# ICES SGOA REPORT 2013

ICES ADVISORY COMMITTEE

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

7–10 October 2013

Copenhagen, Denmark

ICES
International Council for the Exploration of the Sea
CIEM
Conseil International pour l'Exploration de la Mer

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# Contents

## Executive summary

The Joint OSPAR/ICES Study Group on Ocean Acidification (SGOA) held its second meeting in Copenhagen, Denmark from 07–10 October 2013. The meeting was hosted by the ICES Secretariat. The meeting was co-chaired by Evin McGovern (Ireland) and Mark Benfield (USA) and was attended by 17 scientists representing ten nations and AMAP. Two additional guest scientists and ICES DataCentre representatives joined for discussions on data management. A number of participants joined via WebEx conference. NOAA scientists were, unfortunately, unable to participate due to the US federal government shutdown. The objective of the meeting was to address the Study Group's eight terms of reference (ToRs). A final consolidated SGOA report will be prepared at the 2014 meeting.

The group members provided new information on national OA monitoring and research developments. Updates were also provided on international activities, in particular the recently published AMAP Arctic OA assessment and EU FP7 MedSeA project.

The meeting noted the exponential increase in the number of publications on biological effects of OA with many investigations considering the combined impacts of multiple stressors. Experimental research confirms that survival, calcification, growth, development and abundance can all be negatively affected by acidification, but the scale of response varies between taxonomic groups. Volcanic $CO_2$ vents can provide useful proxies of future OA conditions allowing studies of species responses and ecosystem interactions across $CO_2$ gradients. Studies at suitable vents in Italy, Greece, Mexico and Papua New Guinea show that marine systems respond in predictable ways to increased $CO_2$. SGOA 2013 also considered the threat of the projected shoaling of the Aragonite Saturation Horizon to reef forming scleractinian cold-water corals, in particular *Lophelia pertusa,* in the Northeast Atlantic. These reefs are rich in biodiversity but we have a poor understanding of the functional ecology of these ecosystems. Cold-water corals appear sensitive to even small changes in seawater temperature, and the fossil record shows how each major extinction event of previous coral fauna was strongly related to perturbations in the ocean's carbon cycle. SGOA 2013 made arrangements to undertake an assessment of the OA status of cold water coral habitats in the OSPAR area.

To support OSPAR assessments of OA, a first draft of an OA monitoring and assessment framework was developed with a view to finalisation at SGOA 2014. It was recognised that, as an emerging field of research, any OSPAR framework would need to be flexible and responsive to rapidly expanding scientific knowledge and technological developments. The carbonate system parameters are currently included in OSPAR monitoring on a voluntary basis. SGOA concurred with MCWG that an analytical workshop is required to develop best practice and develop quality assurance required to support coordinated monitoring.

The selection of appropriate species for monitoring and description of appropriate morphological or biochemical metrics that can be used to document OA impacts is premature. SGOA updated a table of potential indicator taxa for OA responses. Shell erosion in thecosomate pteropods may provide a useful indicator but given the morphological diversity, identification of suitable species for the OSPAR area and metrics are required. SGOA recommends that a broad suite of organisms likely sensitive to OA, be collected

and archived. This archive will serve as a repository of specimens that can be retrospectively examined for evidence of OA responses once appropriate indicator metrics are developed.

The parameters and checks required for reporting OSPAR OA chemistry data to the ICES environmental database have been defined and tested. Reporting to this database is limited to discrete sample data. Protocols are needed to facilitate OA data exchange with other international data centres and initial discussions involving ICES-DC and the CDIAC data centre, a well-established data repository for marine carbon system data, took place at SGOA 2013. Data synthesis products such as GLODAPV2 and SOCAT (surface ocean $CO_2$ atlas), also available via CDIAC, have an additional level of quality checks.

The next meeting of the SGOA will be held in Copenhagen from October 6–10, 2014 at ICES.

## Opening of the meeting

The Joint OSPAR/ICES Study Group on Ocean Acidification (SGOA) met at ICES Headquarters in Copenhagen, Denmark from 07–11 October, 2013. The meeting was attended, in full or in part, by 17 scientists representing ten nations and the Arctic Monitoring and Assessment Programme (AMAP), plus two guest presenters and representatives of the ICES DataCentre participated for ToR G, (Annex 1). A number of these participants joined the meeting by WebEx.

The co-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 co-chairs noted apologies received from members who were unable to attend. This included all participants from NOAA who were unable to participate due to temporary shutdown of certain US Federal Government services.

# 1 Adoption of the agenda

## 1.1 Agenda

The agenda for the SGOA meeting (Annex 2) followed the Terms of Reference adopted as a resolution by the ICES 2012 Annual Science Conference and Statutory Meeting, and agreed by OSPAR. 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. There were some adjustments to the agenda during the meeting as NOAA colleagues were unavailable to participate and present on certain agenda items due to the US federal government shutdown, which unfortunately lasted throughout the meeting.

The SGOA Terms of Reference are to:

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[1];

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 for 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[2];

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.

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

[2] 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).

SGOA reviewed the action items from the SGOA 2012 meeting. Those not completed were carried forward.

## 1.2 SGOA Membership

SGOA 2012 noted that chemists and, to a lesser degree, biologists were well represented in its membership but identified a number of other gap areas of expertise. Evin McGovern informed the group of additional membership to address some of these gaps. SGOA welcomed the Ocean Acidification International Coordination Centre (OA-ICC) nomination of Richard Feely (US, NOAA PMEL) as their link to SGOA. Richard Bellerby (Norway), though unable to participate in SGOA 2013, has agreed to join SGOA and brings additional expertise on modelling. Murray Roberts (UK) joined SGOA providing specific expertise on deep-sea coral habitats. Moreover, the geographical scope of the membership was expanded with members from the Netherlands and Sweden attending. Participation of a physical oceanographer remains a gap.

## 1.3 Feedback from OSPAR on SGOA 2012 report

Evin McGovern and Claus Hagebro (ICES) reported that updates on progress during SGOA 2012 were provided to OSPAR's Hazardous Substance and Eutrophication Committee (HASEC 2013)[3] and Coordination Group (CoG 1 2013)[4]. The proposals from SGOA 2012 that i) SGOA would draft an outline OA Monitoring Strategy for consideration by OSPAR (ToR E), and ii) target an assessment of OA in the OSPAR area (ToR H) to particular ecosystem components (e.g. coral reefs as vulnerable habitats) for which expertise and resources might be available, were endorsed by OSPAR CoG.

## 1.4 SGOA final report (2014)

SGOA 2014 will be the final meeting of the SGOA cycle and SGOA held a brief discussion on the format of the expected final product to be delivered to OSPAR. It was agreed that a single report would be prepared by SGOA 2014, consolidating the three-year SGOA output, and structured according to the Terms of Reference provided to the group. This would include specific stand-alone products as annexes, specifically: the monitoring guidelines for the chemical aspects of Ocean Acidification (ToR B); the draft OA monitoring Strategy (under ToR E); and the assessment of OA in Cold Water Coral Areas (ToR H). Consequently the SGOA 2013 report contains updates and additions under the individual ToR and short discussions on progress in preparing these products.

## 1.5 Links to other working groups and ICES activities

#### ICES Annual Science Congress. September 2013. Iceland

Solveig Ólafsdóttir (IC) reported on relevant sessions at the ICES Annual Science Conference 2013, where ocean acidification was given a theme session as suggested by the MCWG. The session was titled "Physico-chemical aspects of ocean acidification in the

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[3] http://www.ospar.org/zip/SZ20131030-202535-9509/download.zip

[4] http://www.ospar.org/zip/SZ20131030-202535-9509/download.zip

ICES area". Conveners for the session were Jon Olafsson (Iceland), David Hydes (UK) and Alberto Borges (Belgium). Only Jon Olafsson could attend the conference. Just four presentations were given in this short session. The session was well attended.

At the ICES ASC there was also an invited talk on ocean acidification given by Dr Richard Feely (US) from the NOAA Pacific Marine Environmental Laboratory in Seattle. His presentation was entitled *"Ocean acidification over the next 100 years: implications for marine ecosystems*".

#### Marine Chemistry Working Group (MCWG)

Katrin Vorkamp (Chair of MCWG) reported on OA-related activities of MCWG 2013[5]. This covered three areas of interaction with SGOA:

a ) MCWG worked with the ICES DataCentre to define the formats and codes for reporting OA chemical monitoring data to the ICES seawater database using Environmental Reporting Format (ERF) 3.2. This topic is further addressed in Section 8 (ToR G) of this report.

b ) MCWG discussed the need for ongoing proficiency testing to support analysis of carbonate system parameters, now in the OSPAR pre-CEMP, and identified the need for a workshop on the comparability of sampling and analysis of Total Alkalinity (TA) and Dissolved Inorganic Carbon (DIC). This topic is further taken up in Section 6.4 (ToR E) of this report.

c ) MCWG provided further information on monitoring of chemical aspects of OA and informed that a document on this topic was completed for publication as an ICES Cooperative Research Report (Hydes *et al*., 2013). The final version of this report was circulated to SGOA in advance of the formal publication on the ICES website.

#### Working Group on Biological Effects of Contaminants (WGBEC)

Evin McGovern reported on communications with outgoing WGBEC chair Matt Gubbins (UK) indicating interest of WGBEC in this topic. WGBEC have set up a subgroup to: i) review the literature for recommendations on suitable species/endpoints for monitoring; ii) focus efforts on those parameters relating to expertise of WGBEC (endpoint measurements in individuals/populations rather than e.g. biogeographic trends); iii) to account for in-combination effects with other climate change variables; and, iv) to produce a written review for publication including monitoring recommendations. None of the WGBEC subgroup were in attendance at SGOA but some information was received from Kris Cooreman which was circulated to SGOA. In discussions, SGOA welcomed the proposed input of WGBEC, recognizing that identification of suitable biological effects endpoints is at an early stage. It was highlighted that there is potential for overlap with SGOA activities under ToRs D and F and that it was essential for communication between the two groups to ensure that the work is complementary and not a duplication.

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[5] MCWG Report 2013 can be downloaded at http://www.ices.dk/sites/pub/Publication%20Reports/Expert%20Group%20Report/SSGHIE/2013/MCWG13.pdf

However, given SGOA's fixed term this is unlikely to be long-term concern. Evin McGovern undertook to provide the SGOA 2013 report to chair of WGBEC with a view to alignment of activities with respect to biological effects monitoring for OA. WGBEC are recommended to report progress on their work programme with respect to OA to SGOA 2013 with a view to incorporating any agreed recommendations on biological monitoring in final SGOA report to OSPAR. (cross ref ToR F).

#### Other ICES working groups

Chairs of the Working Groups on Deep-water Ecology and Zooplankton Ecology (WGDEC and WGZE) were contacted for input on biological assessment metrics. Both groups are scheduled to meet in spring of 2014 when this question will be discussed. SGOA 2014 will consider any feedback from these working groups.

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

SGOA 2012 provided information of current OA monitoring activities undertaken in the North Atlantic by Denmark, Germany, Iceland, Ireland, Norway, UK and the US. Updates on monitoring activities in Germany, Norway and the UK were presented at SGOA 2013 and additional information provided on monitoring in Netherlands and Portugal. Information on these activities will be consolidated in the final SGOA report in 2014 along with general observations as documented in SGOA 2012. An inventory of OA monitoring activities for the Northeast Atlantic as included in the ICES Cooperative Research Report "Chemical Aspects of Ocean Acidification Monitoring in the ICES Marine Area" Hydes *et al.* (2013) has been updated and is included as Annex 6 of this report. An action for SGOA members is to update/consolidate text on ongoing monitoring for their countries in advance of SGOA 2014 and update activity table (Annex 6) for inclusion in the overall consolidated SGOA report. Information is additionally required on monitoring activities of Belgium, Sweden, [France] and Spain.

## 2.1 Monitoring in German waters (update)

The BSH (Federal Maritime and Hydrographic Agency, Hamburg, Germany) is continuing monitoring in the German Bight (EEZ - exclusive economic zone) to meet monitoring requirements within OSPAR and the MSFD. Water samples from the surface and near the bottom and sediment samples are taken at about 40 stations for analysing trace metals, organic pollutants, nutrients, pH, chlorophyll, oxygen (August/September) and salinity. CTD data are taken at each station. During the monitoring cruises continuous pH measurements are carried out.

In 2013 the BSH laboratory built a flow-through $pCO_2$ measurement system in the "measurement bunker" of the Alfred Wegener Institute/Biological Institute Helgoland (AWI/BAH). Continuous $pCO_2$ measurements start in July 2013. High-resolution temperature, salinity and pH measurements are taken in parallel.

In 2014 BSH will start measuring alkalinity during monitoring cruises.

The long-term pH dataset shows a decline of about 0.04 units over the period 1990–2013 in the German Bight. Note that this value is incorrectly stated as 0.4 units in the 2012 SGOA report.

Information provided by Sieglinde Weigelt-Krenz.

## 2.2 Monitoring in Dutch waters (new information)

#### National monitoring

There is no coordinated collection of $CO_2$ parameters in the Dutch monitoring programme (MWTL), but pH is measured as part of eutrophication monitoring.

pH has been measured from 1975 onwards at 249 stations, mainly with electrodes on NBS scale. These data were analysed for long-term trends by Provoost *et al.* (2010). In the Dutch section of the North Sea, pH at non-coastal stations increased between 1975–1985, then subsequently declined (at the rate of 0.02 to 0.03 units per year, Figure 1) between 1998–2006). At coastal stations (in the Wadden Sea, Eastern and Western Scheldt and Ems-Dollard estuary) different patterns of pH change occurred. This variability can probably be attributed to changes in the production/respiration balance driven by changes in eutrophication.

Currently, pH is measured within the monitoring program at 19 stations with a frequency of 4–19 times a year and is measured at high frequency on transect (Terschelling) using ferry box and CTD.

#### Research monitoring

The Royal Netherlands Institute for Sea Research (NIOZ) carried out fine-scale measurements of DIC, alkalinity, $pCO_2$ and pH, together with other relevant parameters, on research cruises with RV Pelagia in 2001, 2002, 2005, 2008 and 2011, covering 95 stations in basin wide North Sea (OSPAR II) (Figure 2). A next cruise is planned for 2014. These data revealed a general decrease in pH from 2001–2011. NIOZ has plans to continue ship-based monitoring and to expand two existing fixed time-series stations with continuous $pCO_2$, pH and $O_2$ measurements. There has been no structured monitoring programme for biological indicators or sensitive species.

Information provided by Anna de Kluijver.

### 2.3 Monitoring in Norwegian and Arctic waters

A detailed overview of OA monitoring by Norwegian authorities was included in the SGOA 2012. Two major programmes were outlined as below:

- Climate and Pollution Agency (KLIF) "Monitoring OA in Norwegian waters"
- Ocean Acidification Flagship at the Fram Centre, funded by Ministry of Environment (MD) and Ministry of Fisheries and Coastal Affairs (FKD).

Further information was provided to SGOA 2013 on additional activity in the project in the OA Flagship, Fram Centre, within the programme "*Monitoring Svalbard and Jan Mayen-MOSJ*" led by the Norwegian Polar Institute. MOSJ is mainly a biological monitoring programme where IMR initiated OA studies in July 2012. This activity aims to monitor carbonate system (OA state) in Svalbard fjords and water column sampling for TA and DIC at about eight to ten stations commenced in July 2012 in Kongsfjorden and Rijpfjorden and continued in 2013. The analyses were carried out by IMR in Tromsø, (Chierici *et al*., 2012; Skjelven *et al*., 2013).

Information provided by Melissa Chierici.

