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

11–14 December 2012

Copenhagen, Denmark

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

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

H. C. Andersens Boulevard 44–46
DK-1553 Copenhagen V
Denmark
Telephone (+45) 33 38 67 00
Telefax (+45) 33 93 42 15
www.ices.dk
info@ices.dk

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Executive summary

The Joint OSPAR/ICES Study Group on Ocean Acidification (SGOA) held its first meeting in Copenhagen, Denmark from 11–14 December 2012. 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 18 scientists representing eight nations. Two of the members participated via WebEx conference. The main objective of the meeting was to discuss and address the Study Group's eight terms of reference (ToRs).

The meeting consisted of formal presentations and discussions of each ToR documented by a rapporteur and summarized in this report. Summaries of national and international monitoring programmes on ocean acidification (OA) were provided by the membership. It is clear that there are many OA-relevant chemical data collection activities ongoing in the OSPAR area, albeit, this is still an incomplete picture as many OSPAR Contracting Parties were not represented at SGOA. Data collection is often linked to other monitoring and research activities or as part of large-scale research projects. These are typically short- to medium-term projects and there are few commitments to long-term ongoing monitoring. Monitoring of the biological impacts of OA is still in its infancy and not routinely undertaken.

SGOA summarized the likely main effects of future OA on different groups of marine organisms likely present in the OSPAR region. There has been a rapid increase in research into potential biological impacts of OA, including responses to multiple stressors such as combined pH and temperature changes. This research points to highly variable responses at inter and intraspecific level. Two notable challenges associated with developing biological impact indicators for OA-monitoring in the OSPAR marine area are: a) the large latitudinal range encompassed; and b) the uncertainty in defining the most suitable indicators due to our limited understanding of the potential biological consequences. Nevertheless, some candidate indicator species and groups to detect OA impacts have been provisionally identified by the Study Group.

OA carbonate parameters have been incorporated as a voluntary component in the OSPAR Coordinated Environmental Monitoring Programme. In support of this, SGOA 2012 finalized Technical Guidelines for Monitoring the Chemical Aspects of Ocean Acidification. SGOA also identified a need for a framework document that sets out a "common procedure" for OSPAR OA monitoring and assessment and this will be progressed taking cognisance of a new initiative to develop a global OA observation network.

Currently, OA data are reported to a number of national and international databases and potentially useful ocean carbon data products, for example surface ocean CO_2 atlas, are also available. SGOA, in discussion with the ICES data centre, commenced the task of defining ICES reporting requirements for OSPAR OA data. There is recognition of a need to streamline reporting requirements to the various data centres and for primary data centres to develop data exchange protocols.

SGOA ToR requires a first assessment of OA in the OSPAR region. Given the available resources SGOA decided to initially focus this task on mapping OA state on vulnerable ecosystems and potentially available long-term datasets.

The next meeting of the SGOA will be held in Copenhagen from October 7–11, 2013 at ICES.

Opening of the meeting

The Joint OSPAR/ICES Study Group on Ocean Acidification (SGOA) met at ICES Headquarters in Copenhagen, Denmark from 11–14 December 2012. The meeting was attended by 18 scientists representing eight nations (Annex 1) although some participants were unable to attend the full meeting.

Evin McGovern (Co-chair) opened the meeting at 10:00 and welcomed the members and guests of the group to Copenhagen. Following a round of introductions, the group reviewed its terms of reference (ToR).

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 2010 Annual Science Conference and Statutory Meeting, and agreed by OSPAR. The agenda had been circulated among the study group membership prior to the meeting and incorporated most suggestions and comments. Last minute adjustments were discussed and the agenda was adopted unanimously. 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.

1.2 SGOA Membership

SGOA noted that chemists and, to a lesser degree, biologists are well represented in its membership. There were other areas of expertise not currently represented in SGOA that the members felt would be important to have at the table. Participation of a coupled physical-biogeochemical-ecosystem modeller was highlighted as important. A number of names were suggested and Evin McGovern will follow up. Participation of a physical oceanographer would also be helpful and Mark Benfield undertook to contact Luis Valdes to see if a suitable candidate can be identified.

[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).

1.3 Links to other Working Groups

SGOA recognized the breadth of ICES expertise and the potential resource that could support SGOA's work in developing monitoring and assessment of ocean acidification (OA). There is an overlap in membership of SGOA with ICES Working Groups on Marine Chemistry (MCWG) and Zooplankton Ecology (WGZE), which will ensure good collaboration with these groups. There are also potential links with the Working Group on Oceanic Hydrography (WGOH), for instance in identifying hydrography monitoring stations where carbonate monitoring could be usefully added. Other working groups identified that may be able to provide information on potential ecological impacts of OA include Phytoplankton and Microbial ecology (WGPME), Biological Effects of Contaminants (WGBEC), Working Group on Integrative Physical-biological and Ecosystem Modelling (WGIPEM) and Benthic Ecology (WGBE).

Mark Benfield undertook to contact the chairs of WGMPE, WGOH, WGBEC, WGIPEM and WGBE to make them aware of the work of SGOA and invite them to consider if and how they may input to this topic.

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

2.1 Reports on national monitoring activities in the OSPAR maritime area: general observations

Participants at SGOA presented information on national monitoring activities and the following general observations were made by SGOA:

- Many countries are currently investing resources in monitoring the ocean carbon system and in establishing an ocean acidification baseline. There are variations in the approaches taken by different countries although there is often geographical overlap in areas sampled. Promotion of coherence in monitoring and data exchange would facilitate more efficient use of these resources.
- Typically, OA monitoring activities often take advantage of other ongoing monitoring or platforms (e.g. hydrographic, fisheries surveys) by adding additional carbonate system measurements. This ensures cost-effective and valuable data collection, although such an approach may not necessarily be optimized for OA monitoring.
- SGOA sees the establishment of long-term time-series as essential. However, the funding for much of the current monitoring activities is often short term (finite-life projects) and few resources are currently committed to securing consistent long-term monitoring.
- There are particular gaps for coastal and inshore information and a need to synthesize inshore data. However this presents its own significant set of challenges. For example, many areas that are of interest for monitoring changes in, and impacts of OA, lack adequate biological or chemical time-series that could be used to assess future changes.
- There are few stations where biological (e.g. effects) monitoring is taking place alongside chemical monitoring. Where it does occur, quite high level or general indicators tend to be used and not OA-specific effects monitoring. This reflects the immature stage of development of biological effects indicators of OA. In some cases carbonate parameters have been added to existing biological time-series monitoring such as that undertaken in the Barents Sea as part of the ecosystem surveys performed in a Norwegian-Russian collaboration.
- The reports presented reflect attendance at SGOA which was biased towards northern European countries and the USA with gaps for many North Sea and southern European countries. There are ocean acidification relevant monitoring/research activities in most if not all the OSPAR contracting parties and more information is available in the ICES Cooperative Research Report "Chemical Aspects of Ocean Acidification Monitoring in the ICES Marine Area" produced by MCWG (Hydes *et al.*, in review) and reproduced in Annex 7 of this report.

