are collected from sensors.

6) Establish a mechanism to prevent data duplications in data management. For example, one way of doing this is through matching the platform (e.g. research vessel) ID and the temporal coverage, or the EXPOCODE.

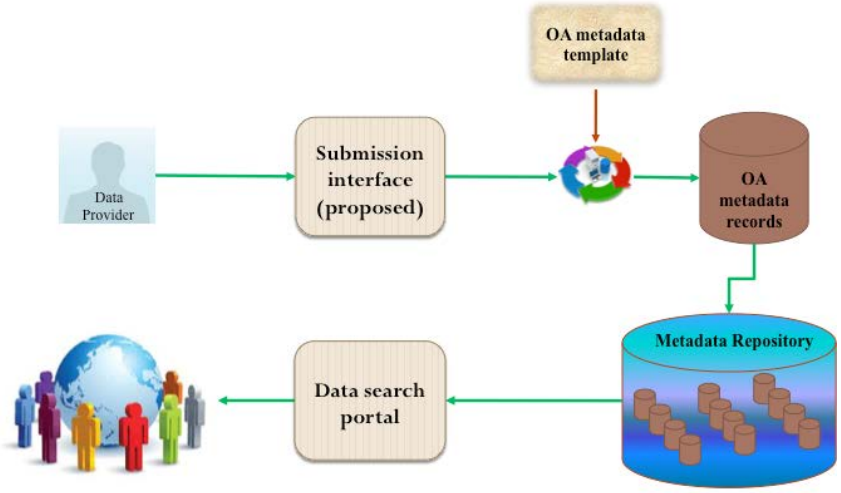

Figure 1. Main components of NOAA's ocean acidification data management.

2.6.2 ICES Data Centre update

Marilynn Sørensen from the ICES Data Centre gave an update on the progress since 2013. MCWG 2014 had been approached to further elaborate on the value checks and conversions to be made to the basic parameters and metadata for the ocean acidification parameters pH, total alkalinity, dissolved inorganic carbon and partial pressure of carbon dioxide. All data requirements can be viewed in the Data Centre's Data Request form for Ocean Acidification data. These additional checks have been implemented in the ICES environment database (ERF 3.2 format). Ireland and UK test data submissions have been used to check the quality control of the database. OSPAR/ICES discrete bottle database is now fully operational for reporting carbonate parameters. Data submissions are now required to test whether data submitted to ICES will pass the quality control requirements of CDIAC.

2.7 ToR H: Report a first assessment of all available data in the OSPAR maritime area

SGOA 2014 concentrated on two agreed assessment activities to address this agenda point.

- **Ocean Acidification: an assessment of current and projected exposure of Cold Water Coral areas in the Northeast Atlantic**.

  Are Olsen (NO UIB) presented the results of mapping of current aragonite saturation states and end of century projections for cold-water coral locations in the OPSAR area. This work was carried out intersessionally by Are and Jerry Tjiputra (NO UIB) as a cornerstone to the assessment proposed at previous SGOA meetings. SGOA reviewed the proposed contents of the assessment as agreed at SGOA 2013 and noted text providing a physical oceanographic context by Martin White (IE NUI Galway). A plan was put in place to complete the assessment for incorporation in the final report to OSPAR with input from the SGOA subgroup and additional experts identified at SGOA 2013. SGOA thanked Are and Jerry for their work and encouraged Are to consider making the output more widely available by publishing this work in the scientific press. The assessment was completed post SGOA 2014 with contributions from Are Olsen (NO), Jerry Tjiputra (NO), Evin McGovern (IE), Jason Hall-Spencer (UK), Melissa Chierici (NO), Martin White (IE), Johanna Järnegren (NO) and Murray Roberts (UK) and is included as Annex 6 of the Final SGOA Report to OSPAR.

- **Long-term trends in ocean acidification in the OSPAR area**.

  Evin McGovern presented a draft table prepared by Triona McGrath (IE) in advance of the meeting and summarizing published information from the scientific literature on long-term temporal trends for OA in the OSPAR regions. SGOA agreed that this was a useful summary and a subgroup developed the table further during the meeting. The table and associated text were finalized post SGOA 2014 with input from Triona McGrath (IE), Caroline Kivimae (UK), Sólveig Ólafsdóttir (IC), Evin McGovern (IE), Toste Tanhua (DE), Richard Feely (US) and Are Olsen (NO) and is included as Annex 7 of the Final SGOA Report to OSPAR.