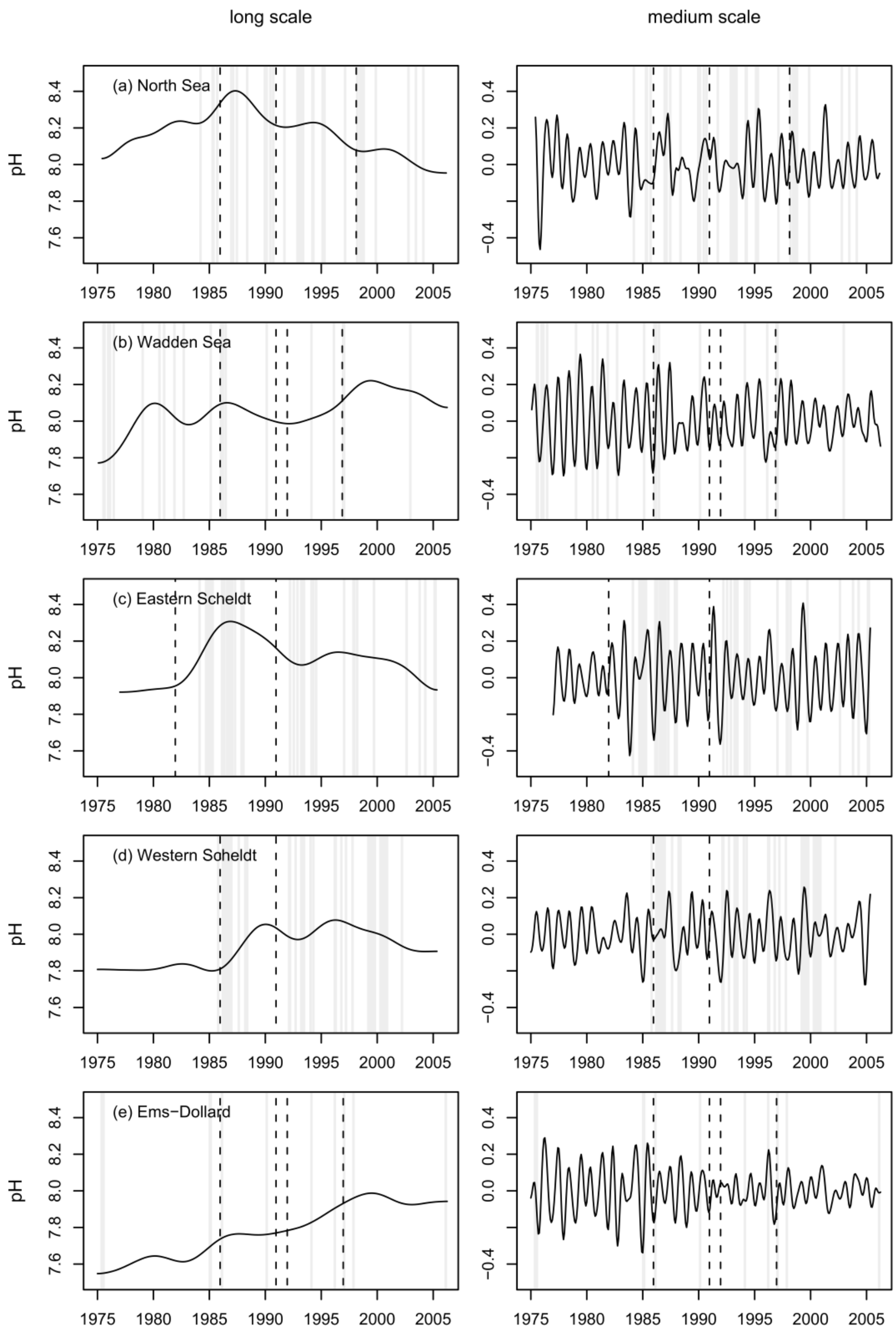


**Figure 1. Long-term trends and medium variability of pH in the Dutch North Sea, Wadden Sea and Dutch estuaries (Figure 4 from Provoost *et al.*, 2010).**

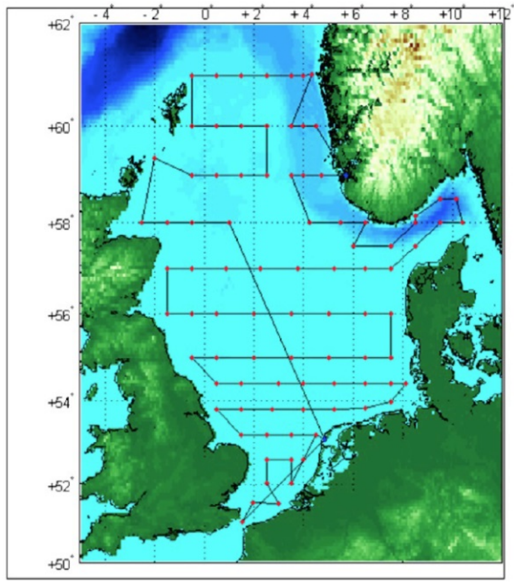


**Figure 2. Cruise track from RV Pelagia in 2011, with nearly identical locations in preceding years.**

## 2.4 Monitoring in Portuguese waters

Portugal was not represented at SGOA 2013 but Evin McGovern related information received from the Portuguese SGOA member in advance of the meeting. There is currently no national monitoring programme in Portugal. The Portuguese Institute for the Sea and Atmosphere (IPMA) has conducted hydrographic surveys and collected samples for DIC and TA measurements over several years in specific areas along the coast, covering mainly the areas influenced by the major Portuguese rivers (Tagus and Douro). In early 2013, IPMA undertook a winter survey over the continental platform covering the entire coast, the first of this kind, and collected samples for DIC and TA. A repeat survey is planned for early 2014, but this is not certain.

Information provided by Marta Nogueira.

## 2.5 Monitoring in Spanish Atlantic waters

Spanish research relevant to the monitoring and assessment of ocean acidification is carried out by a number of institutions and includes both time-series stations and repeat sections. The ocean observation activities including carbonate system measurements are:

Time-Series Stations:

- ESTOC (Canary Island, led by Melchor González Dávila and Magdalena Santana, University of Las Palmas de Gran Canaria);
- GIFT (Gibraltar, led by Emma Huertas, CSIC-ICMAN of Cadiz).

Repeated sections:

- OVIDE (Portugal-Greenland), French-Spanish collaboration (LPO and CSIC-IIM, led by Herlé Mercier and Fiz F. Pérez);

- FICARAM (Falkland-Cartagena), Spanish initiative (CSIC-IIM led by Aida F. Rios);
- VOS lines: QUIMA (UK-South Africa), led by Melchor González Dávila and Magdalena Santana Casiano.

At present there are two different observation systems taking carbon measurements at the Strait of Gibraltar: the GIFT time-series itself (composed by three stations), which is run exclusively by the Consejo Superior de Investigaciones Científicos (CSIC) (ICMAN and IIM) started in 2005; and a mooring line, set up in 2011, placed in one of the stations that form the GIFT. The mooring line contains SAMI sensors and current meters and is managed by the CSIC and the Spanish Institute of Oceanography (IEO).

Information provided by Patrizia Ziveri.

## 2.6 Monitoring in UK waters (2013 update)

### 2.6.1 National framework

UK research relevant to the monitoring and assessment of ocean acidification is carried out by a wide range of governmental bodies, research centres, university groups and other organisations. The monitoring itself is primarily carried by the Centre for Environment, Fisheries and Aquaculture Sciences (Cefas) and by Marine Scotland Science (MSS), as described below. A wider national framework is provided by the UK Ocean Acidification research programme (UKOA; www.oceanacidification.uk.org), jointly funded by the Natural Environment Research Council (NERC), the Department of Environment, Food and Rural Affairs (Defra) and the Department of Energy and Climate Change (DECC).

UKOA provides support for national involvement in the Surface Ocean $CO_2$ Atlas (SOCAT, www.socat.com) with recent publications of global-scale datasets relevant to OA (Bakker *et al*., 2013; Pfeil *et al*., 2013). UKOA research includes regional-scale, high-resolution modelling studies (e.g. Artioli *et al*., 2012; 2013) for European shelf seas and the Arctic; experimental studies of biological responses to OA, with emphasis on long-term, multi-stressor impacts (e.g. Godbold and Solan, 2013); and palaeo-studies, to investigate the impacts of previous global-scale perturbations to the ocean carbonate system. UKOA has also supported four multidisciplinary research cruises, one focused on potential OA impacts on cold-water corals off Northwest Scotland, and three directed at the biotic and biogeochemical consequences of carbonate chemistry changes in the upper ocean, around the UK (June–July 2011), in the NE Atlantic and Arctic (June–July 2012) and the Atlantic sector of the Southern Ocean (January–February 2013). Future conditions have been simulated by on-board bioassay experiments, whilst the effects of present-day variability of the upper ocean have been investigated by sampling over wide spatial scales (Figure 3), with associated measurements of a wide range of chemical and biological parameters.

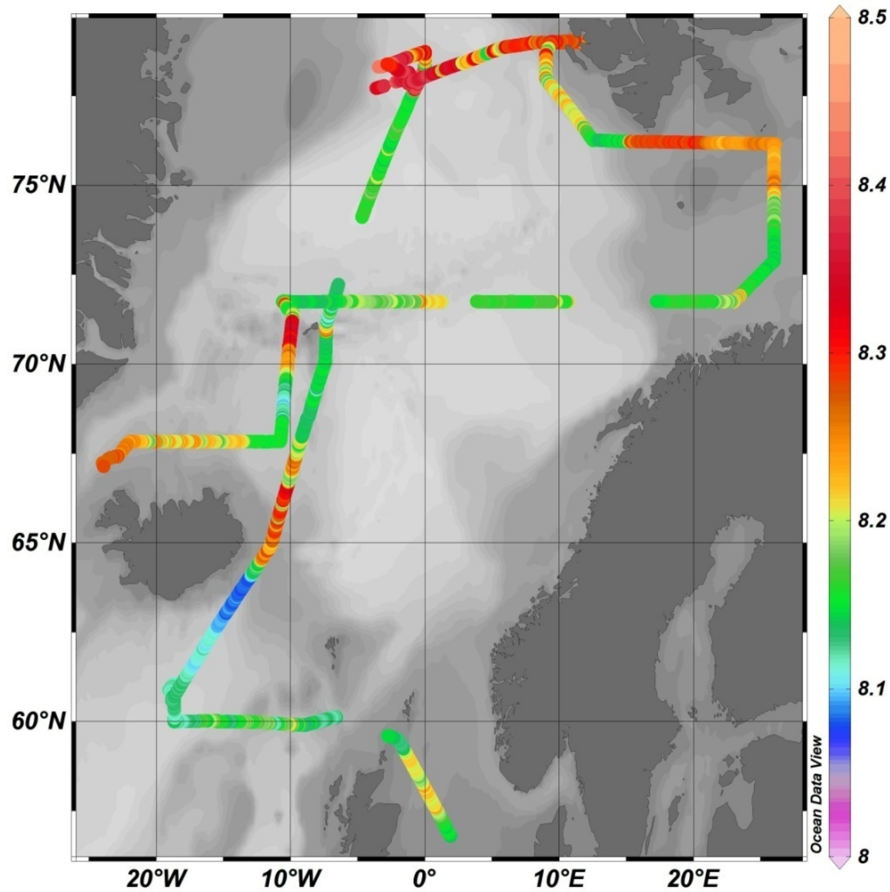


**Figure 3. Spatial variability of near-surface pH (underway data) in NE Atlantic, Norwegian Sea and parts of the Arctic Ocean, June–July 2012. Preliminary data from UKOA Sea Surface Consortium (Victoire Rerolle and Toby Tyrrell).**

In particular, a comprehensive suite of DIC, TA, pH and $pCO_2$ data were collected on all three UKOA Sea Surface cruises, with additional water column information, including $\delta^{13}C$ and standard physical oceanographic variables. These datasets are currently undergoing final quality control; 'over-determination' of carbonate data has not indicated any systematic differences. Biological analyses have included coccolithophore abundance, species composition, and species-specific measures of coccolith size and calcification. Although considerable variability of these parameters has been observed, no obvious first order relationships have been found to date relating them to the pH ranges or other aspects of the present carbonate chemistry, e.g. calcite saturation state (J R Young; pers. comm.).

Most of the research components of the UKOA programme end in late 2013 or early 2014. However, some OA-related biogeochemical studies, on carbon dynamics in shelf seas and sediments, are included in the new UK Shelf Sea Biogeochemistry programme (www.ssb-uk.org; co-funded by NERC and Defra; 2013–2018). UK biological monitoring relevant to OA includes the Continuous Plankton Recorder survey (CPR, www.sahfos.ac.uk) and time-series sites providing long-term data on the abundance of a diverse range of pelagic and benthic organisms (e.g. the century-long records at the Western Channel Observatory, off Plymouth; www.westernchannelobservatory.org.uk). CPR and ICES datasets have been recently analysed to see if ocean acidification effects could be detected in the changing abundances of potentially sensitive, calcifying species. However, evidence of the occurrence of any such signals is currently inconclusive (Beaugrand *et al*., 2013; Beare *et al*., 2013).

### 2.6.2 Activities by Marine Scotland Science

Water samples for TA and DIC analysis have been collected since late 2008 on a weekly basis (weather permitting) at the Stonehaven long-term coastal monitoring site, both at the surface (1 m) and just above the seabed (45 m). Samples collected between November 2008 and August 2011 were analysed by the National Oceanography Centre Southampton (NOC), as part of the Defra pH project and UK Ocean Acidification programme. Samples collected since September 2011 have been analysed by NOC as part of the MSS-funded monitoring project. TA/DIC data collected throughout this period (2008–2012) have been combined and an initial assessment is in progress.

As a consequence of nitrate uptake by phytoplankton cells during an algal bloom TA concentrations will increase. Therefore, it would be expected that TA concentrations will follow an annual cycle around the bloom (Figure 4).

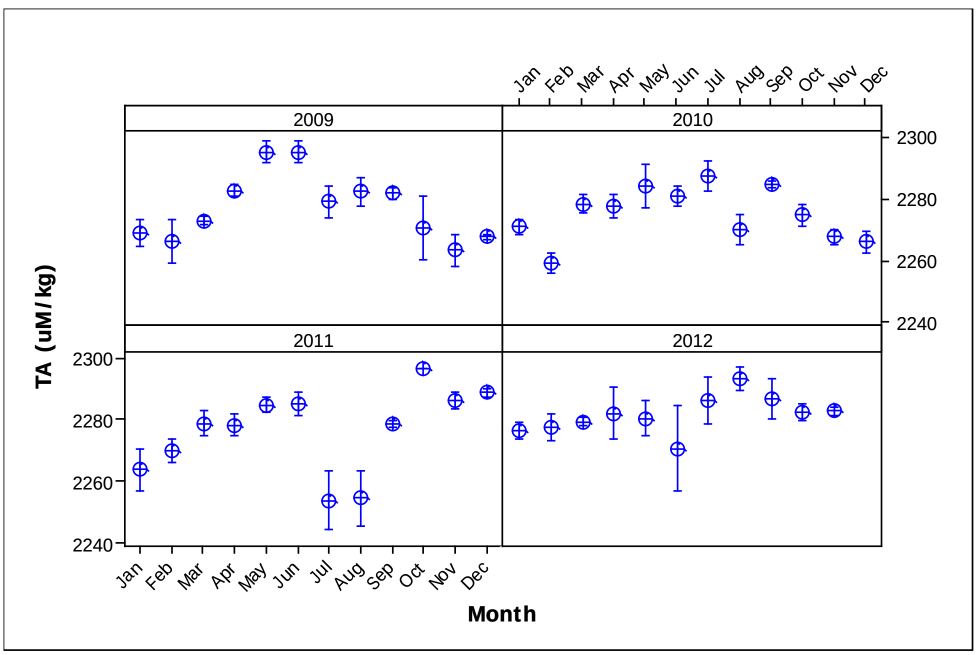


**Figure 4. Total Alkalinity (TA) plot of all monthly observations and for water collected at 1 and 45 m. The error bars represent one standard deviation from the mean.**

In 2009 and 2010 we observed a strong seasonal cycle, maximising during the spring bloom when TA values were just below 2300 µM/kg. In 2011 the cycle continued until July/August when the cycle broke down. There was not a strong seasonal cycle during 2012; the possible reasons for this are under investigation.

DIC concentrations also follow a seasonal and annual seasonal cycle, mirroring that of nitrate where concentrations decrease during the bloom. DIC is following a similar pattern to TA with a loss of the seasonal cycle in 2012.

Additionally MSS are beginning to look at cocolithophores at the Stonehaven site. To date the 2010 dataset has been worked up. Examination of SEM images suggests the possibility of two different morphotypes of *Emiliania huxleyi* present, type A and B. *Emiliania huxleyi B* appears to dominate in May while *E. huxleyi A* is dominant in August.

Seawater samples were collected for TA/DIC analysis from four selected sites during the May and December 2012 hydrographic cruises along transect lines in the Faroe/Shetland channel (Nolso/Flugga and Fair Isle/Munken) and the Atlantic inflow line (Orkney/Shetland) as shown in Figure 5. Water samples were collected throughout the water column at each of the selected sites. TA/DIC data from these stations will be used to establish a baseline for temporal assessments.

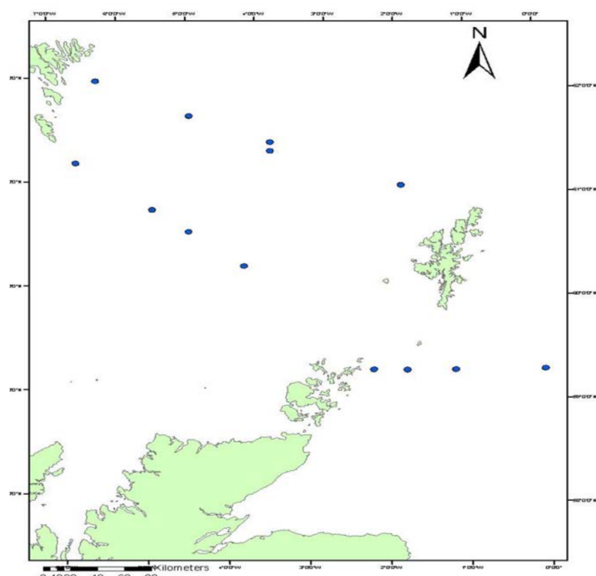


**Figure 5. MSS offshore carbonate chemistry sampling stations.**

### 2.6.3 Activities by Cefas (updated text)

The Centre for Environment, Fisheries and Aquaculture Science (Cefas) established time-series stations in late 2010 at three of the SmartBuoy sites in the Southern North Sea (Warp, West Gabbard and Dowsing). Samples for TA and DIC analyses are collected about eight times a year at these sites. Additional spatial coverage in the North Sea, Channel, Celtic Sea, Irish Sea and Liverpool Bay was also started in late 2010, with discrete samples for TA and DIC analyses being collected on annual fisheries and other environmental monitoring cruises. The absolute values and spatial patterns of DIC data from the North Sea in August 2011 and 2012 showed good agreement with previous surveys at the same time of year (e.g. Bozec *et al*., 2006). In addition, surface measurements taken during the UKOA RV Discovery cruise 366 around the UK showed generally good agreement with Cefas data collected in the North Sea a few weeks later.

An underway $pCO_2$ system was fitted to *RV Cefas Endeavour* in January 2012 and has been successfully used since then on fishery assessment (and other) cruises. Together with underway data from *MRV Scotia* (see above), this system will provide spatial coverage for a high proportion of UK waters and European shelf seas. Although any specific site/area may only be sampled 1–2 times per annum, coverage will be repeated at closely similar times of year. Comparisons between measured $pCO_2$ and values calculated from TA/DIC samples collected during two cruises in September and October 2012 show good agreement, with a root mean squared error (RMSE) of between 10 and 15 μatm.