2.2 Monitoring in Danish waters

There is no coordinated collection of ocean acidification in the Danish marine monitoring program NOVANA, but pH is measured in connection with primary production, mainly by pH-electrodes. Some data on total alkalinity is also available, and

Duarte and Jacobsen *et al* have collected and quality assured (i.e. filtered obvious bad values) a dataset from literature and monitoring data from the beginning of 1900 to 2011 (large gaps in data before 1978). They find that the main difference in pH in top and bottom waters are due to production vs. respiration, and that around 0.03 pH units (10–15%) of the increase in pH can be attributed to CO_2 in the atmosphere, based on aggregated data for top and bottom waters for both Danish fjords and open water stations respectively. There is both a seasonal variation and variation in the water above and below the pycnocline. The publication "Is Ocean Acidification an Open-Ocean Syndrome? Understanding the drivers and impacts of pH variability of the coastal ocean" have been submitted to Estuaries and Coast, and will be made available to the working group when (if) accepted.

Information provided by Martin Larsen.

2.3 Monitoring in German Waters

The BSH (Federal Maritime and Hydrographic Agency, Hamburg, Germany) undertakes four monitoring cruises to the German EEZ (exclusive economic zone) and one monitoring cruise across the North Sea each year. To meet the monitoring requirements within OSPAR and the European Marine Strategy Framework Directive (MSFD) the BSH developed a monitoring network within the German Bight which includes 42 stations. At these stations water and sediment samples are taken for analysis of nutrients, oxygen, pH, trace metals, organic pollutants and radioactivity. Temperature and salinity are also measured at each station.

To analyse the influence of CO_2 to the marine environment long-term pH measurements are carried out from 1990 till now. In 2011 high-resolution pH measurements in the moon pool of the *RV Celtic Explorer* were commenced to get continuous pH datasets.

The long-term pH dataset (1990–2012) shows a decline of about 0.4 (Figure 1). It is planned that the German pH datasets are calculated together with Danish and Belgian long-term pH datasets. (The methods of analysis and quality assessment parameters are comparable).

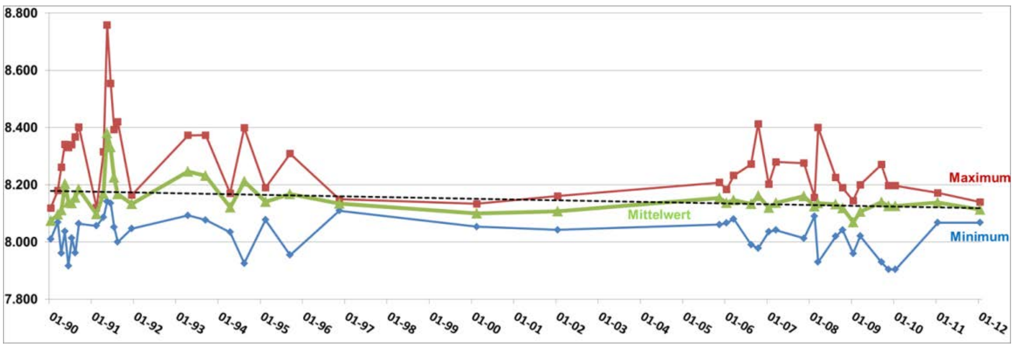

Figure 1. Long-term German pH data illustrating an overall decline of approximately 0.4 pH units.

In 2013 the BSH plans to build up a flow-through pCO_2 measurement system at the BSH station UFS EMS (unmanned fire-ship). High-resolution temperature, salinity and pH measurements are regularly taken.

Information provided by Sieglinde Weigelt-Krenz.

2.4 Monitoring in Icelandic waters

The Marine Research Institute in Iceland measures inorganic carbon at two time-series stations, one in the Irminger Sea to the west of Iceland, the other one in the Iceland Sea north of Iceland. Quarterly measurements started for surface waters in 1983 and a full profile has been taken from 1991. Parameters measured from discrete samples are DIC, pCO_2, O_2, salinity and nutrients.

Information provided by Sólveig Ólafsdóttïr.

2.5 Monitoring in Irish waters

As part of a nationally funded project (2008–2011), the Irish Marine Institute and NUI Galway undertook a baseline study on the carbonate system in Irish coastal, shelf and off-shelf waters. Some initial pCO2 measurements and CO2 flux studies were undertaken at NUI Galway's Mace Head station (a Global Atmospheric Watch station) and onboard the RV Celtic Explorer. DIC and TA measurements were undertaken on samples collected on a number of hydrographic surveys. In particular, annual sampling on a winter standard section on the shelf to the west of Ireland and in the southern Rockall Trough has been continued. An initial assessment compared data obtained for the southern Rockall Trough with WOCE survey data from the same area in the 1990s. An increase in anthropogenic carbon (ΔC_{ant}) of ~1 umol kg^{-1} yr^{-1} was estimated for subsurface winter mixed layer waters of the Rockall Trough between 1991 and 2010. This equates to a calculated pH reduction of 0.02 pH units per decade (McGrath *et al*., 2012), in line with observations reported in other time-series for the North Atlantic. Decreases in pH were also calculated for deeper water masses over the 19 year period including Labrador seawater (LSW) at 1500–2000 m deep a decrease in pH of ~0.015 units per decade was calculated. Studies of inshore waters show highly variable riverine alkalinity inputs into coastal waters.

Information provided by Evin McGovern.

2.6 Monitoring in Norwegian and arctic waters

There are two major programs in Norway and these are described 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), external funding.

Information provided by Melissa Chierici and Are Olsen.

2.6.1 "Monitoring Ocean Acidification in Norwegian waters" funded by the Climate and Pollution Agency (KLIF, *www.klif.no*)

2010–2012: The responsible institutions for this activity were the Norwegian Institute for Water Research (NIVA), the Institute of Marine Research (IMR), and the Bjerknes Centre for Climate Research (BCCR)/Geo physical Institute (GFI) and the client was the Climate and Pollution Agency (KLIF, www.klif.no). In this period (2010–2012) measurements for OA studies were performed for the following hydrographic sections: surface water sampling and analysis during two ocean transect surveys between Oslo–Kiel and Tromsø–Longyearbyen/Ny Ålesund; and water column sampling and analysis from the IMR repeated transects Torungen–Hirtshals (North Sea); Svinøy–NW (Norwegian Sea), Gimsøy–NW (Norwegian Sea) and Fugløya–

Bjørnøya (Barents Sea). BCCR/GFI was responsible for automated pCO_2 instrumentation and measurements onboard RV G.O. Sars in the Norwegian Sea all year-round (depending on the research cruises). See Figures 2a and 2b for location of sampling and underway pCO_2 measurements area.