3 Additional requests received by SGOA 2014

3.1 Advise OSPAR on the revision of the OSPAR JAMP Eutrophication Guidelines to monitor effects of ocean acidification as e.g. on coccolithophorids (e.g. *Emiliania huxleyi*) in line with Descriptor 1 in MSFD

The Study Group on Ocean Acidification has been evaluating possible indicator organisms that are potentially suitable for ocean acidification (OA) monitoring. Included in these organisms are the coccolithophores, principally *E. huxleyi*, but also other species. It is our conclusion that *E. huxleyi* is not a suitable candidate indicator for the following reasons. *Emiliania huxleyi* is a species that consists of a wide range of strains, each with a different genetic signature. Research on the responses of this species suggest that its sensitivity to OA is highly dependent on the strain involved (Langer *et al.,* 2009) with only some strains (e.g. RCC1256, PML B92/11A) showing sensitivity to OA as indicated by reduced calcification under elevated pCO_2. Determination of the particular strain requires genetic sequencing, which is impractical to implement as part of any routine monitoring programme. Moreover, recent research indicates that even strains of *E. huxleyi* that show a negative response to OA, appear capable of rapidly evolving tolerance (Lohbeck *et al.,* 2012). For example, after 500 generations, populations showed increased growth and partially restored calcification rates under high CO_2, which suggests that this species possesses the ability to adapt to OA.

Other coccolithophore species (e.g. *Gephyrocapsa oceanica* strain PC7/1; *Coccolithus pelagicus* strain AC400) have shown an increase in the proportion of malformed coccoliths under elevated pCO_2 (Langer *et al.,* 2006), though the responses may also be strain specific and therefore subject to the same caveats as for *E. huxleyi*. Moreover, the distributions of these species may not extend throughout the OSPAR region, which would mean that monitoring would need to focus on different species in different regions.

In summary, based on current scientific information, the SGOA does not recommend that *E. huxleyi* be included in OA monitoring as part of the revised OSPAR JAMP Eutrophication Guidelines. Other coccolithophore species may be useful as indicators of OA; however, there is currently insufficient information for us to recommend their inclusion. This information was conveyed via e-mail to Sebastian Valanko at ICES during the meeting.

3.2 EMODNET query concerning OA data aggregation

ICES forwarded a request to SGOA from EMODNET group essentially asking 'What does MSFD expect from products in its acidity theme?' i.e. a gross climatology aggregating all carbonate system data (pCO2, DIC, TA, pH (irrespective of scale)); or data aggregated for use by carbonate chemistry community.

SGOA discussed this only very briefly given the time constraints. However, SGOA was not in a position to advise on MSFD requirements given that, while pCO_2 and pH profiles or equivalent are specified characteristics in Annex III of the MSFD, acidification is not specifically mentioned elsewhere in the directive or within GES descriptors. SGOA drew EMODNET's attention to the requirements now specified for reporting OA data to ICES. The chair of SGOA responded via the ICES secretariat subsequent to SGOA.

4 Future of SGOA

The term of the SGOA expires in December 2014 and the group undertook a discussion of what the appropriate structure for OA within ICES might be. Given that OA is affected by a broad range of chemical and processes, and in turn influences a diverse biological assemblage with socio-economic consequences. Aspects of OA are currently dealt with to varying degrees by MCWG, WGOH, WGZE, WGPMI, WGBEC, BEWG, WGDEC, and potentially many other WG within ICES. The SGOA felt strongly that there was a need for a single WG that could synthesize information on OA from within other ICES WG and from external sources. Information needs on OA could be addressed through ToRs from the OA WG to other ICES WG. An ICES WG would allow linkages to external programs and initiatives relating to OA such as AMAP, GOA-ON, etc. The structure of the WG should include expertise in chemistry, physical oceanography, biology, and modelling.

5 Recommendations and actions

Specific recommendations of SGOA 2014 are given in Annex 4. General recommendations to support coordinated OSPAR monitoring are provided in the Final SGOA Report to OSPAR.

6 Closure of the meeting

Evin McGovern and Mark Benfield thanked the members for their contributions during this and previous SGOA meetings and the group expressed their gratitude to ICES for logistical support of the meeting. The meeting was adjourned at 1pm on Thursday 9 October 2014.

7 Literature cited

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Annex 2: Agenda

Joint OSPAR-ICES Ocean Acidification Study Group (SGOA), 3rd meeting

ICES Headquarters, Copenhagen, Denmark. 6th–9th October 2014.

1) Opening of the meeting

The meeting will begin at 10.00 am on the first day, and 09.00 am thereafter.

2) Introductions and tour de table

3) Apologies

4) Adoption of the agenda

5) Review ToR: Progress and feedback
- 5.1) Recap on ToR and agreed tasks;
- 5.2) Feedback from OSPAR COG;
- 5.3) Review of actions from SGOA 2013;
- 5.4) Structure of final report to OSPAR and work arrangements for the meeting;
- 5.5) Additional requests from ICES (see 7f bis).