To provide baseline data (currently lacking) for pH in natural sediments, Cefas obtained cores in summer 2011 and early 2012 at 30 stations from contrasting sea regions (temperature, depth, sediment type) in the North Sea and Channel. Profiles of pH and dissolved oxygen were obtained using microelectrodes; these showed pH reductions of 0.5–1.0 in the top centimetre of muddy sands. These data were supplemented with sediment profile imagery (SPI) visuals, particle size analysis and organic carbon analyses. The results offer insights into factors affecting natural pH variability within a variety of sediments under current conditions.

Defra has recently funded Cefas' Placing Ocean Acidification in a wider Fisheries Context (PLACID) project. This three year project will provide:

1 ) Economic quantification of the impact of OA on UK shellfisheries and aquaculture;
2 ) Information via multi-factorial experiments (considering different life stages) to investigate the effects of OA and other stressors (temperature, pH, oxygen);
3 ) Modelling studies to 'scale-up' from laboratory results to population and ecosystem effects;
4 ) Monitoring data (pH, TA, DIC) for UK territorial waters, beyond the end of the UK OA programme.

It will use Cefas' ocean acidification experimental facility at its Weymouth Laboratory to study commercially important species and Dynamic Energy Budget (DEB) models to of 'scale up' from a detailed knowledge of physiology to population-scale effects, with the aim of assessing the economic consequences resulting from OA on fisheries. The project will also provide funding to continue Cefas' OA monitoring programme, started under UKOA, for a further three years.

Information provided by Phil Williamson, David Pearce, Pam Walsham.

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

## 3.1 Arctic Monitoring and Assessment Programme Jan Rene Larsen (Arctic Monitoring and Assessment Programme)

Jan Larsen presented the Arctic Ocean Acidification Assessment (AOA) carried out by the Arctic Monitoring and Assessment Programme's (AMAP). The assessment was produced by AMAP for the AOA Conference in Bergen in May 2013 and for the Arctic Council Ministerial meeting, in May 2013. The assessment is divided into five chapters: 1) sets the stage for the assessment 2) presents an introduction to the carbon biogeochemical system in the Arctic Ocean, 3) provides a description of the biological responses to ocean acidification, 4) presents analyses of how changes in ocean acidification may affect the economics of marine fisheries, food security and cultural issues for coastal Arctic indigenous communities, and 5) presents an overall summary of the major findings and gaps in knowledge of Arctic Ocean acidification.

The assessment presents ten Key Findings, covering ocean chemistry, biological responses and socio-economic implications of Arctic Ocean acidification. In the recommendations, it is noted that the biological, social, and economic effects of ocean acidification are potentially significant for the Arctic nations and their peoples, as well as global society. In the recommendations there is a call for the Arctic Council to enhance research and monitoring efforts that expand the understanding of acidification processes and their effects on Arctic marine ecosystems and northern societies that depend on them.

The outreach products of the assessment are 1) a scientific report http://www.amap.no/documents/doc/AMAP-Assessment-2013-Arctic-Ocean-Acidification/881, 2) a layman's summary report, 3) a summary for policy-makers, and 4) a film. The reports are available at http://amap.no/documents/, and the film is available at https://vimeo.com/groups/189916.

At the meeting of the AMAP Working Group in September 2013, the group considered potential follow up to the assessment, including the development of a monitoring strategy for measuring Arctic Ocean acidification. A workshop will be arranged to clarify follow-up work and to discuss the scope of an updated assessment with plans to address, among other things, new data and global implications and teleconnections of AOA.

In the following discussion, Jan noted that there has been a close connection between AMAP, ICES and OSPAR since the foundation of AMAP in 1992, and over the years, AMAP has adopted a significant amount of the advice given by ICES on marine monitoring. Jan also noted that AMAP is in the process of updating its guidelines, and the guidelines will be developed to cover new areas, and most likely also ocean acidification. In this context, the outcome of SGOA is very relevant, especially the work on monitoring guidelines, the quality assurance programme and the assessment framework. The OSPAR area also has an arctic subarea, and it was noted that relevant arctic expertise is well represented in SGOA, especially through the participants from countries that are members of the Arctic Council as well as of OSPAR.

The group asked whether as an Arctic nation Russia had been involved in the assessment. Jan indicated that involvement from Russia had been limited and it has proved challenging trying to estimate the large freshwater inflow to the Arctic from Russian rivers. SGOA noted that although Russia is a member of ICES, involvement of Russian scientists in ICES expert groups has historically been limited.

## 3.2 European MedSeA project Patrizia Ziveri (Universitat Autònoma de Barcelona)

During the 2013 SGOA meeting a presentation on the progress and new findings related to the development of the MedSeA project was given by Patrizia Ziveri, the project coordinator. Currently, the MedSeA is the only EC FP7 project focusing on OA research. It has a regional approach assessing uncertainties, risks and thresholds related to Mediterranean OA. To make reliable OA projections, it is key to consider the combined effects of climatic and non-climatic drivers that can be interconnected and interacting with complex dynamics. This applies particularly in the Mediterranean. The update included results from recent laboratory experiments, field studies in naturally acidified waters, and monitoring sites. Mediterranean $CO_2$ vent studies converge in showing the effects of OA on benthic systems. These effects include a reduction of calcareous species and biodiversity, and alteration of the competitive dynamics between species with "regime shifts". In addition, the ocean warming and heat waves may intensify the effects of acidification.

Long-term OA laboratory experiments on target organisms were used in the project to detect the physiological impacts. For example, a 314-day laboratory experiment has demonstrated the detrimental effects of OA on the precious endemic Mediterranean red coral, *Corallium rubrum* (Bramanti *et al*., 2013). The economical important species *Mythilus gallorpovincialis* is largely used in the Mediterranean aquaculture industry. Results from a one-year long experiment focusing on the combined effects of OA and warming, clearly showed that mortality rates increase dramatically in the high temperature treatments, regardless of the pH conditions. All mussels died at high temperature, towards the end of the experiment, and around 50% of the mussels remained at ambient temperature. The loss of periostracum was evident on mussels exposed to low pH conditions after summer warm conditions (Gazeau *et al*., in prep). These results corroborated a previous MedSeA field study based on $CO_2$ vents (Rodolfo-Metalpa *et al*., 2011).

Coastal monitoring sites and physically driven models are showing the large ranges in seasonal surface pH in the North Adriatic and other regions. Recently a MedSeA oceanographic cruise covering the entire Mediterranean collected a variety of chemical and biological samples that are currently being processed. This cruise was run in collaboration with the international GEOTRACES program (http://medseaoceancruise.wordpress.com). This expedition focused on gathering new seawater carbonate chemistry and biological data relative to the elevated $CO_2$ conditions.

A main final aim of MedSeA is to provide in 2014 model projections of changes in Mediterranean Sea temperature, pH, $CaCO_3$ saturation states, and related carbonate-system and biogeochemical variables during the 21st century. The projections will consider the envelope of different climate change scenarios and the spread of the different models. We will also generate socio-economic vulnerability maps. Qualitative assessment of possible socio-economic impacts of different scenarios of OA will be finalized in 2014 for certain parts of the Mediterranean region. In this way, MedSeA research outcomes will be directed at distinguishing specific socio-economic consequences of Mediterranean acidification, and will pinpoint which measures of mitigation and adaptation need to be invoked to best cope with environmental threat.

## 3.3 Other initiatives

SGOA also identified a number International and large national initiatives where further potential linkages may be possible;

- BIOACID Stage 2 (Biological Impacts of Ocean Acidification) a German programme encompassing assessment of future biological responses to ocean change and their possible socio-economic consequences, involving 15 research institutes. http://www.bioacid.de/. Toste Tanhua undertook to contact Ulf Riebesell to request information on BIOACID for SGOA 2014.
- Global Ocean Acidification Observation Network (GOA-ON): See Section 6.2 for more information.
- IMBER (Integrated Marine Biochemistry and Ecosystem Response) an international coordination initiative on global environmental change, with focus on marine biogeochemical cycles, ecosystem sensitivity to global change, and predicting ocean responses. The IMBER Open Science Conference will take place in Bergen on 23–27 June which will have a number of OA-relevant sessions. http://www.imber.info/index.php
- ICOS (International Carbon Observing System) a provider of long-term observations of mainly of surface with limited discrete sampling. There is no funding specifically for marine observations currently. http://www.icos-infrastructure.eu/home
- CHOICE-C; a five year Chinese project investigating carbon cycling in Chinese Seas (budget, controls and ocean acidification).
- Future Earth, a new ten year international research initiative to develop the knowledge for responding to the risks and opportunities of global environmental change, integrating existing global change programmes and projects. http://www.icsu.org/future-earth/
- The SGOA chairs also reported that they had provided a letter of support on behalf of SGOA for a proposed British Antarctic Survey led workshop on pteropods.

# 4 ToR C: Finalize guidelines for measuring carbonate system

Guidelines for monitoring the chemical aspects of ocean acidification had been prepared at the MCWG meetings in 2012 and amended by SGOA 2012 (see SGOA 2012 report Annex V). Evin McGovern reported that these will be considered the OSPAR MIME working group in November 2013 with a view to recommending them for adoption by OSPAR as Joint Assessment and Monitoring Programme (JAMP) Guidelines if deemed acceptable.

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

Two focus topics areas were addressed in plenary presentations at SGOA 2013, namely:

- new information on cold water $CO_2$ vent ecosystems as bellwethers of future acidified oceans;
- current research into cold-water corals response to a changing ocean.

## 5.1 Ecological effects of acidification around marine $CO_2$ vents

**Jason Hall-Spencer (Plymouth University)**

Laboratory and mesocosm research into ocean acidification has been augmented in recent years with work at volcanic vents which show which organisms can survive elevated $CO_2$ levels and what communities of organisms are like after chronic exposure to low carbonate saturation states. Initial work described obvious ecological shifts in rock and seagrass habitats along gradients in carbonate chemistry in the Mediterranean with major losses of calcareous organisms below mean pH 7.8 (Hall-Spencer *et al*., 2008; Martin *et al*., 2008). There has since been improved pH monitoring at these sites(Kerrison *et al*., 2011) and assessments of fundamental processes such as calcification and the ways in which acidification lowers the diversity of communities of seaweeds, sponges and in sediments (Hahn *et al*., 2012; Dias *et al*., 2010; Porzio *et al*., 2011; Goodwin *et al*., 2013) . The vents are useful for studies of invertebrate recruitment revealing that juvenile bivalves are especially vulnerable (Cigliano *et al*., 2010) and can be used to demonstrate how community interactions alter as $CO_2$ levels increase (Kroeker *et al*., 2012). Transplantations (of bryozoans, corals, molluscs) show which organisms can adapt to chronic exposure to elevated $CO_2$ and the extent to which warming exacerbates the effects of OA (Rodolfo-Metalpa *et al*., 2010; Rodolfo-Metalpa *et al*., 2011).

Collaborations with scientists at vents in Italy, Greece, Mexico and Papua New Guinea show that marine systems respond in predictable ways to increased $CO_2$, although confounding factors such as variations in alkalinity or toxic metals need to be avoided (Boatta *et al*., 2013). Observations off Sicily reveal that OA is likely to cause significant microbial community shifts (Johnson *et al*., 2011; Lidbury *et al*., 2012; Pettit *et al*., 2013) to alter plant defence chemicals that act as grazing deterrents (Arnold *et al*., 2012) to benefit anemones, and corrode calcified organisms such as corals (Suggett *et al*., 2012). The ability to adapt physiologically and genetically to acidification at the vents varies in closely related species (Calosi *et al*., 2013a; Calosi *et al*., 2013b). Taken as a whole these results indicate that, within the OSPAR region, aragonitic deep-water reefs formed by species such as *Lophelia pertusa* are likely to dissolve if saturation state is greatly lowered, as are high magnesian-calcite maerl beds formed by species such as *Lithothamnion glaciale*. Seagrasses and invasive seaweeds can be expected to proliferate although the biodiversity of seagrass habitats is expected to decline. Given that NE Atlantic coastal waters have high food availability, commercially important shellfish such as oysters and mussels may not be as vulnerable to ocean acidification as those found in oligotrophic waters. The worldwide occurrence of marine $CO_2$ vent systems strengthens predictions about the effects of ocean acidification that can be applied at the ecosystem scale to all areas, including the NE Atlantic (Johnson *et al*., 2012; Russell *et al*., 2013).

## 5.2 KnowSeas Project

**Jason Hall-Spencer (Plymouth University)**

The EU FP7 Knowledge-based Sustainable Management for Europe's Seas (KnowSeas) used a DPSIR (Driver, Pressure, State, Impact and Response) framework to review the current science to identify the key ecosystem services provided by deep-water coral reefs and the drivers and pressures on the habitat (endogenic managed and exogenic unmanaged). Data were collated on coral distribution and the distribution of aragonitic reefs was modelled to determine whether existing protection of deep-water coral reefs would be fit for future purpose (including meeting GES targets) in the face of ocean acidification, and if not what steps may need to be considered in order to ensure the protection of this habitat (Figure 6).

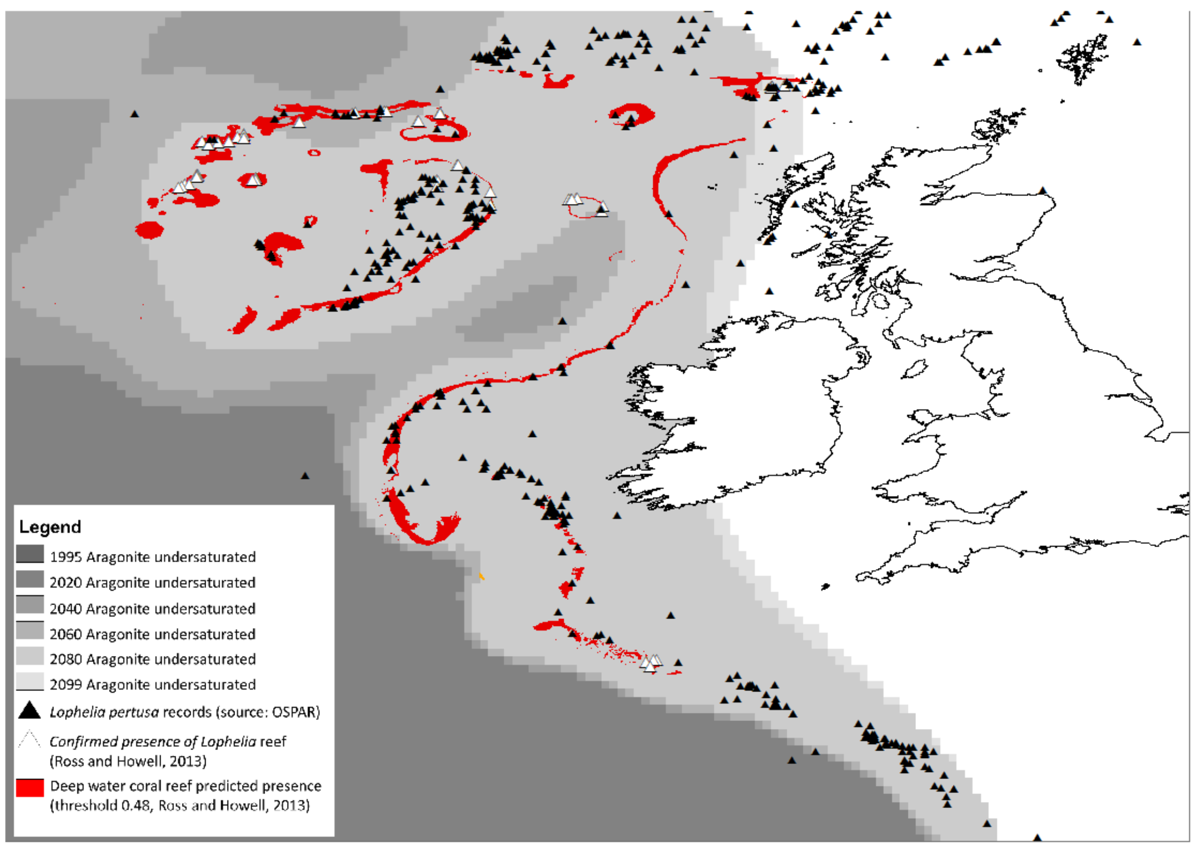


**Figure 6. Aragonite Saturation Horizon shoaling for 2020, 2040, 2060, 2080 and 2099. Stony coral records (MESH database) and predicted aragonitic reef extent (from Jackson *et al*., submitted).**

The KnowSeas project ended in June 2013 and the following paper has been submitted: Jackson EL, Davies A, Howell K, Kershaw P, Hall-Spencer JM. Future-proofing Marine Protected Areas: a deep water coral reef case study.