The IMR repeated sections were sampled between 2–3 times/year, typically January, April, and September. Full water column profiles were sampled for determination of total alkalinity (TA) and total inorganic carbon (DIC) at IMR (Bergen and Tromsø from 2011) and at the KJOS-labs at GFI/BCCR. IMR and BCCR also used historical data to investigate trends in CO_2 system from IMR repeated transects and the CARINA database from 1997 to 2011, mainly focusing on the Norwegian Sea (Chierici *et al*., 2012). Surface water discrete sampling between Tromsø-Svalbard performed by NIVA was sampled about 4–5 times/year. Between Bergen and Kirkenes 1/year (July), and Kirkenes-Tromsø 1/year (winter).

2013–2016: Monitoring OA in Norwegian waters (KLIF), PI: M. Chierici (IMR), partners: IMR, NIVA, UNI research (UiB). (See Figures 2a and 2b).

IMR sections in water column will be sampled once a year (winter): Torungen–Hirtshals, Fugløya–Bjørnøya–Sørkapp, Vardø–N, and Svinøy–NW.

Starting in 2014: Monthly sampling of water column for seasonal resolution will take place at the coastal station "Skrova" starting in 2014. The planned NIVA surface water sampling is similar to the 2010–2012 programme: 4–5 times/year for Tromsø–Longyearbyen/Ny–Ålesund. Underway measurements of pCO_2 in surface waters will be undertaken by UNI research (UiB) onboard G.O. Sars in Norwegian Sea. Seasons depend on research expeditions but usually year-round measurements are achieved.

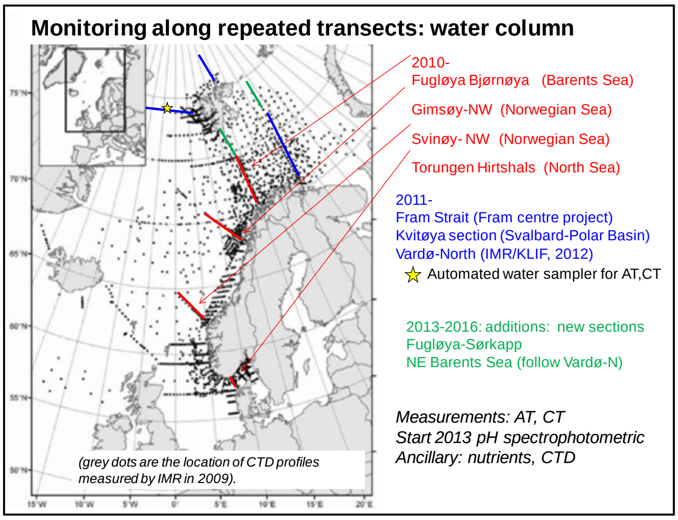

Figure 2a. Sampling locations for water column OA studies during 2010 (red, 3 times/year), start 2011 (blue) and new additions for KLIF project 2013–2016 (green). Star denotes location of auto mated water sampler in the Fram Strait for weekly sampling to obtain seasonal resolution of A_T and (C_T depend on sample volume).

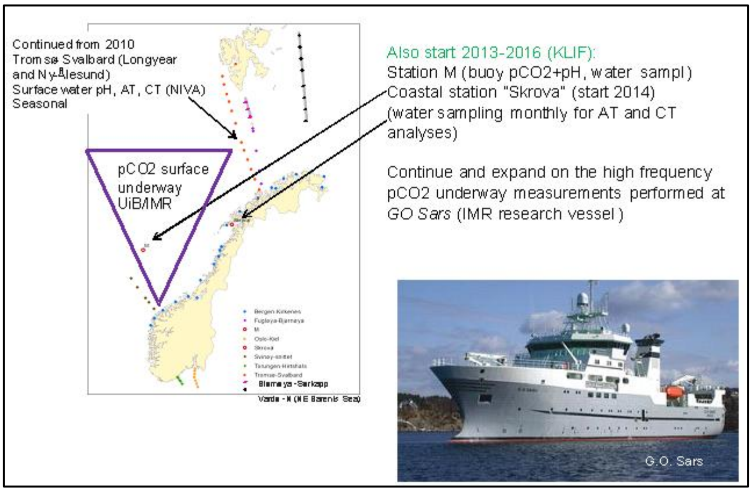

Figure 2b. Surface water sampling within the KLIF project starts 2011, continued in its own program start 2013 (to 2016).

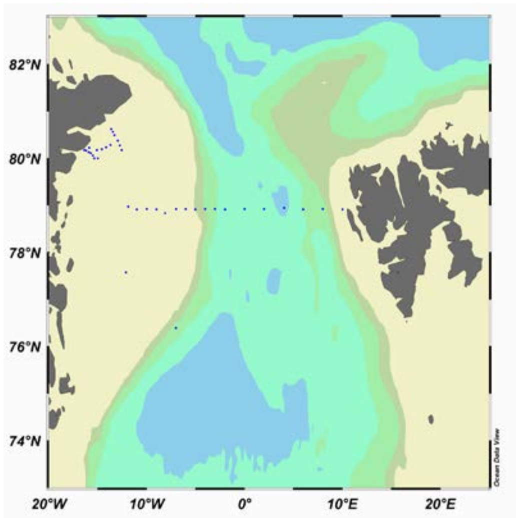

Figure 3. Blue dots show locations water column sampling for AT and CT in the Fram Strait 2011. Similar section (extended at depth) was sampled in 2012. Samples were analysed at IMR.

2.6.2 Ocean Acidification Flagship at the Fram Centre, funded by Ministry of Environment (MD) and Ministry of Fisheries and Coastal Affairs (FKD), external funding

Project: "Establishing the current state of Ocean Acidification in the Norwegian Arctic - OA^{state}" Institute of Marine Research (IMR), Norwegian Polar Institute (NPI).

Commenced in 2011 (Fransson *et al.*, 2012)

Annual sampling (August–September) in Fram Strait onboard RV Lance (NPI) to study Arctic outflow waters started in 2011 (250 samples) and was extended in 2012 (600 samples). Water column samples were determined for A_T and C_T (IMR) (see Figure 3). It is planned to continue annual sampling (likely funded at least until 2015). Annual sampling (summer) for A_T and DIC is undertaken north of Svalbard on a water column section from 80°N to 82°N along 30°E. (IMR and NPI) See Figure 2a.

2.7 Monitoring in UK waters

National framework

UK activities relevant to the monitoring and assessment of ocean acidification are carried out by a wide range of governmental bodies, research centres, university groups and other organizations. OA-directed observational work (Figure 4) is currently focused on carbonate system parameters, covered below fewer than three headings: activities by Marine Scotland Science (MSS); activities by the Centre for Environment, Fisheries and Aquaculture Sciences (Cefas); and activities by other groups. There are, however, many linkages between these studies. A national framework is provided by the UK Ocean Acidification (UKOA) research programme, 2010–2015, 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. It should be noted that:

- monitoring-related, observational OA is only a minor component of the UKOA programme, with most effort directed at process-based understanding;
- there is also other relevant OA research in the UK supported via other funding routes, including the EU;
- UK biological monitoring relevant to OA includes the Continuous Plankton Recorder survey and time-series sites providing long-term data on the abundance of a diverse range of pelagic and benthic organisms (vertebrates, invertebrates and microbes) as well as physico-chemical data (e.g. the century-long records at the Western Channel Observatory, off Plymouth);
- UK marine biological monitoring is funded by many sources; an Integrated Marine Observation Network (UK- IMON) is being developed.