6) Links to other ices working groups/activities
- 6.1) ASC, MCWG, WGBEC…

7) Main terms of reference

As this is the final meeting of SGOA the primary focus of this meeting will be on drafting text for the final report to OSPAR addressing the ToR as given to the group. This will consolidate material from SGOA 2012/2013 and any additional material presented at SGOA 2014.

Format of annotated ToR

1.a ToR as provided by OSPAR

Background and key tasks for SGOA 2014 Final report

i.) Specific inputs

7.1) collate chemical data and information on ocean acidification in the OSPAR Maritime Area;

Provide information on national monitoring activities and general observations (based on information provided SGOA 2012/2013 reports and any updates at SGOA 2014 + Update of Spreadsheet on OA monitoring activities – SGOA 2013 Annex 6).

7.1.1) Brief Updates from members of national OA monitoring and research activities. Including presentation on UKOA and Shelf Sea Biogeochemistry programme (Phil, Caroline).

7.2) seek information from relevant international initiatives on Ocean acidification – as listed in OSPAR MIME 11/3/3 (e.g. EU, Arctic Council);

Additional information on relevant initiatives (ref SGOA 2012/2013) and consolidate with information presented in SGOA 2012/2013 for final report.

7.2.1) **Presentation**: Placid Project – (Dave Pearce)

7.2.2) **Presentation**: CarboChange – (Toste Tanhua)

7.2.3) **Presentation**: Overview of the BIOACID project (Hans Otto Pörtner)

7.2.4) **Presentation**: OA in IPCC AR5 (Hans Otto Pörtner)

7.3) Finalize OSPAR guidelines for measuring carbonate system;

Completed 2012. Adopted by OSPAR.

7.4) collect and exchange information on biological effects on plankton, and macrozoobenthos[3];

Consolidate summary information from SGOA 2012/13 and any key updates e.g. reviewing and updating SGOA 2012 Table I.

7.4.1) Short presentation on CBD review on OA (Phil).

7.5) consider the strategy that would be required for an assessment framework appropriate to long-term assessment of the intensity/severity of the effects of ocean acidification, including any assessment criteria required;

Finalize draft of an OSPAR monitoring strategy document taking account of GOA-ON developments (Ref SGOA 2013 6.3).

Finalize advice to OSPAR on "Assessment Criteria" that may be pertinent to monitoring framework ((Ref SGOA 2013 6.3).

Recommendations on QA/QC requirements to support OSPAR OA monitoring.

7.5.1) Update Global OA – Observation Network (GOA-ON) report Phil Williamson.

7.5.2) Update on progress with respect to proposed QA/QC workshop for OA monitoring Pam Walsham/Caroline Kivimae.

[3] It is not clear why this ToR only specified these groups. SGOA has agreed not to limit the discussions to these groups only.

7.6) to inform the development of biological effects indicators for ocean acidification, including the identification of suitable species and key areas [4)];

Review and update information/table (ref SGOA 2013 Table II). Final report should include specific advice to OSPAR as to status of impact indicators for inclusion in monitoring and roadmap on how to progress with a view to developing suitable indicators.

Consider if any potential synergies with MSFD biological monitoring as proposed by Member states specifically for D1 (biodiversity) and D4 (Foodwebs)

7.6.1) **bis** Additional request via ICES Advise on review of draft OSPAR JAMP Eutrophication Guidelines on phytoplankton species composition with respect to monitor effects of ocean acidification as, for example, on coccolithophorids (e.g. *Emiliania huxleyi*) in line with Descriptor 1 in MSFD[5]

7.7) Elaborate reporting requirements to ICES (taking account of the information in Table at OSPAR MIME 2011 SR Annex 6);

Review any developments for ICES data reporting for OSPAR OA data (ERF Format), and highlight links to other databases (CDIAC) and role of data products such as GLODAP and SOCAT based on SGOA 2012&2013 discussions.

Recommendations for reporting of OSPAR OA data and consider any future work required to enhance data sharing between OSPAR-ICES and US/global OA data centres.

7.7.1) **Presentation**: – NOAA OA data management activities– - Liqing Jiang (NOAA) and Alex Kozyr (CDIAC).

7.7.2) ICES 3.2 ERF reporting – Status update (ICES MDC).

7.7.3) Update: GLODAPV2; SOCAT.

[4] OSPAR Biodiversity Committee footnote: In understanding the interactions between ocean acidification and biodiversity agreed that although it is not possible to identify parameters at this time, there is a need for the monitoring of biodiversity aspects for MSFD to look at the issues of climatic variation and ocean acidification. It was agreed that there are research gaps and hence to put forward a request for advice from ICES to inform the development of OSPAR monitoring tools to detect and quantify the effects of ocean acidification and climate change on species, habitats and ecosystem function, including the identification of suitable species and key areas (OSPAR BDC 2012 SR, Annex 16, §A3).