## 5.3 Cold-water Corals in a Changing Ocean

**J Murray Roberts (Heriot-Watt University)**

Although spread across the globe we understand little about the functional ecology of cold-water coral (CWC) ecosystems. This presentation focused on the reef frameworks built by a small group of scleractinian CWCs, in particularly the species *Lophelia pertusa* since this dominates CWC reefs and mounds in the OSPAR area. These CWC structures are now known to be rich in local biodiversity and important in the life cycles of certain deep-water fish, although our understanding of these relationships remains poorly developed. CWCs appear sensitive to even small changes in seawater temperature, and the fossil record shows how each major extinction event of previous coral fauna was strongly related to perturbations in the ocean's carbon cycle. This sensitivity to geological periods of carbon cycle change underpins our present understanding of the sensitivity of CWCs to anthropogenic ocean acidification. Although there is clear evidence of prior periods of ocean acidification both the magnitude and rate of $CO_2$ release in geological history are far lower than the present day. The talk then structured the present scientific understanding of the impacts of ocean acidification (OA) on CWCs around three overarching aims: (1) Understanding global patterns of OA; (2) understanding ecosystem response; (3) providing data necessary to optimize modelling, each aim derived from the goals set by the nascent Global OA Observation Network. In summary:

Aim 01. Global OA condition: CWCs provide a valuable new archive of intermediate water mass history with boron isotopes in coral carbonate a potentially important new pH proxy derived from fossil coral skeletons that can be precisely dated.

Aim 02. Ecosystem response: Global ocean modelling predicts rapid shoaling of the aragonite saturation horizon that would expose most CWCs to corrosive seawater by the end of the 21st century. Experimental work to examine CWC response to OA has begun. Early studies show evidence of declining growth over relatively short time periods, but did not factor temperature increase into experimental design. More recently temperature has been included, experimental periods have increased and effects on coral skeletal structure have been examined.

Aim 03. Providing data to optimize modelling: There has been increased effort made in characterizing the dynamics of carbonate chemistry around CWC sites with work at the Mingulay Reef Complex (NE Atlantic) showing up to 0.1 pH unit shifts associated with tidal downwelling. Predictive habitat suitability modelling shows the importance of aragonite saturation state as a key variable in controlling CWC distribution with recent studies employing increased resolution environmental data. The importance of water mass in controlling CWC occurrence was reviewed with a focus on the Hebrides Terrace Seamount where framework-forming CWCs were present at low aragonite saturation states (at times $<1$), but the species present was different from that at shallower depths. Further work is clearly needed to fully understand the factors controlling CWC distribution, and the need for long-term *in situ* environmental datasets, repeat surveys and work to track changes in community ecology over time were all highlighted.

## 5.4 Overview of ocean acidification publications

Scientific interest in ocean acidification has increased exponentially in the past few years, with the number of publications increasing from around 25 in 2004 to around 350 in 2012. The total number of papers is now around 1800 by over 3000 authors.

No attempt was made by SGOA 2013 to carry out a comprehensive assessment of recent literature; however the meeting noted that Kroeker *et al*. (2013) provides an updated metadata analysis of biological responses to ocean acidification, based on 228 experimental studies. That meta-analysis confirmed that survival, calcification, growth, development and abundance can all be negatively affected by acidification, but the scale of response varies between taxonomic groups. The variability of species' responses is apparently greater when they are exposed to acidification in multispecies assemblages, showing the importance of indirect effects and the need for caution when forecasting ecological consequences from single-species laboratory studies. Nutritional status can cause substantial variation in organisms' responses, whilst elevated temperatures may result in enhanced sensitivity to acidification when taxa are concurrently exposed to elevated seawater temperature.

The meeting also noted that:

- ocean acidification has been included in all three Working Group reports of the 5th assessment of the Intergovernmental Panel on Climate Change (IPCC). The WG I report has now been published (IPCC, 2013) with the other WG reports to be available in 2014.
- An assessment of ocean acidification impacts on biodiversity is currently in progress by the Convention on Biological Diversity (with involvement by UK SGOA members), for publication in 2014.

A summary for policymakers on ocean acidification (IGBP, IOC and SCOR, 2013) was published soon after the SGOA 2013 meeting, based on the 3rd Symposium on the Ocean in a High $CO_2$ world.

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

## 6.1 Background

SGOA 2013 recapitulated on discussions at SGOA 2012 and noted that OSPAR HASEC and CoG were in agreement with the proposal that SGOA develops an overarching OA Monitoring Strategy for consideration by OSPAR. SGOA agreed that the strategy should be in a similar vein to other OSPAR monitoring and assessment strategies but also should align as far as possible with global monitoring initiatives such as the developing Global OA Observing Network (GOA-ON). With that in mind SGOA 2013 reviewed developments in GOA-ON (Section 6.2) and spent considerable time developing the draft OSPAR monitoring strategy, due for finalisation at SGOA 2014 (Section 6.3). At present OA carbonate parameters are in the OSPAR "pre-CEMP" (i.e. voluntary component in the OSPAR Coordinated Environmental Monitoring Programme, OSPAR 2010). To be fully included in the CEMP (mandatory monitoring component) requires technical guidelines and QC/QA tools to be in place. SGOA 2013 further developed the discussions from SGOA 2012 and MCWG 2013 on enhancing analytical quality assurance to support OSPAR monitoring of these parameters. (Section 6.4).

## 6.2 Development of Global Ocean Acidification Observing Network (GOA-ON)

At its first meeting in 2012, SGOA noted that a global network for OA observing was under development, with opportunity for collaborative linkage with OSPAR-ICES activities, for mutual benefit. The Global Ocean Acidification Observing Network (GOA-ON) had arisen from recognition of shared needs between the international research community, national funding agencies and intergovernmental bodies; its three main goals and overall approach are closely congruent to the SGOA framework (and vice versa), and there is also scope for alignment of effort regarding recommendations on parameter selection, measurement protocols, quality control and data management arrangements.

The presentation on GOA-ON (by Phil Williamson) at the 2013 SGOA meeting identified the following main developments of the global network in the past year:

- publication of "Toward a Global Ocean Acidification Observing Network" (Newton *et al*., 2013), based on the first GOA-ON international workshop (Seattle, June 2012) with associated website, including an interactive map
- further planning of GOA-ON and its implementation at a 2nd international workshop, held at the University of St Andrews, UK, 24–26 July 2013. A total of 87 participants from 26 countries and four international bodies attended, with ~12 also being involved in SGOA. Darius Campbell (Executive Secre-

tary, OSPAR) gave an introductory presentation at the St Andrews workshop that was supported by a wide range of national and international bodies[6].

The 2nd GOA-ON workshop gave particular attention to standardizing the monitoring of ecosystem impacts of OA in shelf and coastal seas. Acknowledging the heterogeneity of such environments, separate attention was given to defining the optimal observing systems to detect OA impacts in five ecosystem groupings: tropical regional seas; temperate regional seas; polar regional seas; warm and cold-water corals; and nearshore, intertidal and estuarine habitats. The organizers of the GOA-ON workshop recognized that there was overlap between these groupings, and that 'shelf and coastal seas' could be defined in different ways. Nevertheless, the groupings provided a working structure to discuss potential OA impacts for habitats and ecosystems influenced by both terrestrial/riverine and seabed processes (in contrast to the open ocean; the focus of the first GOA-ON workshop). It was also recognized that the scope for biological observing is extremely wide, potentially encompassing all marine taxa and biotic processes; it was therefore considered essential that GOA-ON should build on, and work in close liaison with, biological components of the IOC-led Global Ocean Observing System and its Framework for Ocean Observation, currently in preparation.

Preliminary information was presented to the SGOA meeting on the parameters that might be included as GOA-ON Level 1 observations ( 'critical minimum measurements') and Level 2 ('enhanced suite of measurements… promote understanding of mechanisms') for GOA-ON Goal 2, i.e. relating to ecosystem response to changing OA conditions. The distinction between Levels 1 and 2 was not an easy one to make: it depended to some degree on the expected availability of resources and technological capabilities, and the intended spatial and temporal coverage; also whether the approach was inherently aspirational, targeting as much 'basic' information as possible for scientific interpretation of observed variability, or inherently pragmatic (and resource-limited), with focus on a do-able core suite that would be widely applicable. Further attention to these issues (discussed in the OSPAR-ICES context in later sections of this report) will be given in the Global OA Observing Plan, for publication in 2014 as a combined outcome of the Seattle and St Andrews workshops. In addition to giving information and guidance on observing approaches appropriate to the GOA-ON goals, the Plan will also set out:

- the new GOA-ON governance structure, based on an Executive Council including representatives from main sponsoring bodies and individual scientists with relevant expertise;

[6] Sponsors of the 2nd GOA-ON Workshop included the UK Ocean Acidification research Programme (UKOA, co-funded by NERC, Defra and DECC); the International Ocean Carbon Coordination Project (IOCCP, a joint initiative of IOC/UNESCO and SCOR); the Ocean Acidification International Coordination Centre of the International Atomic Energy Authority (OA-ICC/IAEA); the UK Science and Innovation Network; the NOAA Ocean Acidification Program; and the Intergovernmental Oceanographic Commission of UNESCO and its Global Ocean Observing System (with WMO, UNEP and ICSU).

- the groundwork for international OA data sharing arrangements, based on defined data and metadata standards, and open access to observing data.

A new, integrated GOA-ON website is under development, hosted by NOAA PMEL. Cathy Cosca is the Network's Technical Architect, with responsibility for developing and maintaining the GOA-ON interactive map. Phil Williamson agreed to circulate GOA-ON St Andrews' workshop report when available and update SGOA 2014 on any further developments.

## 6.3 An OSPAR monitoring and assessment framework

Having discussed the developments in GOA-ON and recognizing that identification of indicators and parameters in that forum were still under development, especially for determining impacts of OA, SGOA reiterated that any monitoring strategy would need to be flexible to accommodate new scientific knowledge in this relatively young but rapidly expanding field of research. An outline draft of a monitoring strategy, prepared by Evin McGovern, was uploaded to the SGOA SharePoint site in advance of meeting and this document served as a ”thought starter” to develop discussions. SGOA proposes that the strategy should be relatively short and sufficiently flexible to form a sound basis for coordinated monitoring that can evolve with time. Some of the key conceptual elements of the proposed strategy as discussed at SGOA are outlined below.

#### Guiding principles

Guiding principles which will frame the monitoring strategy were elaborated as follows:

- OA is a stressor that requires a long-term monitoring strategy and commitment so as to distinguish long-term anthropogenic signals from short-term spatial and temporal variability.
- This monitoring strategy is envisaged as a flexible framework. It is essential that the monitoring network is responsive to developments in scientific knowledge, emerging tools and technology, and remains consistent with advances in the global observation network.
- As well as characterizing long-term (decadal) changes to the carbonate system, monitoring should characterise spatial and temporal variability on shorter time-scales. Monitoring will need to identify deviations in the range of variability that may be ecologically relevant, for example, seasonal changes in spatial and/or temporal extent of seasonal saturation states. It was discussed that the concept of “climate departure” (Mora *et al*., 2013) may be a useful analogue although this requires further consideration.
- Moreover, marine ecosystems are subject to a variety of concurrent pressures such as warming, eutrophication, hypoxia, and pollution, which may act in concert to produce responses that may be additive, synergistic or antagonistic. In recent years research has begun to focus on the potential interaction of OA with other stressors, and in particular with ocean warming. This should be taken into account when selecting variables to monitor and assess ecosystem health and where possible combined monitoring relating to different pressures/stresses should be undertaken.

- Monitoring of the response of ecosystems, and the services they provide, to OA should ideally consider all levels of ecosystem organisation in an integrated manner. Thus, monitoring could ultimately incorporate responses at subcellular, morphology/pathology, whole-organism, population and community levels as may be deemed appropriate.
- The development of appropriate biological indicators for OA, especially robust indicators that are sensitive and OA-specific and broadly applicable across wide biogeographic areas is at a very early stage and further development is required before recommendations can be given.
- While some areas may be inherently more vulnerable, OA is a threat to all marine ecosystems, with $CO_2$ taken up by surface oceans subsequently penetrating deep oceans. While the strategy should emphasise monitoring of the most vulnerable areas, which should provide clearest and earliest signals of change, monitoring should represent the full OSPAR maritime area.

Some practical considerations that will further guide monitoring are:

- In so far as possible OA monitoring should leverage available infrastructure and monitoring assets to support cost-effective monitoring and to supply integrated datasets.
- OA monitoring requires an interdisciplinary approach. For instance understanding of the hydrodynamic context is critical to understanding local and regional aspects, whilst knowledge of 'natural' variability of species' abundance is also crucial to interpreting ecosystem responses. Such factors should be considered in monitoring programme design.
- Modelling will increasingly become important as monitoring data should support validation/calibration of predictive models and models will in turn provide tools for design of monitoring.

#### Objectives of monitoring

The high-level objectives of the monitoring strategy were discussed. The purpose of the OSPAR OA monitoring strategy is to document the spatial and temporal changes in the $CO_2$-driven changes in ocean biogeochemistry in the OSPAR region and to detect and interpret ecosystem responses to these perturbations. The information gathered through such monitoring is essential to develop an understanding, and inform projections, of both ecosystem and socio-economic responses. Monitoring and assessment outputs should inform policy development and provide products that will simply and effectively communicate the key issues at an appropriate level to a wide range of stakeholders including the public.

The goals of the monitoring programme were considered to be twofold. **Goal 1** is to determine the spatio-temporal pattern of biogeochemical conditions relating to OA throughout the OSPAR region, while **Goal 2** involves characterization of the ecosystem responses to OA in time and space.

Achieving Goal 1 (OA conditions) requires the following:

- Describe spatial and temporal patterns in carbon chemistry;

- Document and evaluate variation in carbon chemistry to infer mechanisms (including biological mechanisms) driving OA;
- Quantify rates of change, trends, and identify areas of potential vulnerability or resilience.

Goal 2 (ecosystem response) requires:

- Biological responses, and their socio-economic consequences, be tracked in concert with physical/chemical changes;
- Rates of change are quantified and locations/habitats and species of heightened vulnerability or resilience identified.

#### Framework

Goal 1 and goal 2 monitoring variables are grouped as level 1 (core set of variables) and level 2 (extended suite of useful parameters) broadly aligning with the concepts elaborated in the GOA-ON framework. The Goal 1 monitoring variables as initially discussed in SGOA 2013 are presented in Table 1.

**Table 1. Initial proposals of SGOA for core measurements and extended suite of measurements that may be incorporated in OSPAR monitoring programme. These proposals will be further elaborated during SGOA 2014.**

| | OPEN OCEAN INCL. DEEP WATER | COASTAL AND SHELF SEAS |
|---|---|---|
| Goal 1 | Tracking OA conditions and Changes | |
| Key assessment variables | Ω, pH, $CO_3^{2-}$ | |
| *Core Measurements (Level 1)* | Carbonate-System Constraints (2 of 4 – $pCO_2$, DIC, TA, pH)*, T,S, O, Dissolved inorganic nutrient (PO4,SiO4,NO3)**, Fluorescence, pressure….. | Carbonate-System Constraints (2 of 4), T,S, O, Nutrients**, Fluorescence, Pressure….. |
| *Extended Suite of Measurements (Level 2)* | Carbon System Constraints (3 of 4), + others to be elaborated e.g. bio-optical, · water mass tracers, particulate carbon | Carbon System Constraints (3 of 4); DOC+ others to be elaborated |
| *Where:* | Open ocean, mode and deep water, shelf edge. | Coastal Waters, estuaries, Shelf Seas (all OSPAR regions) |
| *How* | •Hydrogaphic Surveys, VOS, OceanSites… | •Hydrogaphic surveys, VOS, moorings….<br>•Where possible OA parameters should be included in Eutrophication monitoring<br>•Include TA/DIC in Riverine Input monitoring for major rivers. |
| *Timing/Frequency* | •Dependent on monitoring platforms. •Surface Winter key period for surface waters for long-term trend assessment. | • emphasis on winter for trend.<br>• High frequency monitoring to determine natural variability and seasonal shifts |

***In some cases for offshore waters TA may be calculated from Lee *et al.*, 2006.**

****It is recognized that nutrients won't be available for some monitoring platforms.**

The need to commence chemical monitoring at an early stage and establish a current reference against which future changes can be assessed has been highlighted (Hydes *et al*., 2013). A phased approach to monitoring is proposed with an initial phase, suggested as ~6 years, focusing on intensive chemical monitoring across the OSPAR region. The output would contribute to a vulnerability assessment of the OSPAR area that would identify areas of heightened vulnerability. Phase 2 would involve monitoring of OA across the OSPAR area (Goal 1) but would require prioritised and more intensive monitoring of areas identified as of heightened vulnerability (Goal 1 OA Conditions and Goal 2 Ecosystem Response considering level 1 and 2 parameters) with a tailored plan for the areas/regions). Vulnerable areas would have one or more of the following attributes:

- More rapid rate of acidification for example driven by cold-water temperatures, freshwater input changes, low buffering capacity, specific hydrodynamics such as upwelling of $CO_2$-rich waters, and/or subject to other drivers of acidification such as eutrophication;
- Contain particularly susceptible ecosystems, species and/or habitats;
- A high socio-economic dependence on marine ecosystem services.

While the vulnerable areas are expected to provide earliest indications of impacts they are also a bellwether for wider scale impacts across all marine ecosystems. An outline schematic of the proposed approach is given in Figure 7. The focus on Goal 1 during phase 1 monitoring allows time to further develop indicators for Goal 2 monitoring.