2.7.1 Activities by Marine Scotland Science

In 2012 Marine Scotland Science (MSS) began a five year project on carbonate chemistry monitoring, based on TA and DIC analyses of discrete water samples. As follows:

- Weekly sampling from the MSS long-term monitoring site at Stonehaven (3 km offshore; ~20 km S of Aberdeen). Previous TA and DIC analyses for this site (2008–2010) were carried out as part of a Defra project, with the National Oceanography Centre (NOC), Southampton. That initial study showed high seasonal variability of calculated pH at Stonehaven (Figure 5), strongly influenced by calcification.
- Biannual sampling from three standard hydrographic lines (two in the Faroe/Shetland Channel and one between Orkney and Shetland). Samples are collected at fixed stations throughout the water column in May and December of each year.

In addition, MSS has installed an underway pCO_2 system for MRV Scotia, in collaboration with NOC and the UKOA programme. This will be operational in early 2013 and will provide large-scale surface data for Scottish waters, until at least 2015.

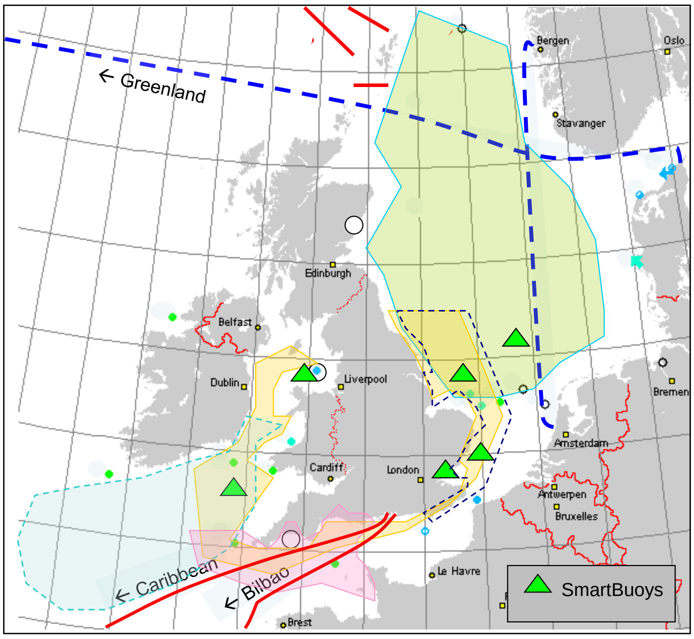

Figure 4. A diagrammatic summary of current UK OA-related monitoring in European shelf seas. The polygons indicate the main coverage of underway measurements to be covered in annual fishery surveys by Cefas. There may be some year-to-year variability. See text for details.

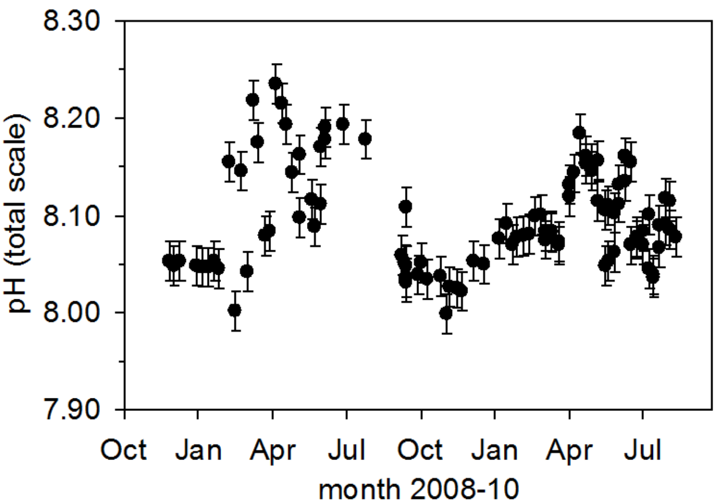

Figure 5. Calculated pH (from TA and DIC) at Stonehaven, November 2008–August 2010, showing the range of seasonal change (~0.2), with low values in winter and high values in spring.

2.7.2 Activities by Cefas

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 showed good agreement with previous surveys at the same of year (e.g. Bozec *et al*., 2006).

An underway pCO_2 system to *RV Cefas Endeavour* in January 2012, and has been successfully used on several 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.

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.

Cefas has an ocean acidification experimental facility at its Weymouth Laboratory, used to study the effects of co-stressors on commercially important species and micro-contaminants. Experiments have been undertaken to study the effects of reduced pH on disease progression in crustaceans (e.g. lobster), changes in benthic bacterial community structure, shellfish growth and bioenergetics (e.g. scallops) and the toxicity of legacy pollutants (e.g. metals).

2.7.3 Other relevant UK activities

- Closely linked to the above MSS and Cefas work, and also involving the Agri-Food and Biosciences Institute (AFBI) Northern Ireland, Defra has funded a nine month project in 2013 to collect discrete samples for carbonate chemistry analyses from an Ullapool–Stornoway transect route, the North West Irish Sea Mooring, and two Cefas SmartBuoys (Celtic Deep and Liverpool Bay). This work is a pilot study for the UK Integrated Marine Observation Network.
- The University of East Anglia, with EU funding from CarboOcean and CarboChange and national funding from UKOA and other sources, has used underway sampling systems on commercial vessels to obtain Atlantic-wide data on pCO_2 and related variables continuously since 2002, with earlier data from the 1990s.
- NOC Southampton, with funding from the Swire Group Trust has used an underway measurement system on a Swire Group ship to obtain data in the Atlantic and between Australia and the USA and Canada. pCO2 is measured continuously and samples are collected by the crew (www.noc.soton.ac.uk/snoms).
- Western Channel Observatory; Carbonate chemistry measurements are routinely made by Plymouth Marine Laboratory at the E1 and L4 stations south of Plymouth, with other biogeochemical and biological parameters (www.westernchannelobservatory.org.uk). pCO_2 data have been collected since 2005 (Litt *et al.*, 2010) with additional analyses supported by the DEFRApH project (2008–2010) and continued since.
- Porcupine Abyssal Plain monitoring site. pCO_2 has been measured at the PAP site since 2005 using instrumentation on the mooring (www.eurosites.info/pap.php; Koertzinger *et al.*, 2008). Since 2008, water

column samples for DIC and TA determination have been collected at least annually during servicing of the mooring.