[5] This is a summary of additional request from the secretariat that has been addressed to four working groups (full details on sharepoint). This will only be addressed subject to expertise and time availability at SGOA 2014.

7.8) Report a first assessment of all available data in the OSPAR maritime area[6].

Assessment of OA status in Cold-Water Coral Areas of NE Atlantic and Review of OA temporal trends for North Atlantic.

7.8.1) Carbon chemistry Projections for CWC areas (Are Olsen).

8) Plenary discussion of SGOA draft report to OSPAR.

9) Future arrangements for OA work in ICES/OSPAR.

10) Recommendations from SGOA;

Recommendations to OSPAR, ICES and other organizations.

11) Any other business.

12) Closure of the meeting;

Close by 1600.

[6] Agreed a focus on assessment of OA status [&trends] in Cold-Water Coral areas as SGOA 2012 and accepted by OSPAR.

Annex 3: SGOA Terms of Reference as provided by OSPAR

The **Joint OSPAR/ICES Study Group on Ocean Acidification** (SGOA), co-chaired by Evin McGovern, Ireland, and Mark Benfield, USA, will meet in Copenhagen, Denmark from 6–9, October 2014. The Terms of Reference remain the original ones for the Group. SGOA 2014 will produce a final consolidated report of SGOA's output for submission to OSPAR.

a) Collate chemical data and information on ocean acidification in the OSPAR Maritime Area;

b) Seek information from relevant international initiatives on Ocean acidification; as listed in OSPAR MIME 11/3/3 (e.g. EU, Arctic Council);

c) Finalize guidelines for measuring carbonate system[7];

d) Collect and exchange information on biological effects on plankton, and macrozoobenthos;

e) Consider the strategy that would be required for an assessment framework appropriate to long-term assessment of the intensity/severity of the effects of ocean acidification, including any assessment criteria required;

f) Inform the development of biological effects indicators for ocean acidification, including the identification of suitable species and key areas[8];

g) Elaborate reporting requirements to ICES (taking account of the information in Table at OSPAR MIME 2011 SR Annex 6);

h) Report a first assessment of all available data in the OSPAR maritime area.

[7] OSPAR Footnote to ToR c) Building on the draft guidelines coming forwards from ICES Marine Chemistry Working Group (MCWG).

[8] OSPAR Footnote to ToR f) OSPAR BDC, in understanding the interactions between ocean acidification and biodiversity agreed that although it is not possible to identify parameters at this time, there is a need for the monitoring of biodiversity aspects for MSFD to look at the issues of climatic variation and ocean acidification. It was agreed that there are research gaps and hence to put forward a request for advice from ICES to inform the development of OSPAR monitoring tools to detect and quantify the effects of ocean acidification and climate change on species, habitats and ecosystem function, including the identification of suitable species and key areas (OSPAR BDC 2012 SR, Annex 16, §A3).

Supporting information

Priority	The Study Group is established based on a request from OSPAR to further the current activities on Ocean Acidification. Consequently, these activities are considered necessary and to have a very high priority. The expected time frame for the Study group is two to three years.
Scientific justification	The current level of scientific knowledge is not sufficiently developed for monitoring of biological parameters. Data on physical and chemical parameters relating to ocean acidification are a prerequisite for understanding the potential response of biological organisms. At the same time, monitoring of physical and chemical parameters should be informed by susceptibilities of species and habitats, depending on their situation (e.g. biogeographic range). It is, therefore essential that the consideration of biological parameters is taken into account, so that as knowledge advances, this can inform the evolution of monitoring for ocean acidification in an iterative manner.
Resource requirements	The research programmes which provide the main input to this group are already underway, and resources are already committed. The additional resource required to undertake additional activities in the framework of this group is negligible.

Annex 4: Recommendations

RECOMMENDATIONS	FOR FOLLOW UP BY
Form a Working Group on Ocean Acidification to ensure ongoing coordination of OA science within ICES.	ICES/OSPAR
Continue to review developments in QA to support OSPAR OA monitoring and specifically review progress at 2015 OA QA/QC workshop and address issues arising.	MCWG
Encourage and summarize development of protocols for the collection and preservation of thecosomate pteropod shells for future evaluation of OA-driven changes in morphological characteristics.	WGZE
Review the data reporting requirements of CDIAC for ocean carbon data and assess how transferable they are to ICES reporting system (oceanographic database).	ICES-DC with the support of MCWG