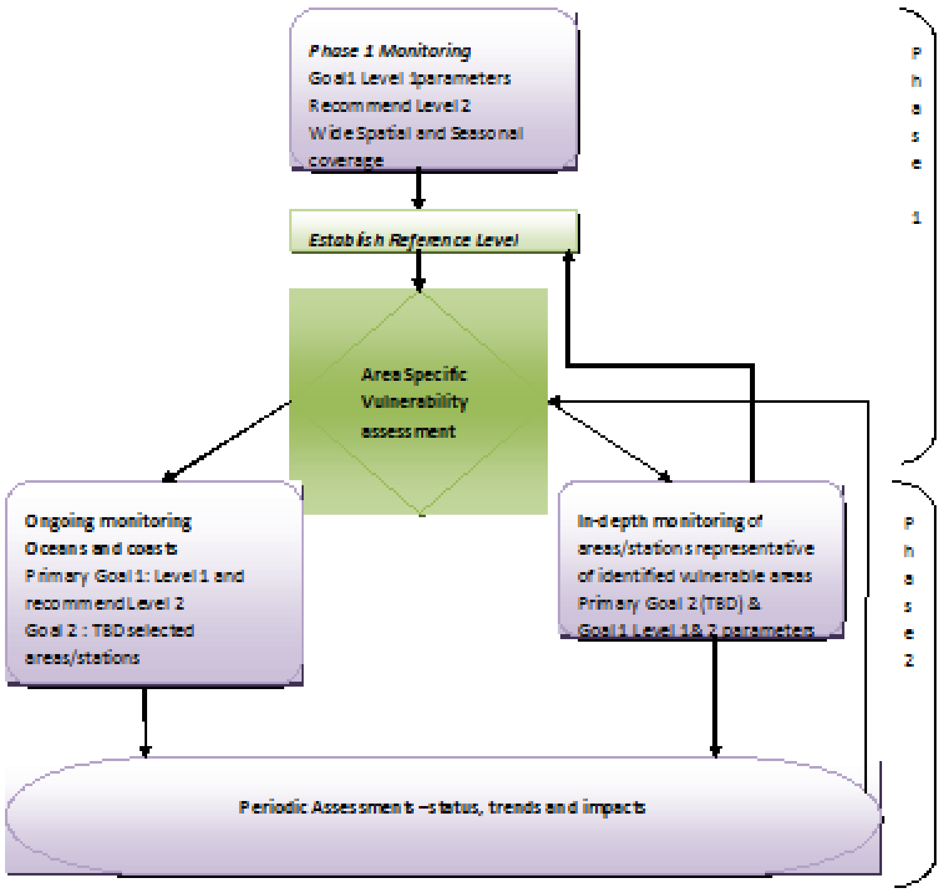


**Figure 7. A possible conceptual diagram for a proposed OSPAR OA monitoring strategy.**

Data management and quality assurance are also components of the monitoring strategy that will be further elaborated with the GOA-ON approach of “weather” vs. “climate” data quality objectives deemed useful, the latter having more stringent data quality requirements.

The monitoring strategy will be further developed by SGOA 2014 with a view to subsequent submission for consideration by OSPAR.

### Assessment criteria

OA is currently part of OSPAR preCEMP monitoring (OSPAR, 2010). For components of the voluntary pre-CEMP to be adopted into the mandatory CEMP, OSPAR specifically requires that technical guidance, QC and assessment criteria are in place. The development of quantitative assessment criteria for ocean acidification in the OSPAR area assumes that it is possible to distinguish different levels of acidity (or associated conditions) on the basis of their acceptability and need for remedial management action. Three categories are frequently used for other marine monitoring, with objective means to distinguish them: acceptable (green, in a ‘traffic lights’ colour-coding); some cause for concern (orange/amber); and unacceptable (red). Whilst such assessment criteria can apply to single measurements, it is more usual for data to be spatially and/or temporally aggregated, providing mean vales for the locality and time-scale of concern. OSPAR use two types of assessment criteria in the CEMP: criteria which represent a deviation from natural conditions ("background"); and criteria which demark a level representing concern, taking into account the precautionary principle. These can be applied to pressure and impact indicators. For example with respect to hazardous substances "Background Assessment Concentrations" and "Environmental Assessment Criteria" have been adopted; the latter representing a ecotoxicological thresholds below which there is confidence that deleterious effects will not be observed in the marine environment (OSPAR, 2009). This is graphically represented with a variation of the traffic light system: Blue (at background); green (acceptable); red (unacceptable), enabling simple communication of assessment outputs to a non-technical audience.

For chemical pollution involving toxic compounds, there are well-established methodologies for criteria setting, mostly based on lethal or sublethal impacts on model organisms. This approach is most straightforward for synthetic contaminants, where all sources are anthropogenic; however, similar methods can be applied to naturally occurring chemicals, e.g. heavy metals or nutrients, providing that 'clean' baselines can be established, the main sources are known, and pollutant dynamics are relatively well understood. The setting of thresholds is more problematic for stressors that naturally occur over a very wide range of values that have global drivers (causing long-term trends; i.e. a changing baseline) and where biological responses are complex and uncertain. All those factors apply to ocean acidification.

Good progress has been made in developing protocols for measuring pH and other carbon chemistry parameters, with strong ICES involvement (Hydes *et al*., 2013). However, whilst high data quality is a prerequisite for meaningful assessment, methods and measurements do not directly define acceptability criteria, since information is also needed on ecological consequences of different conditions. For ocean acidification the situation is complicated by:

- The multiple chemical parameters affected ($pCO_2$; ionic concentrations of $H^+$, carbonate and bicarbonate; carbonate saturation state). Components of that suite, although closely linked, do not necessarily all change together.
- The inherent variability of such carbon chemistry parameters, particularly in shelf seas and coastal waters (Provoost *et al*., 2010; Duarte *et al*., 2013). This is due to both physico-chemical and biological processes, operating on hourly-to-seasonal time-scales and on metre-to-kilometre spatial scales, both vertically and horizontally.
- The variability of organisms' responses to ocean acidification (Kroeker *et al*., 2013; also see Section 7 below), without clear and consistent distinctions between 'safe' and 'dangerous' levels. In addition to taxonomic differences that may be at the strain level, organisms may be affected differently by different components of the chemical changes (e.g. calcifying phytoplankton increasing photosynthesis in response to higher $CO_2$, but decreasing calcification in response to decreased pH/carbonate). Interactions with nutritional status and other stressors are complications that provide additional challenges to single-value assessment criteria.

Nevertheless, consistent means of tracking ecologically meaningful changes are needed, and pH and carbonate saturate state are the two parameters that would seem to provide the most suitable basis for developing quantitative assessment of ocean acidification. But provisos are necessary: because of existing variability, pH values *per se* have limited usefulness for comparative purposes; instead pH change is likely to be more meaningful, either in pH units or as a ratio to existing temporal variability. The latter can be estimated at the global scale from models (Figure 8), with potential for high resolution regional projections; however, it requires extensive data collection for direct site-specific computation, and the logarithmic scaling of pH complicates the interpretation of this ratio. The inclusion of information on existing, 'baseline' pH variability within assessment criteria assumes that organisms/ecosystems currently exposed to high variability will be more tolerant of future change than those used to more stable conditions. Whilst intuitively attractive, that concept has not been demonstrated for ocean acidification.

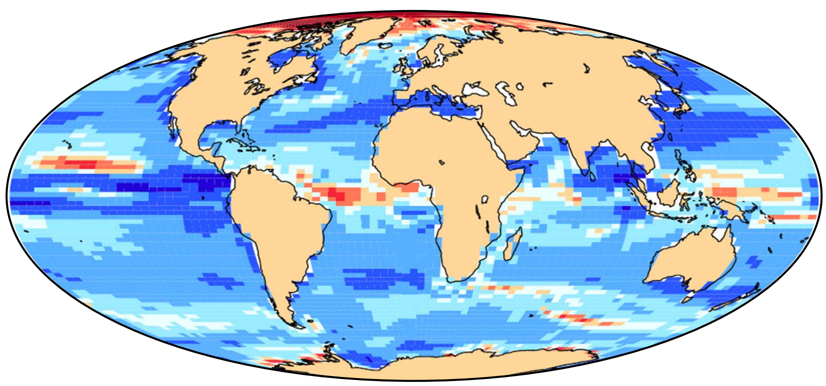

**Figure 8. Potential ecosystem impact of pH change, as ratio of surface change (2100 values minus 2000 values, under scenario A1B) to current annual pH variability.** ***L Gregoire and A Ridgwell/UKOA unpublished.***

The rationale for basing assessment criteria on carbonate saturation state, Ω (with values differing slightly between Ω aragonite and Ω calcite) is that calcification requires more metabolic energy when Ω is decreased, and that unprotected carbonate structures dissolve when Ω <1.0. Model-based global maps of the depth of saturation horizons (below which Ω <1.0) have been produced (Feely *et al*., 2004; Guinotte *et al*., 2006), and the shoaling of such horizons has been recorded in the Iceland Basin (Olafsson *et al*., 2009). Assessment criteria based on Ω would preferably also need to be rate-based; i.e. not just the mapped position of saturation horizons, but the rate of Ω change, that could be integrated through the total water column in shelf seas, or to a specified depth in the open ocean.

If upper ocean water chemistry were directly tracking changes in atmospheric $CO_2$, year-to-year change in measured pH and Ω would be near-uniform across the OSPAR region, from polar waters to the near-tropics. However, such uniformity is unlikely (and has not been observed to date). Areas of higher-than-average pH or Ω change, as identified from monitoring, are of particular interest, not only to provide the focus for more intensive biological studies, but also potentially to assist in the identification of other driving factors (that might be amenable to more direct management).

The use of a limited suite of indicator organisms as the basis for assessment criteria for ocean acidification is currently considered premature. That does not mean that monitoring potentially sensitive species (e.g. cold-water corals; Section 5.1.3) should not occur, but it is not yet possible to define reliable measures of biological impacts that can be uniquely linked to ocean acidification and thereby used to define acceptability thresholds. However, there will be a role for assessment criteria for biological effects as indicators are developed.

Further discussion focused on the purpose of assessment criteria in communicating the threat of OA in the context of the requirement for mitigation or other management action. OA is a pervasive and inexorable consequence of the projected increase in atmospheric $CO_2$, albeit at variable rates in different regions/areas. Moreover it is essentially irreversible on practical time-scales. While identifying areas that are subject to most rapid acidification to OA is of value, it should not obscure the message that OA is progressive and a concern for all marine areas.

For climate change a global mean temperature increase of 2°C has been used as a reference point, representing the threshold above which it is considered there is a risk of dangerous anthropogenic interference[7] with the climate system; i.e. "dangerous climate change" (Copenhagen Accord, 2009; Anderson *et al*., 2011). There are no equivalent accepted reference points for ocean acidification. Such thresholds, while having foundations in science, are ultimately policy reference points in that they require a societal judgement on an accepted degree of impact to aid formulation of policy measures and target setting for mitigation and adaptation strategies.

#### Next steps

The monitoring strategy will be further developed with a view to finalisation at SGOA 2014. The following intersessional actions are required to achieve this:

- SGOA Chairs will seek interim feedback on proposed conceptual model from OSPAR and other ICES working groups;
- SGOA Members to review draft monitoring strategy and provide input and comments by 31st August 2014;
- Evin McGovern will revise the draft monitoring strategy prior to SGOA 2014 based on comments received with a view to finalising at the meeting.

## 6.4 Quality assurance and quality control (QA/QC)

MCWG 2013 discussed the need for ongoing proficiency testing to support analysis of carbonate system parameters, now in the OSPAR pre-CEMP, and identified the need for a workshop on the comparability of sampling and analysis of Total Alkalinity (TA) and Dissolved Inorganic Carbon (DIC).

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[7] The 2°C threshold temperature increase is not necessarily 'dangerous' *per se*, but represents a threshold where a suite of other climate-driven changes (sea level rise, extreme events, etc.) and the triggering of positive feedbacks are considered "dangerous."

SGOA strongly agreed that such a workshop is essential to progress coordinated OA monitoring. SGOA discussed the topics that should be covered, identifying measurement of pH [and $pCO_2$] as an important topic that could be considered for inclusion. SGOA noted that QUASIMEME had long experience in providing technical Quality Assurance support for monitoring parameters in the CEMP. However, Scripps Institute of Oceanography (SIO) is the only laboratory with experience in producing intercalibration and reference materials to support measurement of TA and DIC and SGOA agreed with MCWG that it was essential to involve Andrew Dickson from SIO. Funding (<€3000) has yet to be identified but NOC had agreed to host the workshop should it proceed. On contacting QUASIMEME during the meeting SGOA were informed that their advisory board did not see the need for such a workshop and were considering adding TA/DIC to a workshop on nutrients/ and algal pigments provisionally proposed for 4–6 February in Ostende. SGOA were not satisfied that this would address the need to deliver quality-assured measurements in the context of the OSPAR CEMP. SGOA prepared a document outlining the scientific justification and purpose and expected outcomes of the workshop (Annex 5) and the following actions were identified to try to progress this.

- ICES to submit workshop justification to OSPAR for consideration as to how they could facilitate the search for funding;
- Phil Williamson to copy document to OA-ICC to identify any possibilities for support (e.g. by extending the remit to developing countries);
- Pam Walsham to follow up with QUASIMEME to discuss possibilities of their involvement.

MCWG should review progress on advancing the QA workshop and continue discussions with QUASIMEME.

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

### Ecological indicators

The current state of understanding of how individual species respond to OA is growing and the literature continues to add new species to a list of taxa (Table II) that are either directly or indirectly sensitive to the impacts of declining ocean pH. Our understanding of the mechanisms by which individual species are affected by OA is still an emerging area of research. Moreover, we do not have suitable biochemical or morphological metrics with which to quantify the impacts of OA on most species. It is also likely that useful metrics are likely to be species-specific. Consequently, no universal metric can be applied to all species. For example, research in the Southern Ocean (Bednaršek *et al*., 2012) has demonstrated that pteropods belonging to the species *Limacina helicina antarctica* exhibited shell erosion in response to reduced pH. The challenge is that measurements that are suitable for *L. helicina antarctica* may not be suitable for other species because thecosomate pteropods display a high degree of morphological diversity (e.g. Figure 9). The vast area of the OSPAR domain, which spans a broad latitudinal range and contains waters that range in depth from the coast to the bathypelagic, contains many species potentially sensitive to OA. Identification of which of these species should be selected for monitoring and description of appropriate morphological or biochemical metrics that can be used to document OA impacts is premature. For these reasons, we recommend that a broad suite of organisms likely sensitive to OA, be collected and archived during the initial OA monitoring program. This archive will serve as a repository of specimens that can be retrospectively examined for evidence of OA responses once appropriate indicator metrics are developed.

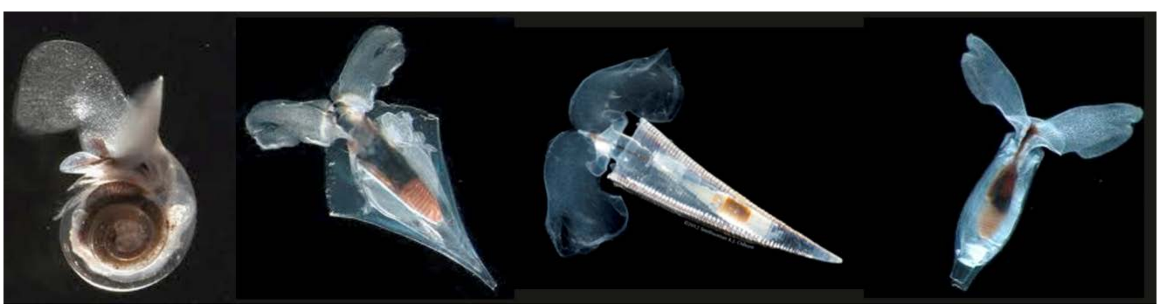

**Figure 9. Examples of thecosomate pteropod morphological diversity. Image credits (left to right): R. Hopcroft, R, Hopcroft, K. Osborn, R. Hopcroft.**

In the absence of sufficient data to provide guidance on specific species that are likely to be sensitive to OA, we have provide a list of taxa (Table II) for which there is published data documenting responses to OA in either laboratory or field studies. Selection of reference specimens of appropriate indicator species from within the groups listed in Table II is recommended as a starting point for biological monitoring. The selection of species that are appropriate for monitoring should be undertaken by surveying existing biological inventory databases for each of the OSPAR regions. We recommend that this inventory be completed early within the initial six-year baseline monitoring phase of the assessment (see Section 6.3).

Once all potentially vulnerable species have been identified in each OSPAR region, the next phase will be selection of a subset of species from each broader taxonomic category for monitoring. It is recommended that the criteria for selection of species for monitoring include the following: (1) the species have broad distribution within the each of the OSPAR regions; (2) it is abundant within the time frame anticipated for monitoring; (3) practical protocols exist for sorting individuals during, or shortly after surveys; and (4) there exist long-term methods for archiving specimens so that their calcareous structures are not degraded. Broad distributions and abundance during surveys are essential to ensure that the species remains available throughout the assessment time-series. Given that regional warming is likely to be superimposed on changes in ocean pH, selection of species that are near the boundaries of their range could lead to their disappearance from the survey area over time. Effective sorting and archiving protocols are essential so that target species can be efficiently sorted from bulk samples and preserved in a manner so that anatomical structures that can inform about OA effects are not degraded during storage.

EU member states are also in the process of defining monitoring programmes under Article 11 of the Marine Strategy Framework Directive (MSFD Directive 2008/56/EC). While OA is not specifically considered in the eleven descriptors of Good Environmental Status, monitoring of biological parameters is required under a number of these descriptors, such as descriptor 1 on biodiversity, descriptor 4 on foodwebs and descriptor 5 on Eutrophication. SGOA 2014 will review the biological monitoring proposals of Member States to identify possible synergies with OA monitoring based on information provided by members.

It was also commented that there may be potential links to the European Network of Marine Research institutes and Stations (http://www.marsnetwork.org/index.php) Phil Williamson undertook to contact Mike Thorndyke to explore this further.

Additional potentially useful monitoring tools included the use of settlement or dissolution plates that could be placed in potentially sensitive and control areas to monitor recruitment, growth, and erosion.