- An ocean section between Oban, Rockall and Iceland (the "extended Ellett Line") has been sampled annually by NOC and the Scottish Association for Marine Science (SAMS) with NERC support since the 1990s, with carbonate chemistry data since 2008 (http://www.noc.soton.ac.uk/obe/PROJECTS/EEL/index.php).
- Underway sampling from NERC research vessels. pCO2 systems were installed in 2007 on three NERC research ships (RRS *Discovery*, *James Cook* and *James Clark Ross*) and two inshore vessels (RV *Prince Madog* and *Plymouth Quest*) as part of the CarbonOps project (www.bodc.ac.uk/carbon-ops). Data are collected most regularly on the annual Atlantic Meridional Transect (AMT) surveys.
- UKOA research activities. Experimental studies to determine biological and biogeochemical impacts of ocean acidification have been carried out on four UKOA research cruises (2011–2013): around the UK, at cold-water coral sites off northwest Scotland, in the Arctic, and in the Southern Ocean. Such work is complemented by laboratory studies on a wide range of pelagic and benthic organisms (with focus on long-term responses and temperature interactions); modelling of carbonate chemistry changes in European shelf seas, in the Arctic, and at the global scale; palaeo-studies of past ecosystem responses to large pH changes; and collaborative work with European partners at CO_2 vent sites in the Mediterranean. Over 120 researchers at 26 laboratories are involved in UKOA; for details, see www.oceanacidification.org.uk.

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

2.8 Monitoring in US waters

Given the social and economic importance of living marine resources on the Northeast US continental shelf, the potential large-scale and long-term impacts of OA are being evaluated. The existing global carbon observatory network of repeated hydrographic surveys, time-series stations and ship-based underway surface observation in the open ocean provides a foundation of carbon chemistry observation. During the Marine Resources Monitoring Assessment and Prediction Program (MARMAP, 1977–1987), some pH and alkalinity measurements were made as part of primary productivity studies. Preliminary analysis of MARMAP data (1977–1987; Figure 6) shows spatial variability of pH and total alkalinity, which indicates that measurements are needed over the entire ecosystem to assess the potential effect of ocean acidification on resource species.

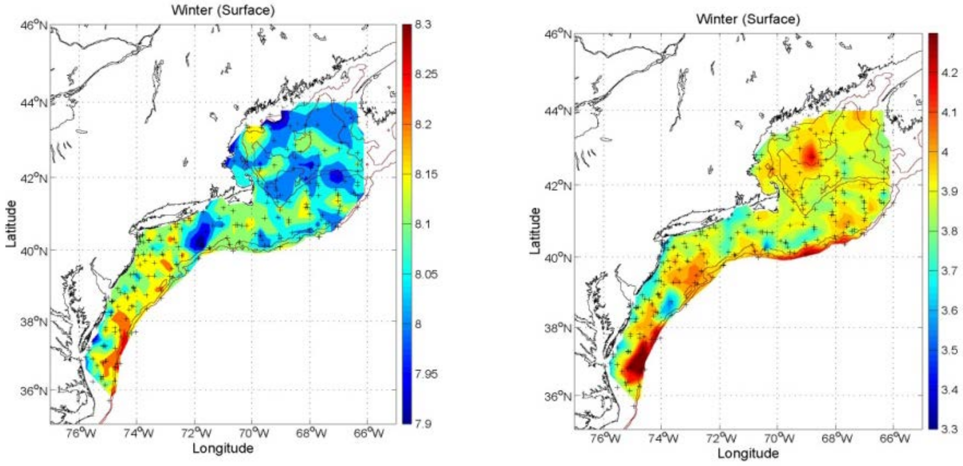

Figure 6. Winter climatology of surface layer pH (left) and total alkalinity (right) derived from MARMAP samples (1976–1984).

New observations will need to be made both at the surface and through the water column, since most marine species are not found at the surface and there is extensive stratification in different parts of the systems at different times of year. Within the Northeast, repeated hydrographic cruises are starting to assemble a database of ocean acidification information. National Oceanic and Atmospheric Administration (NOAA)/Atlantic Oceanographic and Meteorological Laboratory (AOML) researchers are measuring pCO_2 from vessels in the NEFSC Ship of Opportunity Program (SOOP) providing broad temporal and spatial scale monitoring of the variability of ocean carbon chemistry and the observational basis for developing predictive models for future changes in OA and its consequences for marine ecosystems networks. Currently pCO_2 sampling (surface water and air) takes place monthly on transects conducted on merchant vessels Reykjafoss (in collaboration with AOML/(Oceanic and Atmospheric Research (OAR)) and Oleander (operated by Bermuda Biological Station) as part of the Ship of Opportunity Program (SOOP). Reykjafoss sails between Boston and Iceland and the Oleander sails between New Jersey and Hamilton, Bermuda. Four shelf-wide surveys for pCO2 (surface and air) are made on the NOAA Ship Bigelow in collaboration with AOML OAR Water samples were collected on CLIVEC/ ECOMON (Climate Variability on the East Coast/ Ecosystem Monitoring Program) cruises working with NASA (National Aeronautic and Space Administration) and ODU (Old Dominion University) from 2009–2012 and continue to be collected on seasonal ECOMON cruises in collaboration with AOML OAR.

The University of New Hampshire has been measuring pCO_2 in the Gulf of Maine since 2004 as part of their Coastal Ocean Observing Centers Coastal Carbon group (Hunt *et al*., 2011; Vandemark *et al*., 2011). The Gulf of Maine CO_2 dynamics are dominated by a seasonal cycle, with a large spring influx of CO_2 and a fall-to-winter efflux back to the atmosphere. The average annual flux is in near balance and is a net source of carbon to the atmosphere over five years, with a value of +0.38 mol m $^{-2}$ yr $^{-1}$ (Vandermark *et al*., 2011). The Ocean Margins Program (OMP) measured pCO_2 from 1994–2000 and quantified annual air-sea CO_2 flux on the Middle Atlantic Bight (MAB). These calculations indicate that the MAB is a net annual sink for atmospheric CO_2 with the inner, mid and out-shelf regions taking up ~0.1, 0.7, and 0.2 Mt C yr^{-1}, respectively, for a net uptake of ~1± 0.6 Mt C yr^{-1}. The annual cycle of heating and cooling combined with high winds during the period of undersaturation (winter) appear to account for a significant portion of the uptake (DeGrandpre, *et al*., 2002). The multi-scale Pioneer Array planned by WHOI (Woods Hole Oceanographic Institute) in the shelf break of the Middle-Atlantic Bight south of Cape Cod, Massachusetts will provide a more detailed, three-dimensional view of key biophysical interactions. The Pioneer Array will contain: ten moorings distributed among seven sites; three Autonomous Underwater Vehicles and six gliders. At sea equipment tests and seabed mapping was completed in spring 2012. The region of the continental shelf where the Pioneer Array will be deployed is characterized by sharp gradients in ocean temperature and other properties across the shelf, currents that flow along the shelf, and strong biological productivity. The data collected from the Pioneer Array will be freely available to all, including researchers seeking to improve understanding of the region.