**Table II. Potential indicator organisms for OA responses, requiring further expert consideration. This list represents initial thoughts; it is not exhaustive, and very different recommendations for indicator species may subsequently be developed.**

| GROUP | SPECIES | QUANTITATIVE BASIS FOR USE AS INDICATOR? | ISSUES/COMMENTS |
|---|---|---|---|
| **Benthic** | | | |
| Cold-water corals | *Lophelia pertusa*, *Madrepora* spp., *Solenosmilla* spp., *Eunicella* spp. | Slowed growth/mortality at lower depth limit, in response to raising of saturation horizon | Mortalities may be difficult to determine without high resolution repeat ROV/AUV mapping of specific study sites |
| Echinoderms (particularly some brittlestar species) | *Ophiothrix fragilis* | Abundance (taking account of other factors)<br>Larval calcification | *O. fragilis* particularly sensitive to OA under experimental conditions (Dupont *et al.*, 2010): 100% larval mortality in response to pH decrease of 0.2 |
| Coralline macroalgae | *Lithothamnion gracile*<br>*L. corallioides*, *Phymatolithon calcareum*, *Lithophyllum dentatum* | Growth rate (using annual rings and changes in boron isotope composition)? | Technique not yet well-developed; sensitivity to OA uncertain |
| Gastropods | *Littorina littorea* | Currently monitored in Dutch waters as part of OSPAR eutrophication monitoring | Although no direct data on responses by this species to OA, lab studies (Parker *et al.*, 2013) suggest sensitivity. |
| Calcareous Annelids (*Serpulids*) | *Serpula* | Changes tube composition (calcite/aragonite ratio, Mg/Ca ratio) in undersaturated water | Requires special techniques, applied in an experimental study by San Chen *et al.*, 2013 |
| Calcareous epiphytes and epibionts on seagrasses | ??? | i) coverage on seagrasses (abundance)<br>ii) $CaCO_3$ weight | Sensitive to $CO_2$, but restricted to areas with seagrass. |
| Seagrasses | | Increased abundance, but unlikely to be unambiguously linked to OA | Might benefit from increased $CO_2$, but this response depends on other environmental conditions |
| Mussels | *Mytilus edulis* | Currently monitored by Dutch as part of a heavy metal contaminant assessment. | Gazeau *et al.* (2007) documented a decrease in calcification in laboratory studies. Little affect on larval development. |
| Crustaceans | *Lobster (Homarus sp.)* | Growth and mold, fertility | Agnalt *et al.*, 2013 reported carapace deformation in larvae and juveniles lobster exposed to elevated $pCO_2$ at different temperatures |

| Group | Species | Quantitative basis for use as indicator? | Issues/Comments |
|---|---|---|---|
| **Water column** | | | |
| Pteropods (planktonic sea snails) | *Limacina* spp and other shelled pteropods | Abundance (taking account of other factors)<br>Shell thickness/condition | High sensitivity to OA under experimental conditions; shell dissolution of *Limacina helicina antarctica* observed in response to existing pH variability of Southern Ocean (Bednaršek *et al*., 2012) |
| Coccolithophores | | Abundance and biodiversity (taking account of other factors)<br>Calcification<br>Coccolith morphology/mass/malformation | High variability of responses of *Emiliania huxleyii* probably makes it unsuitable as an indicator; The genome variability within this species complex seems to underpin its capacity to thrive under a wide variety of environmental conditions. However, suitability of other species warrants further study. A first study based in CO2 vents is showing a decrease in biodiversity in elevated $CO_2$ conditions (Ziveri *et al*., subm.) |
| Foraminifera | Benthic spp from intertidal sandy sediments | Shell morphology/thickness | Relevant features that might be suitable for quantitative assessment currently under investigation |
| Bivalve larvae | Commercially cultivated species | Larval survival<br>Calcification<br>[both for mariculture conditions] | Risk of OA impacts on cultivated shellfish much less in Europe than in NW USA (the latter subject to upwelling) but routine chemical and biological monitoring of aquaculture facilities would nevertheless be desirable |
| Phytoplankton | Range of species | Abundance changes unlikely to be unambiguously linked to OA, but change in C:N ratio may be detectable | Effect currently under investigation. Some dinoflagellates appear to be sensitive to OA. |

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

## 8.1 Ocean acidification and carbonate system data; Background

SGOA recalled discussions at the 2012 meeting which highlighted:

- The ICES DataCentre (ICES-DC) is the repository for OSPAR CEMP data and Contracting Parties are required by OSPAR to submit monitoring data to ICES.
- There are two ICES databases that can accept carbonate-system data. The ICES environmental database is a relational database requiring reporting in ERF 3.2 format. It can accept detailed metadata/QC information but only holds data for discrete samples. The oceanographic database allows for free format reporting but is very limited in its ability to accept associated metadata and QC information.
- OA-relevant chemical and biological data are also reported to a number of other international data centres, often as a requirement of specific projects. An example is the Carbon Dioxide Information Analysis Centre (CDIAC).
- Global ocean carbon data synthesis products such as the surface $pCO_2$ atlas (SOCAT) and GLODAP are also available and these include additional levels (secondary) of quality control.
- SGOA 2012 recognized that OA-monitoring may be linked to other monitoring/research activities which may define the preferred reporting route for these data.

The challenge for SGOA is to develop tools for reporting CEMP OA data to ICES but also consider how ICES-DC would interface with other international data centres to maximise data exchange and availability and limit requirements for multiple reporting of datasets to different data centres. Assessment of OA and its impacts would require observations of physical, chemical and biological parameters. The data reporting session at SGOA 2013 reviewed progress to date in defining ICES reporting requirements for carbonate-system parameters and also provided an opportunity to develop links between ICES and other data centres. The session was structured around short presentations outlining activities at ICES-DC (Hans Mose Jensen), CDIAC (Alex Kozyr by WebEx), GLODAPV2 (Toste Tanhua by WebEx), SOCAT (Benjamin Pfeil by WebEx).

## 8.2 ICES OA data management update

Hans Mose Jensen from the ICES DataCentre presented how ocean acidification parameters could enter the ICES databases and the progress made since 2012. The ocean acidification parameters could be reported to ICES environment database (ERF 3.2 format) or oceanographic database (IOF free format using BODC codes). At present the ICES oceanographic system does not include method information for the standard parameters, but if reported using new BODC codes then this allows for some method information to be included. The ERF 3.2 format used in the ICES environment database uses the ICES vocab parameter list and accepts metadata including detailed method and QA information.

MCWG 2013 recommended basic parameters, metadata and checks for the ocean acidification parameters pH, total alkalinity, dissolved inorganic carbon and partial pressure of carbon dioxide. These recommendations have been implemented for the ICES environment database which stores metadata directly with the data. The first test set of data has been reported, checked and entered into the environmental database so the OSPAR/ICES discrete bottle database is now operational for reporting carbonate parameters. There are some remaining questions concerning value checks and conversions which will be dealt with at the 2014 MCWG meeting (see Section 8.6).

Entering ocean acidification parameters into the ICES oceanographic database is possible without metadata. Whether these data would be eligible for entry into CDIAC requires further investigation into the CDIAC requirements.

## 8.3 CDIAC Data Centre Alex Kozyr (Oak Ridge National Laboratory)

Alex Kozyr of the Carbon Dioxide Information Analysis Centre (CDIAC) gave a short overview of CDIAC activities (http://cdiac.ornl.gov/). CDIAC is located at US Department of Energy's Oak Ridge National Laboratory (ORNL) and includes the World Data Center for Atmospheric Trace Gases. CDIAC's data holdings include estimates of carbon dioxide emissions from fossil-fuel consumption and land-use changes; records of atmospheric concentrations of carbon dioxide and other radioactively active trace gases; carbon cycle and terrestrial and ocean carbon management datasets and analyses; and global/regional climate data and time-series.

CDIAC serves as a global Ocean Carbon Data repository for discrete (bottle), time-series and moorings, coastal, and surface (underway) $CO_2$ data (http://cdiac.ornl.gov/oceans/). The formats for reporting ocean carbon data to CDIAC are well established and available at http://cdiac.ornl.gov/oceans/submit.html. Accepted datasets are issued with a digital object identifier (DOI). CDIAC works closely with CLIVAR and Carbon Hydrographic Data Office (CCHDO) and NOAA NODC. CDIAC quality controls carbon hydrography datasets, merges them with latest hydrographic data files, posts them on the CDIAC web, and sends the merged set to CCHDO and NOAA NODC. A process has been put in place for automated synchronised transfer of Ocean $CO_2$ data to the NODC via the Mercury system. Figure 10 provides a view of CDIAC's role in Ocean $CO_2$ data exchange in the OA Network. CDIAC also provides a portal to synthesis data products such as GLODAP and SOCAT (see Section 8.4).

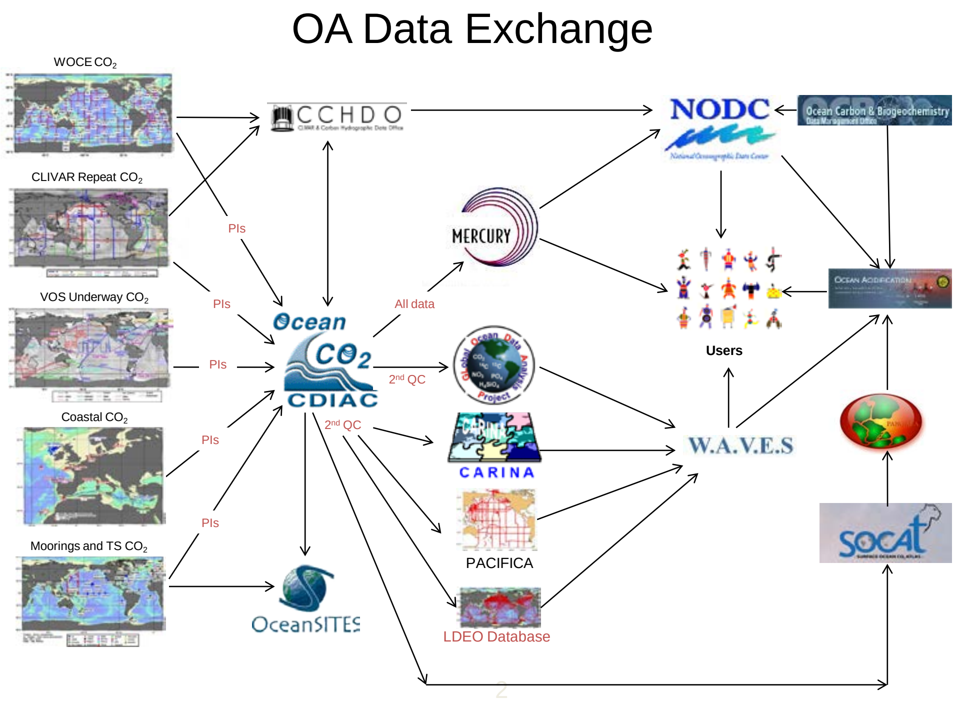


**Figure 10. CDIAC role in data exchange of Ocean CO2 data and OA network.**

## 8.4 Ocean Carbon Data Synthesis Products: GLODAP Toste Tanhua (Helmholtz-Zentrum für Ozeanforschung Kiel) and SOCAT Benjamin Pfeil (Bjerknes Centre for Climate Research)

This text is modified from the text in (Tanhua *et al.*, 2013).

The most important aspects of the interior ocean carbon data products are that they consist of carefully quality controlled, internally consistent, data available in a common format. The Global Ocean Data Analysis Project (GLODAP) provided a dataset from the global $CO_2$ survey of 1990s (Key *et al.*, 2004; Sabine *et al.*, 2005), including significant historic cruises. A second data collection for the Arctic, Atlantic and Southern Oceans was published in 2009; CARINA (Carbon IN the Atlantic) (Key *et al.*, 2010 and additional articles in the special issue). Recently a data product covering the Pacific Ocean including data from 213 cruises (additionally 59 datasets from line P, and 34 WOCE cruises) were published; PACIFCA (PACIFic ocean Interior CArbon) (Suzuki *et al.*, 2013). In addition, a current effort known as GLODAPv2 aims to merge those three products and add additional data not included in any of those. These data products consist of two or three main products; individual cruise files, merged data products and (for GLODAP) gridded products (Key *et al.*, 2004). The individual cruise files are all reported in a common format with standardized units and quality flags, and were in all instances scrutinized and quality controlled (1st level of QC). The primary QC is designed to find outliers, but is insensitive to systematic biases; those can be assessed by the so-called secondary quality control (2nd QC). Biases in the reported data are often due to incorrectly quantified standard concentrations, blank problems or other analytical difficulties that are very difficult to assess in the field. Note that 2nd QC only addresses the accuracy of the data, not the precision.

The gridded products are valuable components of the data products, particularly for easy comparison with model results and for calculating inventories of properties such as $C_{ant}$. Due to sparseness on the data, significant interpolation and extrapolation errors can be expected on local scales (e.g. Schneider *et al.*, 2012).

Surface ocean $pCO_2$ data products are also available from two different but complementary sources: The LDEO $pCO_2$ data product (V2012) contains 6.7 million surface $pCO_2$ datapoints (Takahashi *et al.*, 2013) from which climatological fields have been constructed (Takahashi *et al.*, 2009); The SOCAT data product contains more than ten million datapoints over the period 1968–2011 (Bakker *et al.*, 2013; Pfeil *et al.*, 2013). SOCAT is available as a merged product, individual cruise files (in a common format) and also as a gridded product (Sabine *et al.*, 2013).

The access to these products can be found here:

| | |
|---|---|
| GLODAP | http://cdiac.ornl.gov/oceans/glodap/ |
| CARINA | http://cdiac.ornl.gov/oceans/CARINA/ |
| PACIFICA | http://cdiac.ornl.gov/oceans/PACIFICA/ |
| GLODAPv2 | http://cdiac.ornl.gov/oceans/ (will be published in 2014) |
| LDEO pCO2 | http://cdiac.ornl.gov/oceans/LDEO_Underway_Database/ |
| SOCAT | http://www.socat.info/ |

## 8.5 General discussions

In the USA an *ad hoc* data management team has been established to develop an integrated OA data management strategy with NOAA National Oceanographic Data Centre (NODC) as the focal point (Draft available at http:/www.nodc.noaa.gov/media/pdf/oceanacidification/InteragencyOADataMgmtPlan_June2012-2.pdf). This may provide a useful model for developing data management strategies in Europe and it is desirable that reporting formats are globally harmonised in so far as practicable. With this in mind, Hernan Garcia (NOAA NODC) had been invited and agreed to give a presentation to SGOA 2013 on NODC activities but unfortunately, as with other NOAA participants, had to withdraw from the meeting due to the US Federal Government shutdown. It is hoped to take this up again at SGOA 2014.

SGOA welcomed the progress made in defining ERF 3.2 reporting requirements and automated quality checks. The discussions centred on the potential for data exchange between ICES and CDIAC. It is not clear if the CDIAC reporting formats and QC protocols are transferable to ICES and this needs to be investigated. The ICES DataCentre will communicate directly with CDIAC to compare reporting formats and see how useful their model/tools are for ICES. The CDIAC metadata form for discrete measurements is available at http://mercury-ops2.ornl.gov/OceanOME/newFormDis.htm and the form for underway $pCO_2$ measurements at http://mercury-ops2.ornl.gov/OceanOME/newForm.htm.

It was again stressed how important it is to make data submission as simple as possible and also to make the reporting as flexible as possible since measurement platforms, methods, etc. will evolve over time. It is thus positive that it is fairly easy for the DataCentre to add new parameters to the database.

There is a clear need for more discussions of how effects of OA can be reported and the development of this reporting needs to follow the evolution of biological indicators.

It was also noted that the OA parameter data will be collected concurrently with other monitoring parameters and how unfortunate it would be if the information had to be split when reported since this would make the data more difficult to access. The ideal situation would require submission of data to the most appropriate data repository and using appropriate flags to enable automated data exchange between data centres (i.e. report once use often). For example, in some cases OA parameters may be included as additional parameters in OSPAR Eutrophication monitoring. In this case it would be relatively simple to add these to current reporting to ICES. These data in turn could be made available to CDIAC. Alternatively, OA data collected as part of oceanographic surveys may be submitted to CDIAC in the first instance but an OSPAR flag on the data could highlight that these data be transmitted on to ICES. This ideal scenario would require data centres to have common data exchange protocols in place. It was noted that CDIAC already have an automated data transfer to NODC for OA data which may provide a model.

It is recommended that contracting parties monitoring OA for the preCEMP submit suitable data (discrete sample) to ICES Environmental database. Furthermore, it is suggested that relevant data are submitted to the CDIAC global database.

For future assessments of the acidification status of the OSPAR area, there is merit in using GLODAP and SOCAT data products which have been subjected to additional quality control and corrections applied where deemed appropriate, recognizing that GLODAP primarily covers oceanic waters and that SOCAT is limited to one carbonate system parameter ($pCO_2$).

## 8.6 Next steps

This topic will be further addressed by MCWG 2014 with respect to ICES reporting formats and at SGOA 2014 to consider:

- Experiences of Contracting Parties in submitting OA data;
- Global developments on standardising OA data formats, in particular feedback from NOAA NODC on US activities;
- Next steps to improve links between ICES oceanographic and environmental database and CDIAC based on review of CDIAC protocols;
- Develop any reporting guidelines that are deemed necessary.

MCWG 2013 specified checks for the carbonate system parameters. See https://groupnet.ices.dk/sgoa2013/Data/ENV_SGOA_MCWG2013_v20130307.xlsx

Based on discussions at SGOA 2013 and test datasets of OA data submitted using ERF3.2, further work is needed on ERF3.2 formatted submissions and it is recommended this is progressed by MCWG 2014:

- MCWG should review the units needed for each of the carbonate system parameters (ALKY, PCO2, DIC) and determine whether they should be mandatory for entry into the environment database.
- MCWG needs to consider how reference temperatures should be reported with pH and $pCO_2$ and what the reference temperature should be (i.e. are new parameters such as "PH-REF25", "PCO2-REF25" required?)