The goal is to provide a comprehensive view of the spatial and temporal variability and long-term trends in dissolved CO_2 in the ecosystem and to use this information to guide field sampling and in the assessments evaluating the effect of ocean acidification on marine resources in the ecosystem. The long-term monitoring data can then be coupled with forecast models to provide assessments of the effect of ocean acidification on marine resources. The monitoring data can also be used to direct fieldwork and to provide a framework for the studies of the effect of ocean acidification on primary productivity and the dynamics of resource species.

Information provided by Beth Phelan.

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)

Jan Rene Larsen of the **Arctic Monitoring and Assessment Programme (AMAP)** Secretariat presented an outline of an Arctic OA Assessment (2010–2013) that AMAP are about to publish. This assessment has covered: carbonate chemistry, sedimentary processes, sub-sea vents, historical OA events, biological global response of organisms, impacts on foodwebs, taxon-specific responses, impact on calcifying organisms and economic impacts. The report will be made available to SGOA once it has been published.

Patrizia Ziveri, coordinator of the **Mediterranean Sea Acidification in a changing climate (MedSeA)** European FP7 project, presented an overview of MedSeA activities. This project started in 2011 and is the first concerted effort to study ocean acidification in the Mediterranean Sea, a highly populated region with complex and diverse physiochemistry and biology.

MedSeA is assessing the chemical, climatic, ecological, biological, and economical changes of the Mediterranean Sea driven by increases in CO_2 and other greenhouse gases. The emphasis is on the combined impacts of ocean acidification and warming on endemic calcifying species and related biogeochemical processes, in order to detect changes in calcification, fitness, productivity, biodiversity and foodweb functioning. The approach is fully interdisciplinary, involving biologists, earth scientists, numerical modellers, and economists, using field observations, laboratory and mesocosm experiments, and models. MedSeA consists of 22 partner institutions (including five associated partners) from 12 countries, mainly from the Mediterranean. The project focuses mainly on the following themes: I. Past and present carbonate system dynamics, II. Pelagic and benthic community responses to ocean acidification and global warming, III. Modelling projected acidification and warming, and their impacts on ecology, IV. Socio-economic effects of ocean acidification and potential adaptation strategies and policy tools. In each theme, MedSeA's work programme consists of three phases: 1. Examination and reinterpretation of existing data from the Mediterranean Sea, 2. Obtaining new observational and experimental data and 3. Projecting future changes and related uncertainties.

An interesting point discussed at the meeting was the generation of new data and in particular new observations from monitoring sites located in the western and eastern Mediterranean basins. Since carbonate system data in the Mediterranean Sea are relatively scarce, project members are performing new field measurements of the carbonate system variables, both in the Western and Eastern basins. Time-series measurements of the present-day carbonate system are needed to understand the temporal variations of the carbonate properties in the Mediterranean Sea. These new data (from both cruises and time-series stations) will complement existing datasets and provide a solid basis for understanding the temporal evolution of the penetration of anthropogenic carbon into the Mediterranean Sea. Datasets from survey cruises provide the necessary links to the time-series stations and facilitate the construction of spatial gradients, thus allowing insights on the penetration of anthropogenic carbon into the various Mediterranean water masses.

SGOA noted that the EU-funded **European Project on Ocean Acidification (EPOCA; www.epoca.project.eu)** ended in June 2012. There is no direct follow-up, although ocean acidification research is expected to be supported within a multiple marine stressors programme, with proposals currently under review.

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 based on an initial draft of OSPAR MIME working group. A subgroup of SGOA critically reviewed the existing document and made some updates to it. The revised guideline is appended as Annex 5 of this report.

SGOA recommends that the Monitoring Guidelines for Chemical Aspects of Ocean Acidification as in Annex 5 should be adopted by OSPAR as a part of the Joint Assessment and Monitoring Programme (JAMP) guidelines.

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

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

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

Because of the rapid developments in this field, and complexity of the interactions of OA with other factors, it would be a major undertaking for this Study Group to undertake a comprehensive and up-to-date literature review and synthesis of all potentially relevant direct and indirect effects of OA on marine organisms. Furthermore, there are a number of summary reports on OA impacts by reputable bodies and organizations that are in progress, planned or have recently been completed, and that together provide a relatively thorough overview of the current state of knowledge in this area. These include:

- the Arctic Ocean Acidification Assessment, by the Arctic Council's Arctic Monitoring and Assessment Programme; report currently under review for publication in April 2013;
- Working Group 2 (Chapters 5, 6, 19 and 30) of the 5th Assessment of the Intergovernmental Panel on Climate Change (IPCC), for publication in 2014;
- A new synthesis of OA impacts on marine and coastal organisms and systems to be carried out by the Convention on Biological Diversity (CBD; Decision X1/18 paragraphs 22–24 of 2012 Conference on Parties) for completion by spring 2014;
- An in-preparation report from the 2nd International Workshop on Ocean Acidification Impacts on Fisheries, Aquaculture, Economics and Industry held in Monaco, Nov 11–13, 2012, which examined impacts by FAO fishing areas;
- The Washington State Blue Ribbon Panel Report on Ocean Acidification (Adelsman and Whitely Binder, 2012), which focuses on impacts on mariculture and fisheries in the NE Pacific.

An action arising from discussion of this agenda item at the first SGOA meeting is that the group will prepare a summary of the findings of these and other relevant reports and peer-reviewed papers.

Table I. Summary of likely main effects of future ocean acidification on different groups of marine organisms likely present in the OSPAR region. This information is mostly from laboratory experiments, while also taking account of the 'natural experiments' of CO_2 vents and evidence from palaeo- OA events. Based on Williamson and Turley (2012) that gives ~50 references relating to this table.