- MCWG needs to check all relevant parameters to determine which parameters require reference temperatures (ex. “at 20 degrees”).

It is further recommended that:

- OSPAR CPs to submit suitable monitoring data to ICES environmental database using ERF 3.2 format;
- ICES-DC to review the data reporting requirements of CDIAC to consider if they are transferable to the ICES reporting system (oceanographic database).

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

With respect to the above Term of Reference, SGOA 2012 proposed that the required assessment could focus on acidification status of scleractinian cold-water corals areas as vulnerable habitats. This was considered a more achievable task given the resources available to SGOA and the proposal was accepted by OSPAR CoG 2013. SGOA 2013 also drew attention to the work already carried out by MCWG 2010, led by Alberto Borges, which assessed the variability of OA parameters in the OSPAR regions over different spatial and temporal scales within OSPAR regions. This is included in Hydes *et al*., 2013.

As described in Sections 5.2 and 5.3 reef-building scleractinian corals, primarily *Lophelia pertusa* but also others such as *Madrepora oculata* are found in the Northeast Atlantic, typically along the shelf slopes and on flanks of seamounts at depths ranging from 200–2000 m, although they can occur in shallower water, for example in some Norwegian Fjords (OSPAR, 2009; Tittensor, 2010). They are clustered in a number of provinces in hydrodynamically active environments where the supply of organic material is sufficiently abundant to support growth. The most important factors in determining cold-water coral habitat suitability are temperature, aragonite saturation state and salinity (Davies and Guinotte, 2011). Respective temperature and salinity boundaries are 4–13°C and 35–38 psu (OSPAR, 2009; Roberts *et al*., 2006). Globally, cold-water scleractinian reefs occur above the depth of the Aragonite Saturation Horizon (ASH; Guinotte *et al*., 2006), and this may be factor that helps explain the relative abundance in the NE Atlantic where the ASH is >2000 m. Consequently the projected dramatic shoaling of the ASH over the next century is a threat to these reef structures (Orr *et al*., 2006; Jackson *et al*., submitted; see Figure 6, Section 5.2).

A subgroup of SGOA 2013 discussed the steps for delivering an assessment which will focus on a description of the current carbonate system in the bottom water at the coral habitats within the OSPAR area and the implications of projected OA for these habitats. The most complete database for the distribution of *Lophelia* reefs in the Northeast Atlantic is the OSPAR Habitats database available through the MESH website (Helen Ellwood JNCC, personal communication). There are also detailed distribution maps on the reefs in Norwegian waters available at the MAREANO website (www.mareano.no). An outline for this assessment was agreed (see below) and it was clear that as well as consideration of the OA-status of coral reef areas (e.g. aragonite saturation states) the assessment should also consider biological aspects (such as calcification) and physical oceanography.

There are currently several research groups working on the vulnerability of cold-water coral habitats. Flogel *et al*. (2013) considered the physical and hydrochemical constraints for the occurrence of living corals in the NE Atlantic and Mediterranean Sea. They concluded that pristine reefs are limited to bottom waters with DIC values of <2170 μmol, revealing a "tipping point" with respect to DIC. They also highlighted the need for more research into the calcification process of scleractinians. Other relevant activities include the German BIOACID project, the UK Ocean Acidification Research Programme and the EU MedSeA (http://medsea-project.eu/) and Knowseas projects (Section 5.2). IMR (NO) are also contributing to a report as part of the CoralFISH project (http://eu-fp7-coralfish.net/).

GLODAP V2 is expected to be available in 2014 and this is a preferred source of carbon data for the assessment given the additional level of quality assurance that it has undergone. However, there may also be other available data that can be incorporated and these data can be used to construct maps of aragonite saturation states of bottom waters in reef areas. It was also proposed that modelled projections of changing saturation states for these habitats should be included. It was agreed that a number of specific case studies should be incorporated with the following areas suggested: Mingulay, Røst reef (drawing on the work of Richard Bellerby), Rockall Bank, and along the Svinøy section (Storegga reef). The proposed assessment requires bringing in additional expertise not available to SGOA and subgroup members agreed to approach certain experts to contribute to specific elements of the report.

The aim is to produce a final draft document for review and sign-off at SGOA 2014. Preparation of the report will be led by Murray Roberts with input from Melissa Chierici, Jason Hall-Spencer, Evin McGovern, Mark Benfield, Are Olsen and Richard Bellerby. Potential additional contributors identified were Johanna Jærnegren (coral physiology), Martin White (physical oceanographer) and Jan Helge Fosså (biologist). The current Coral Value project, led by the Claire Armstrong (socio-economist) at the University of Tromsø-The Arctic University of Norway (http://en.uit.no/prosjekter/prosjekt?p_document_id=349718) and funded by the Norwegian Research Council was also identified as a potential source of information on the socio-economic value of CWCs. The group expressed a preference that the assessment should be structured so that it can be published in the peer review literature, although a target journal was not selected at the meeting. The following provisional structure for the assessment was proposed:

1 ) Introduction: Status of Corals in OSPAR region and Ecosystem Services provided; OA and potential consequences/projections: Shoaling of ASH.
2 ) Carbonate system status for CWC habitats in the OSPAR area:
    2.1 ) Mapping CWCs locations and depth range (species); Mapping bottom Ωarag, [DIC, TA];
    2.2 ) information on variability/trends?; Projections for $\Omega_{arag}$ to end of century.
3 ) Biological and Physical aspects: Current knowledge of key biological processes and vulnerability of scleractinian cold-water corals to OA; hydrodynamic context and constraints on coral growth.
4 ) Case Studies-Candidates include: Mingulay (Hebrides), Røst reef (Norway), Storegga reef (Norway), Rockall Bank (UK, IE).
5 ) Discussion and synthesis.
6 ) Information gaps and recommendations.

A number of actions were identified to progress this work:

- Murray Roberts to lead on preparation of an assessment with input from the following SGOA members: Melissa Chierici, Jason Hall-Spencer, Evin McGovern, Mark Benfield, Are Olsen, Richard Bellerby, and other identified experts, with the intention of having a final report by September 2014 with a view to sign off by SGOA 2014.
- Melissa Chierici and Evin McGovern undertook to contact additional experts to request input on, *inter alia*, case studies, modelling, physical oceanographic context and socio-economic context.

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# 11 Identification of Terms of Reference for 2013

The SGOA 2014 Terms of Reference (Annex 3) are unchanged and remain those agreed by ICES/OSPAR.

## 12 Recommendations and actions

Recommendations from SGOA 2012 are provided in Annex 4.

The following actions items were identified for follow up at SGOA 2014.

| ACTIONS | WHO | SGOA 2013 REPORT SECTION |
|---|---|---|
| Provide SGOA 2013 report to chair of WGBECs to ensure alignment of activities with respect to biological effects monitoring for OA. | Evin McGovern | 1 |
| SGOA members to update/consolidate text on their national OA monitoring in advance of SGOA 2014 and update activity table (Annex 6) for incorporation in consolidated final SGOA report. | All SGOA | 2 |
| Provide information on national OA monitoring activities of Belgium, Sweden, [France] and Spain. | Patrizia Ziveri (Es), Sofia Hjalmarsson/Elisabeth Sahlsten (SE), Alberto Borges (BE), | 2 |
| Contact Ulf Riebesell to request information on BIOACID for SGOA 2014 | Toste Tanhua | 3 |
| Circulate GOA-ON St Andrews Workshop Report and updated SGOA 2014 on any further developments | Phil Williamson | 6 |
| Seek feedback from OSPAR and other ICES working groups on proposed conceptual framework for OA monitoring strategy | Evin McGovern, Mark Benfield | 6 |
| Review draft monitoring strategy and provide input and comments by 31st August 2014 | SGOA members | 6 |
| Consolidate revised draft of monitoring strategy based on comments received with a view to finalising at SGOA 2014 | Evin McGovern | 6 |
| Submit OA QA/QC workshop outline/justification to OSPAR for consideration as to how they could facilitate the search for funding | ICES | 6 |
| Contact OA-ICC to identify any possibilities for support of OA QA/QC workshop (e.g. by extending the remit to developing countries) | Phil Williamson | 6 |
| Follow up with QUASIMEME to discuss possibilities of their involvement in OA QA, QC workshop | Pam Walsham | 6 |
| Report to SGOA 2014on the proposed national biological monitoring for MSFD, especially any parameters with potential synergies to OA monitoring | All SGOA | 7 |
| Contact Mike Thorndyke to explore any useful links with the MARS network | Phil Williamson | 7 |
| Contact chair of WGZE to explore whether they could produce protocols for selection and archiving of pteropods for retrospective analysis | Mark Benfield | 7 |
| Invite Hernan Garcia to present at SGOA 2014 on OA data management activities of NOAA NODC | Evin McGovern | 8 |

| ACTIONS | WHO | SGOA 2013 REPORT SECTION |
|---|---|---|
| Preparation of assessment on OA in NE Atlantic CWC for September 2014 with a view to sign off by SGOA 2014 | Murray Roberts (Lead) with Melissa Chierici, Jason Hall-Spencer, Evin McGovern, Mark Benfield, Are Olsen, Richard Bellerby. | 9 |
| Contact additional experts to invite input into OA-CWC assessment | Melissa Chierici, Evin McGovern | 9 |

## 13 Date and venue of the 2014 meeting

It was provisionally agreed that SGOA 2014 would take place on October 6th–9th, 2014 at ICES Headquarters in Copenhagen.

# 14 Closure of the meeting

Evin McGovern and Mark Benfield thanked the members for their contributions and the group expressed their gratitude to ICES for logistical support of the meeting. The meeting was adjourned at 1pm on Thursday 10th October.

# Annex 1: List of participants

| NAME | ADDRESS | PHONE/FAX | E-MAIL |
|---|---|---|---|
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# Annex 2: Agenda

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 2012

6 ) Links to other ICES working groups/activities

6.1 ) ASC, MCWG, WGBEC…

7 ) Main terms of reference

| |
|---|
| Format of annotated ToR<br>1.a) ToR as provided by OSPAR<br>Background and key tasks for SGOA 2013<br>i) Specific inputs |

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

Additional/ updated information on national monitoring activities (ref SGOA 2012 and Spreadsheet on OA monitoring activities)

i) Brief updates from members of national OA monitoring and research activities

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 or updated information on relevant initiatives (ref SGOA 2012)

i) **Presentation**: Ocean Acidification in the Arctic: The AMAP Assessment- *Jan Rene Larsen* AMAP

ii) Update MedSeA *Patrizia Ziveri*

7.3 ) Finalise OSPAR guidelines for measuring carbonate system;

**Completed 2012**

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

Initial summary of findings from reports identified in SGOA 2012 and other relevant publications

i) **Presentation**: Ecological effects of acidification around marine $CO_2$ vents. Jason Hall-Spencer (WebEx)

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

Prepare 1st draft of an OSPAR monitoring strategy document

Consider requirement for any "Assessment Criteria" that may be pertinent to monitoring framework

i) **Presentation**: Progress during 2nd Global OA; Observation Network (GOA-ON) meeting. Phil Williamson

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

Additional or updated information (ref SGOA 2012)

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

Review progress wrt ICES 3.2 ERF reporting and discuss further needs to facilitate data reporting to ICES

Consider how to ensure interoperability between global OA data centres (and need for a reporting manual?)

i) **Presentation**: Hernan Garcia, NOAA OA data management activities (WebEx)

ii) CDIAC $CO_2$ Data centre, Alex Kozyr

iii) ICES 3.2 ERF reporting, Status update (ICES MCWG); ICES MDC

iv) Updates GLODAPV2; SOCAT?

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[8]) 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).

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

Agreed focus on assessment of OA status [&trends] in Cold-Water Coral areas. Agree structure of assessment, collate and assemble data and prepare initial draft (with a view to completion in SGOA 2014). Consider any other elements approaches for an OSPAR assessment e.g. broad brush assessment of vulnerable areas.

i) **Presentation**: Cold-Water Corals in Northeast Atlantic, Murray Roberts

8 ) Plenary discussion of SGOA 2013 draft report

9 ) Any other business

10 ) Recommendations and action list

11 ) Date and venue of the next meeting

12 ) Closure of the meeting

Close by 1600

## Annex 3: SGOA Terms of Reference for the next meeting

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

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

e ) Inform the development of biological effects indicators for ocean acidification, including the identification of suitable species and key areas[9];

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

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

[9] 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.<br>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 |
| --- | --- |
| Report progress on WGBEC work programme with respect to OA to SGOA 2013 with a view to incorporating any agreed recommendations on biological monitoring in final SGOA report to OSPAR. (Section 8 ToR F) | WGBEC |
| Review Progress and advancing OA QA/QC workshop (Section 6.4 ToR E) | MCWG |
| Further review reporting requirements to ICES environmental database for OA data, specifically in relation to units and reference temperature for pH and other parameters as elaborated in Section 8 of the SGOA 2013 report | MCWG |
| OSPAR Contracting Parties are recommended to submit appropriate OA pre-CEMP monitoring data to the ICES environmental database | OSPAR |
| 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 |

# Annex 5: Proposal for workshop on Quality Assurance (QA) for inorganic carbon system measurements

Proposal for workshop on Quality Assurance (QA) for inorganic carbon system measurements in context of ocean acidification monitoring:

| | |
|---|---|
| Scope | 10–20 participants, with technical competence in marine chemistry |
| Timing and venue | Early/mid 2014; National Oceanography Centre, Southampton (NOC), UK |
| Organisers | Susan Hartman and Caroline Kivimae, NOC/ Pam Walsham, Marine Scotland Science |
| Support sought | to be decided (depends on whether participation is limited to OSPAR/ICES parties, or made fully international) |

***Scientific justification***

Several initiatives are now underway to develop and connect ocean acidification monitoring activities at national, regional and global levels. ICES Marine Chemistry Working Group (MCWG) highlighted that as Ocean Acidification monitoring is taken forward by OSPAR and other International monitoring initiatives there is a clear need to facilitate meaningful data comparison, collations and assessments across the OSPAR region, but limited QC tools to support this (Hydes *et al.*, 2013). A consistent approach to sampling, sample pretreatment, analysis, calculation of derived variables and an understanding of methodological limitations is required. There is an awareness that samples for carbonate chemistry parameter measurements will in the near future be analysed by a wider range of monitoring agencies with varying levels of experience in this field.

Andrew Dickson has raised concerns that too many laboratories may be using the Scripps reference materials as calibration standards for their TA/DIC analysis without having a separate way of ensuring that their measurement system is in control and has a known linearity of calibration. Thus, even when reference materials are used there are likely to be unidentified uncertainties that could show up on a well-designed proficiency study. Moreover, although there are globally accepted standard operating procedures for sampling and testing (Dickson *et al.*, 2007), variations in how these are applied in different laboratories can contribute to measurement errors. The proposed workshop would help address some of these issues.

TA and DIC have recently been added to the OSPAR pre-CEMP (Coordinated Environment Monitoring Programme). Determinants can move from the pre-CEMP to CEMP once guidelines, assessment criteria and Quality Assurance are in place.

During ICES MCWG 2013 discussions were held as to whether there was a requirement to organise a workshop. Participants at MCWG felt that a workshop covering TA/DIC and related parameters would be valuable. MGWG recommended that a workshop to address these issues should be organised under the QUASIMEME banner. The National Oceanography Centre (NOC) would be willing to host such a workshop. MCWG felt it would be essential to invite Andrew Dickson (USA) as a leading expert in the field; being one of the editors of the Guide to best practices for ocean $CO_2$ measurements (Dickson *et al.*, 2007). Andrew Dickson's laboratory at

Scripps Institute of Oceanography (SIO) provides the only recognised reference material for ocean carbonate parameters.

Following on from MCWG 2013, the OSPAR/ICES Study Group on Ocean Acidification (SGOA) participants have identified the key aims and objectives of the proposed workshop;

#### Proposed aims of the workshop

1 ) Introduction to Quasimeme Quality assurance and Quality assessment.

2 ) To obtain a consistent approach to sampling, sample pretreatment sample storage across the OSPAR contracting parties for all four carbonate parameters (TA/ DIC/ $pCO_2$/ pH).

3 ) Discuss the key analytical techniques for all four carbonate chemistry parameter measurements; challenges, limitations and misconceptions affecting quality of results. The emphasis of the workshop will be on the parameters of TA/DIC since these are likely to progress to the OSPAR CEMP but considerations will also be given to pH and $pCO_2$.

4 ) To obtain a consistent approach to the analysis of TA/DIC, and correct use of reference materials/standards across the OSPAR region.

5 ) Consider the limitations of reference materials across the OSPAR region i.e. salinity ranges, open oceans and coastal waters.

6 ) Address issues with calculation of data using the various software packages.

7 ) Address data quality objectives needed for various assessment purposes. GOA-ON identified the need for two different levels of data quality to ensure the availability of data and permit assessment of short-term variability as well as longer term trends.

#### Potential outcomes

Workshop report and if deemed appropriate the preparation of a technical guide for carbonate chemistry sampling, sample pretreatment, sample storage, analysis, use of reference materials and calculation for use within OSPAR.

#### Estimated Costs

Invited Experts =£3000

Refreshments at NOC =To be determined

There will be a charge to participants wishing to attend, but this has yet to be decided and will be dependent on any consumable costs for practical work.