GROUP	MAIN ACIDIFICATION IMPACTS
Cold-water corals	Cold-water corals provide habitat structure at the shelf edge, and hence have high conservation value. Their long-lived nature and their proximity to aragonite saturation horizons, makes them vulnerable to future shoaling of the aragonite saturation horizon (ASH). Around 70% of known cold-water coral locations are estimated to be in undersaturated waters by the end of this century, under current CO_2 emission trends. Experiments found the effect of pH change on calcification was stronger for fast growing, young polyps. Synergistic effects of OA and temperature have been reported.
Molluscs	Significant effects on growth, immune response and larval survival of some bivalves, although with high interspecific variability. Shelled pteropods (pelagic sea snails) seem particularly sensitive and are a key component of high latitude foodwebs. Molluscs are important in aquaculture, with locally high economic significance; in many parts of the world they provide a small yet significant protein contribution to the human diet.
Echinoderms	Juvenile life stages, egg fertilization and early development can be highly vulnerable, resulting in much reduced survival. Adult echinoderms may increase growth and calcification; such responses are, however, highly species-specific.
Crustaceans	The relative insensitivity of crustaceans to ocean acidification has been ascribed to well-developed ion transport regulation and high protein content of their exoskeletons. Nevertheless, spider crabs show a narrowing of their range of thermal tolerance by ~2°C under high CO_2 conditions.
Foraminifera	Shell weight sensitive to CO_3^{2-} decrease in the laboratory with field evidence of recent shell-thinning.
Fish	Adult marine fish are generally tolerant of high CO_2 conditions. Responses by juveniles and larvae include diminished olfactory and auditory ability, affecting predator detection and homing ability in coral reef fish, reduced aerobic scope and enhanced otolith growth in sea bass.
Coralline algae	Metaanalysis showed significant reductions in photosynthesis and growth due to ocean acidification treatments. Elevated temperatures (+3°C) may greatly increase negative impacts. Field data at natural CO_2 vents show sensitivity of epibiont coralline algae.
Non-calcified macroalgae; seagrasses	Both groups show capability for increased growth. At a natural CO_2 enrichment site, seagrass production was highest at mean pH of 7.6.
Coccolithophores	Most studies have shown reduced calcification in higher CO_2 seawater. However, the opposite effect has also been reported, and ocean acidification impacts on coccolithophore photosynthesis and growth are equivocal, even within the same species. This variability may be due to the use of different strains, experimental conditions and species-specific sensitivities to different carbonate chemistry parameters.
Bacteria	Most cyanobacteria (including *Trichodesmium*, a nitrogen-fixer) show enhanced photosynthesis and growth under increased CO_2 and decreased pH conditions. Heterotrophic bacteria investigated to date show many responses with potential biogeochemical significance, including decreased nitrification and increased production of transparent exopolymer particles (affecting aggregation of other biogenic material and its sinking rate). Adaptation to a high CO_2 world is likely to be more rapid by bacteria and other short-generation microbes than by multicellular organisms.

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 and scene setting

As an introduction and to provide background to SGOA, presentations were given covering,

- The OSPAR monitoring and assessment approach:
  - OSPAR's Joint Assessment and Monitoring Programme [JAMP] and the OSPAR Eutrophication Monitoring and Assessment Procedure (Evin McGovern);
  - OSPAR's Coordinated Environmental Monitoring Programme-(CEMP) and Hazardous Substances monitoring assessment (Martin Larsen).
- The developing Global OA Observation Network (Phil Williamson).

SGOA held discussions around each of these presentations.

6.2 OSPAR monitoring

OA, along with marine climate change, falls within the "general" theme as part of the OSPAR JAMP but there are potential synergies with current monitoring and assessment activities undertaken under OSPAR thematic strategies, namely Eutrophication, Hazardous Substances, and Biodiversity and Ecosystems. Gert Verreet, OSPAR Deputy Secretary, also reported the outcome of discussions on OA at the November meeting of the OSPAR Coordination Group (CoG). CoG indicated that SGOA should consider *the question on how vulnerability (and the need for its evaluation as underpinning further policy steps) and possible adaptation measure information needs would affect the monitoring and assessment strategy for ocean acidification*. In principal the group agree that reviewing data and identifying potential problem or vulnerable areas is a sensible approach. However, SGOA did not feel separate assessments by individual countries were advisable: the preferred route would be through a joint assessment.

Since long-term changes in OA are primarily driven by global scale changes in atmospheric chemistry, the SGOA recommends that any OSPAR regional assessment is aligned to global initiatives.

6.3 Global OA observation network

In June 2012, a workshop was held at Seattle to develop a global OA observation network, including ecosystem responses. The workshop was attended by 62 scientists from 23 countries (www.pmel.noaa.gov/co2/OA2012Workshop); its sponsors included the US National Oceanic and Atmospheric Administration (NOAA), the International Ocean Carbon Coordination Project (IOCCP) and the Global Ocean Observing System (GOOS). The workshop aims were to:

- Provide the rationale and design of components and locations for an international observing network that includes repeat hydrographic surveys, underway measurements on volunteer observing ships (VOS), moorings, floats and gliders, taking into account existing activities;

- Identify a minimum suite of measurement parameters and performance metrics for each major component of the observing system;
- Develop a strategy for data quality assurance and data distribution;
- Discuss requirements for international programme integration.

The Seattle workshop identified the following three goals, closely aligned to those recommended by ICES to OSPAR (ICES Advice 2010):

1) Understanding global OA conditions; Identify spatial/temporal patterns and assess response, quantify rate of change;

2) Understanding ecosystem response to OA; measure biological response, quantify rate of change and identify areas of vulnerability;

3) Input data to optimize OA modelling; provide spatially and temporally resolved data for modelling.

At the workshop, a tiered approach to required measurements was agreed (Figure 7), with three levels. Measurement specifications would differ between the different levels and goals, and between three main habitat groupings: the open ocean, coastal areas and shelf seas, and coral reefs:

- *Level 1*: critical minimum measurements;
- *Level 2:* measurements for integrated assessment to enhance interpretation;
- *Level 3*: measurements that are not yet fully ready for standardization; in development/evaluation.

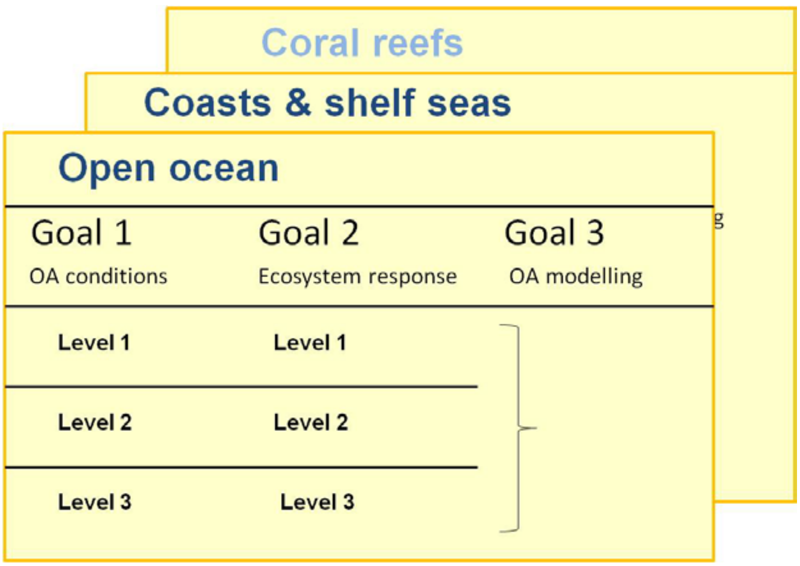

Figure 7. Schematic showing the nested tiered approach to monitoring proposed at the workshop on Global OA Observation Network in Seattle in 2012.

The Seattle workshop also considered a binary data quality classification, depending on assessment of accuracy and precision of OA measurements. The two classes were denoted "climate" and "weather", defined as follows:

- ***Climate data*** are of sufficient and defined quality to assess long-term trends with defined level of confidence. Hence the detection of long-term, anthropogenically driven changes in state and carbonate chemistry over multidecadal time-scales;
- ***Weather data*** are of sufficient and defined quality to identify relative spatial patterns and short-term variation and for work on mechanistic interpretation of the ecosystem response to, and impact on, local, short-term (intra-annual) OA dynamics.