Dickson, A.G., Sabine, C.L. and Christian, J.R. (Eds.) 2007. Guide to best practices for ocean $CO_2$ measurements. PICES Special Publication 3, 191pp. http://cdiac.ornl.gov/ftp/oceans/Handbook_2007/Guide_all_in_one.pdf

Hydes, D. J., McGovern, E., and Walsham, P. (Eds.) 2013. Chemical aspects of ocean acidification monitoring in the ICES marine area. ICES Cooperative Research Report No. 319. 78 pp.

# Annex 6: Chemical monitoring activities relevant to OA in the OSPAR and HELCOM areas

**Table 1. Recent and current carbonate system monitoring activities in the NE Atlantic and Baltic Sea. (Table updated from SGOA 2012).**

| Country/Institute | PI | Area | OSPAR/HELCOM region | Platform/type | Parameters | Period |
|---|---|---|---|---|---|---|
| Belgium/ ULg | Borges | Southern Bight of North Sea | OSPAR II | RV Belgica (research vessel) | Underway $pCO_2$ | 2000–on going |
| Belgium/ ULg | Borges | Ste Anna (Scheldt estuary) | OSPAR II | FS Fixed station, continuous | $pCO_2$ | 2002–on going |
| Belgium/ ULg | Borges | Celtic Sea | OSPAR III | RV Research cruises, OMEX-II, CCCC, PEACE | $pCO_2$, TA, pH | 1997–1999, 2002, 2004, 2006–2009 |
| Belgium/ ULg | Wollast / Chou | Iberian upwelling system | OSPAR IV | RV Research cruises (OMEX-II) | $pCO_2$, TA, pH | 1997–1999 |
| Belgium/ ULg/ NIOO | | RV Luctor monitoring (Scheldt estuary) | OSPAR II | RV monthly cruises | $pCO_2$ TA | 2008–on going |
| Estonia/ | Lipps | Helsinki–Talinn | HELCOM | SOO | Underway $pCO_2$ | 2010 |
| France | | Plymouth–Roscoff (FERRYBOX Armorique | OSPAR II | SOO | Underway $pCO_2$ | 2010 |
| France | | ASTAN (48°46'N; 3°56'W) | OSPAR II/III? | FS Mooring | $pCO_2$ | 2009– |
| France/ Ifremer | | MAREL Iroise (48°22'N; 4°33'W) | OSPAR II | FS Mooring | $pCO_2$, pH | 2003– |
| France/ Ifremer | | MAREL Carnot (50°44.71'N; 1°34.18'W) | OSPAR II | FS Mooring | pH | 2004– |
| France/ Ifremer | | MAREL La Tremblade–Marennes Oléron | OSPAR II | FS Mooring | pH | |

| Country/Institute | PI | Area | OSPAR/HELCOM region | Platform/type | Parameters | Period |
|---|---|---|---|---|---|---|
| France/ EDF | | Cordemais (Loire Estuary) | OSPAR IV | FS Mooring | pH | 2005– |
| France/ CNRS–INSU | Patrick Raimbault (patrick.raimbault@univmed.fr) | MOOSE (DYFAMED, ANTARES, MOLA)-Mediterranean Sea | Barcelona Convention | Niskin bottles RV monthly or annually cruises | pH, DIC, carbon flow | 1995–(DYFAMED)<br>2003–(MOLA)<br>2005–(ANTARES) |
| France | Benoit Sautour (b.sautour@epoc.u-bordeaux1.fr) | SOMLIT-English Channel, Atlantic Ocean and Mediterranean Sea | OSPAR II, IV Barcelona Convention | SO | pH | 1984–according to station |
| France | Nathalie Simon (Nathalie.Simon@sb-roscoff.fr) | RESOMAR-PELAGOS-English Channel, Atlantic Ocean and Mediterranean Sea | OSPAR II, IV Barcelona Convention | SO | pH | 1987–according to station |
| France/ AAMP–PNMI | Patrick Pouline (patrick-pouline@aires-marines.fr) | PNMI-Iroise Sea | OSPAR II | SO RV cruises three/year | pH | 2010 |
| France | | RNF (Seine estuary, Bouches de Bonifaccio) | OSPAR II Barcelona Convention | Seine: monthly measure<br>Bonifaccio: RV cruises four/year during summer | pH | |
| France/ GIP Seine-Aval | Céline Dégremont (cdegremont@seine-aval.fr) | SYNAPSES (Seine Estuary) | OSPAR II | FS Mooring | pH | 2011 |
| France LOCEAN | Lefevre | France–French Guiana | ? | SOO (MN Colibri) ~6/year | Underway $pCO_2$ | 2006– |
| France LOCEAN | Lefevre | France–Brazil | ? | SOO (Monte Olivia) ~6/year | Underway $pCO_2$ | 2007– |
| Germany | Weigelt-Krenz/BSH | German Bight | OSPAR II | National monitoring programme (four times/year) | pH/ continuous pH measurements | 1990–<br>2011– |

| Country/Institute | PI | Area | OSPAR/HELCOM region | Platform/type | Parameters | Period |
|---|---|---|---|---|---|---|
| Germany | Weigelt-Krenz/BSH | Helgoland | OSPAR II | Measurement station | Continuous $pCO_2$ measurements | July 2013 |
| Germany | | Irregular | | RV Polarstern | Underway $pCO_2$ | |
| Germany/ AWI? | | Nordic Seas (Greenland Sea?) | OSPAR I | RV Research cruises | ? | ? |
| Germany/ IFM-GEOMAR | | Boknis Eck (54.52°.N 10.03° E) | | FS Time-series station | ? | ? |
| Germany/ IOW | Schneider now Reider | Helsinki–Lübeck | | SOO | Underway $pCO_2$ | |
| Germany IFMGeomar Kiel | Koertzinger/Wallace | Liverpool–Halifax | OSPAR V | SOO (A. Companion) | two per five weeks Underway $pCO_2$ | 2005 |
| Iceland/ MRI | Olafsson /Olafsdottir | Iceland Sea and Irminger Sea | OSPAR I | FS Single time-series stations | DIC, discrete $pCO_2$, pH | from 1983 |
| Iceland/ MRI | Olafsson Olafsdottir | Icelandic waters and the Iceland Sea | OSPAR I | RV Bjarni Saemundsson | Underway $pCO_2$ | from 1995 |
| Ireland/ NUI Galway and MI | Ward | Irish Shelf and off-shelf | OSPAR III & V | RV Celtic Explorer | Underway $pCO_2$ | 2009–2011 |
| Ireland/ NUI Galway and MI | O’Dowd/Ward | Mace Head Coastal Atmospheric research station | OSPAR III | FS Buoy | $pCO_2$ | 2008–2009 |
| Ireland/ NUIG and MI | McGovern/ Cave | Irish Shelf and off-shelf | OSPAR III & V | RV Research Cruises | TA, DIC | 2008– |
| Ireland/ NUIG and MI | McGovern/ Cave | Rockall Trough Winter Transects | OSPAR V | RV Celtic Explorer | TA, DIC | 2008– |
| Netherlands/ NIOZ | de Baar | Basinwide North Sea | OSPAR II | RV Research cruises | DIC $pCO_2$ (TA) | 2001, 2005, 2008, 2011 |
| Netherlands/ NIOZ | | Southern Bight of the North Sea/ German Bight | OSPAR II | SOO ?JetSet (53°N; 4° 46'E) Weekly time-series | Underway DIC, TA? | ? |

| Country/Institute | PI | Area | OSPAR/HELCOM region | Platform/type | Parameters | Period |
|---|---|---|---|---|---|---|
| Netherlands | Houben | North Sea | OSPAR II | Research vessel | pH | Ongoing |
| Norway/ IMR | Chierici | Torungen–Hirtshals | North Sea | IMR research vessels | water column DIC, TA, nutrients | start 2010–2012, 2–4 times annually: 2013–2016: one/year |
| Norway/ IMR | Chierici | Gimsøy-NW | Norwegian Sea | IMR research vessels | water column DIC, TA, nutrients | start 2010–2012, 2–4 times annually: Pending funding |
| Norway/ IMR | Chierici | Svinøy-NW | Norwegian Sea | IMR research vessels | water column DIC, TA, nutrients | start 2010–2012, 2–4 times annually: 2013–2016: one/year |
| Norway/ IMR | Chierici | Fugløya-Bjørnøya | Barents Sea (SW) | IMR research vessels | water column DIC, TA, nutrients | start 2010–2012, 2–4 times annually: 2013–2016: one/year |
| Norway/ IMR | Chierici | Bjørnøya-Sørkapp | Barents Sea (SW) | IMR research vessels | water column DIC, TA, nutrients | start 2013 to 2016: one/year |
| Norway/ IMR | Chierici | Vardø-N | Barents Sea (NE) | IMR research vessels | water column DIC, TA, nutrients | start 2010–2012, 2–4 times annually: 2013–2016: one/year |
| Norway/ IMR and FRAM centre (OA Flagship) | Chierici/Fransson (NPI) | Fram Strait | Arctic Ocean/Greenland Sea | RV Lance | water column DIC, TA, nutrients | start 2011 ongoing |

| Country/Institute | PI | Area | OSPAR/HELCOM region | Platform/type | Parameters | Period |
|---|---|---|---|---|---|---|
| Norway/ IMR and FRAM centre (OA Flagship) | Chierici/Fransson (NPI) | N of Svalbard to Polar Basin, 81–82N, 30E | Arctic Ocean | RV Lance | water column DIC, TA, nutrients | start 2012 on going. 1/year |
| Norway/ IMR and FRAM centre (OA Flagship) | Chierici/Fransson (NPI) | Svalbard fjords | Artic Ocean, Svalbard | RV Lance | Water column DIC, TA | Start 2012 on going.<br>one year |
| Norway/ UiB and Bjerknes | Johannessen | 75° N transect | OSPAR I | RV Research cruises | DIC, TA | 2003, 2006, 2008? |
| Norway/ UiB and Bjerknes | Skjelvan/Johannessen | OWS M | OSPAR I | FS WS Monthly profiles | DIC, TA | 2001–2009 |
| Norway/ UiB and Bjerknes | Skjelvan/Johannessen | OWS M | OSPAR I | FS WS Continuous | $pCO_2$ | 2005–2009 |
| Norway/ UiB and Bjerknes | Skjelvan/Johannessen | OWS M | OSPAR I | FS Buoy Continuous | $pCO_2$ | 2011 |
| Norway/ UiB and Bjerknes | Johannessen/Olsen/Lauvset | Nordic Seas | OSPAR I | RV G. O. Sars (research vessel) | Underway $pCO_2$ | Ongoing |
| Norway/ UiB and Bjerknes | Johannessen/Olsen/Omar | Aarhus–Nuuk | | SOO (Nuka Arctica) | Underway $pCO_2$ | 2005– |
| Norway/ UiB and Bjerknes | Johannessen/Omar | Bergen–Amsterdam | OSPAR II | SOO / weekly | Underway $pCO_2$ | 2005–2009 |
| Norway/ UiB and Bjerknes | Johannessen/Omar | North Sea | Sleipner | RV G. O. SARS | Underway $pCO_2$ | June 2012 |
| Norway/ UiB and Bjerknes | Johannessen/Omar | North Sea | Sleipner | RV G. O. SARS | TA, DIC | June 2012 |
| Norway NIVA | Sorensen | line up to Svalbard | Ferry-box | SOO | Underway $pCO_2$ | 2012 4-6 times/year |

| Country/Institute | PI | Area | OSPAR/HELCOM region | Platform/type | Parameters | Period |
|---|---|---|---|---|---|---|
| Spain/ IIM | Perez/ Rios | OVIDE, Iberian Peninsula-Greenland | OSPAR V | RV Research cruise | Underway $pCO_2$,pH,TA | 2002–2012 |
| Spain/ IIM | Rios/ Perez | FICARAM, Spain-Antarctic | OSPAR V | SOO | Underway $pCO_2$, pH, TA | 2001, 2002, 2013 |
| Spain/ ULPGC | Davila | English Channel–Durban | OSPAR V | SOO various ships | Underway $pCO_2$ | 2005 |
| Spain/ ULPGC | Santana Casiano | Greenland-Scotland 59.5ºN | OSPAR V | RV Russian Research cruise | pH, TA, TIC | 2009–2012 |
| Spain/ ULPGC | Davila | ESTOC Station | Canary Islands | FS Time-Series | $pCO_2$, TA, pH | 1996– |
| Spain ICMAN | Huertas | Gulf of Cadiz | OSPAR IV | RV P3A2 Cruises | pH, TA | 2003–2008 |
| Spain ICMAN/IIM/IEO | Huertas | Strait of Gibraltar (35.862 ºN, 5974 ºW) | OSPAR IV | FS Mooring | $pCO_2$, pH | 2011– |
| Spain ICMAN/IIM/IEO | Huertas | GIFT (35.862°N, 5.974°W; 35.957ºN, 5.742°W; 35.985ºN, 5.368ºW) | OSPAR IV | FS Time-series stations | Water column pH, TA | 2005– |
| Spain IEO/ IIM | Rios | Cantabric Sea and west coast | OSPAR IV | RV VACLAN cruises | Underway $pCO_2$, pH, TA | 2005, 2007, 2009 |
| Spain IEO-Gijon | Scharek | Cantabric Sea | OSPAR IV | FS Time-series (three stations) | pH, TA | 2010–2011 |
| Sweden/ SMHI | | Swedish waters | | RV Monitoring cruises? | TA, pH | ? |
| Sweden/ SMHI | Karlson | Kemi–Gothenburg | | SOO | Underway $pCO_2$ | 2010 |
| Sweden/ U Gothenberg | | Arctic Ocean | OSPAR I | RV Research cruises | DIC, TA, pH | 2005, ? |
| UK/ Cefas | | Liverpool Bay | OSPAR III | Buoy, DEFRA tests | $pCO_2$ | 2010 |
| UK/ Cefas | Greenwood/Pearce | Irish Sea and Celtic Sea | OSPAR III | RV Research cruises | DIC, TA and underway $pCO_2$ | 2011 |
| UK/MSS | Walsham | Stonehaven | Coastal site | Time-series | TA/DIC | 2008– |

| Country/Institute | PI | Area | OSPAR/HELCOM region | Platform/type | Parameters | Period |
|---|---|---|---|---|---|---|
| UK/ MSS | Walsham | Faroe Shetland Channel, Atlantic inflow to North Sea | OSPAR I & II | RV Research cruise, May and Dec | TA/DIC, hydrography | 2012– |
| UK/ MSS/ NOC: | Walsham | | OSPAR I, II, III & V | RV Scotia | | |
| UK/ NOC/ UEA | | 26° N line | ? | RV | ? | ? |
| UK/ NOCS | Hydes | English Channel | OSPAR II | SOO (Pride of Bilbao) | DIC, TA | 2005–2010 |
| UK/ NOCS | Lampitt | Porcupine Abyssal Plain (49°N; 16.5°W) | ? | RV Mooring | $pCO_2$ | ?– |
| UK/ NOCS? | Hydes | Portsmouth–Spain | OSPAR II & IV | SOO (Pride of BIlbao), two/week | Underway $pCO_2$ | 2005 |
| UK/ PML | Mountford / Kitidis | Holyhead–Dublin, | OSPAR III | RV Prince Madog (research | Underway $pCO_2$ | 2006–2009 |
| UK/ PML | Mountford / Kitidis | Irish Sea Coastal Observatory | OSPAR III ? | RV (quasi-monthly) | Underway $pCO_2$Transects (Prince Madog) | 2007–2010 |
| UK/ UEA | Schuster | Portsmouth (UK) Windward Islands– | ? | SOO (Santa Lucia/Santa Maria) | Underway $pCO_2$ | Monthly from 2002– |
| UK/MSS /NOC | Walsham | Stonehaven | OSPAR II | FS Weekly single time-series station | TA/DIC | 2008– |
| UK/PML | Mountford / Kitidis | English Channel (E1, L4) | OSPAR II | Weekly (L4) and monthly (E1) | TA/DIC | 2008– |
| UK/ PML | Mountford / Kitidis | English Channel (E1, L4) | OSPAR II | Weekly (L4) and monthly (E1) | Underway $pCO_2$Transects (Plymouth Quest) | |
| UK "Ellett Line" | Reid / Hartman | Greenland–UK | OSPAR I & III | Scientific cruise | Hydrography | 2008 2010 2011 |

| Country/Institute | PI | Area | OSPAR/HELCOM region | Platform/type | Parameters | Period |
|---|---|---|---|---|---|---|
| UK/ Cefas | Greenwood/ Pearce | Basinwide North Sea and English Channel | OSPAR II | RV Research cruises RV Endeavour | DIC, TA and underway $pCO_2$ | 2011– |
| USA/ France | Metzel | Charleston–Reykjavik | ? | SOO (Reykjafoss) | Underway $pCO_2$ | From 2005 |
| Portugal/ IPMA | Nogueria | West and South Portugal Coast, Continental platform | OSPAR IV | RV Research cruise, April | pH, DIC, TA and underway $pCO_2$ | 2013 |
| Portugal/ IPMA | Nogueria | Douro estuary adjacent coast (40.54–41.30°N;8.45–9.20°W) | OSPAR IV | Scientific cruise | pH, DIC, TA and $pCO_2$ | 2004 |
| Portugal/ IPMA | Nogueria | Tagus and Sado estuary adjacent coast (38.15–38.45°N; 8.51–9.36°) | OSPAR IV | Scientific cruises | pH, DIC, TA and $pCO_2$ | One per year 1999–2007 |

**Note: Reproduced from Hydes *et al*., 2013 and updated at SGOA 2013. This table is based on information received by MCWG and SGOA and does not purport to be definitive or complete.**