For Goal 1, (understanding global OA conditions), research cruises and VOS will provide 'climate data' and validate 'weather' data. Moorings/fixed platforms will yield high temporal resolution 'weather data', useful for elucidating mechanisms, and putting proximal climate data into the context of the intra-annual cycle. Gliders and instrumented floats will potentially yield high spatial resolution 'weather data', useful for assessing vertical variation (shoaling of saturation horizons) and elucidating physical related mechanisms; data that cannot be gathered in any other way.

For Goal 2 (understanding ecosystem response to OA) research cruises or intensive shore-based studies are currently needed for nearly all data, except phytoplankton (fluorescence and PAR) because of the wide range of parameters that need to be measured.

SGOA concurred that, with some adjustment for OSPAR areas, this basic conceptual model provided an excellent template to develop a monitoring programme for the OSPAR region. A full report from the Seattle workshop is expected to be available in early 2013, and there are plans for a 2nd workshop to be held (in Europe) in 2013. SGOA agreed that the design was a good basis for its own work, and that we should therefore try to align and build from the global initiative. Phil Williamson has agreed to act as a liaison between the two groups, with additional contacts to be developed through NOAA, GOOS, IOCCP and other interested parties.

6.4 Quality assurance and quality control (QA/QC)

Currently there are no intercomparison QA schemes or QA/QC standards for biological aspects of OA work. This situation is likely to remain unchanged until specific indicator tools have been developed. SGOA acknowledge that the chemical aspects of OA monitoring are at a more advanced stage of development.

To assess accuracy of measurements, reference materials (RM) are available for DIC and TA analysis. The carbonate analysis community have set up a reference material supply service provided by Andrew Dickson's laboratory at the Scripps Institute of Oceanography (University of California). These reference materials consist of natural seawater sterilized by a combination of filtration, ultraviolet radiation and addition of mercuric chloride. The RM is only available at one salinity and may not be applicable to all areas. SGOA echoes the views by MCWG that there is concern about the available capacity to produce sufficient quantities of reference material to support the needs of an expanding monitoring community and all efforts to increase this capacity should be supported. This may be taken forward by the International Carbon Observing System–Ocean Thematic Centre (ICOS-OTC).

Andrew Dickson's group are currently developing two reference materials ($p\mathrm{CO_2}$ 400–500 and 1200–1500) which will be available in 2013 for use in an intercalibration exercise. However, for long-term monitoring work the SGOA recognize there is a need for a proficiency-testing scheme for carbonate parameters, similar to that offered by QUASIMEME.

SGOA noted the initial discussions held between ICES MCWG and QUASIMEME in 2012. SGOA recommend that QUASIMEME should be encouraged to develop a proficiency-testing scheme for TA and DIC.

Discrete samples collected for DIC for later analysis are preserved (poisoned) using mercuric chloride. In some countries use of mercuric chloride has been severely restricted and even acquiring it is proving problematic. These constraints seem likely to be adopted in other countries. Since no suitable alternative biocide has been identified, this presents a significant problem for the carbonate monitoring programme. Efforts are needed to identify and test suitable alternative preservation techniques to avoid the current sampling programmes being undermined.

Additional recommendations for QA/QC are provided in Section 8 of Annex 5: Draft Monitoring Guidelines for Chemical Aspects of Ocean Acidification.

6.5 An OSPAR monitoring and assessment framework

The group agreed to put together a high level document of 3–4 pages setting out a Monitoring and Assessment Framework that can be presented to OSPAR Contracting Parties as a basis for an Agreement on a harmonized OSPAR monitoring strategy ("Common Procedure"). A draft document should be ready for next year's meeting, in order to ensure that final document will be presented to OSPAR within the lifetime of this group, which is expected to be three years. Evin McGovern will prepare an Outline for this document and circulate to the group in early 2013.

The document must take into account recommendations from the Global OA community as will be expressed in the report from the June meeting in Seattle. OSPAR region monitoring should form a component of the global network.

The document should address issues related to the monitoring strategy, which should enable comprehensive assessment of the effects of OA on ocean chemistry as well as biological effects and consequences for ecosystems. While the required data for assessing changes to the carbonate system are known, those for the latter are much more obscure with indicators less well developed (see Section 7, below). In addition to ecological and socio-economic perspectives the design of a monitoring system for biological responses to OA should be led by consideration of potentially vulnerable species or specific effects, which may act as early warning indicators. The group further noted that the existing concept of OSPAR assessment criteria as currently applied in the CEMP do not appear immediately transferable to OA due to the long-term and global nature of this issue. The monitoring and assessment framework needs to pay special attention to this. A primary focus should be on temporal trend assessment and a requirement for assessment criteria should not be a barrier to initiating harmonized OSPAR monitoring. It would be beneficial if the system was closely integrated with the system monitoring ocean CO_2 fluxes, which is to be implemented at a European level through the Integrated Carbon Observing System.

The group noted that while OA is a fairly slow process, evolving on decadal timescales, the existing observation networks, however, are funded only for a few years at a time. Important existing programmes are near the end of their lifetime, and it is important that we keep up momentum and justify long-term efforts so that the present activities do not come to a stop. Lack of specific biological indicators should not halt development of monitoring activities; on the contrary, monitoring should be as broad as possible, in order to maximize chances for detecting response. The framework should therefore be sufficiently flexible to allow new indicators to be added as they mature to strengthen the integrated chemical–biological effects approach over time.

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

There are two challenges associated with developing biological indicators for the OSPAR marine area. The first challenge is that this area encompasses a large latitudinal range (36°N to 90°N) within which there are large temperature gradients (mean annual sea surface temperatures 20°C to -2°C; Figure 8). This broad temperature range means that no single species is sufficiently ubiquitous to be suitable as an indicator throughout the OSPAR area. This issue is not unique to OA, but the problem is greater since OA is caused by a global driver, the rise of atmospheric CO_2, that affects the whole OSPAR marine area. An example of the differences in the distributions of two species of pteropods from the genus *Limacina* (Figure 9) illustrates the importance of identifying regionally abundant indicator species.

Furthermore, the effects of OA are expected to be relatively long term, mostly on decadal to century time-scales, hence superimposed on climate change, together with other future pressures and perturbations. In particular, the distributional patterns of marine species and communities are expected to shift markedly in response to a projected global temperature change of >2°C, and a high latitude temperature change of ~8°C (based on unmitigated emission trends; IPCC, 2007). Indeed, northward movements of hundreds to thousands of kilometres have already been reported for fish and plankton respectively (Perry *et al.*, 2005; Beaugrand *et al.*, 2002). Thus particular indicator species, if they can be identified, may not even be applicable to the full latitudinal range of an OSPAR subregion on a decadal time-scale.

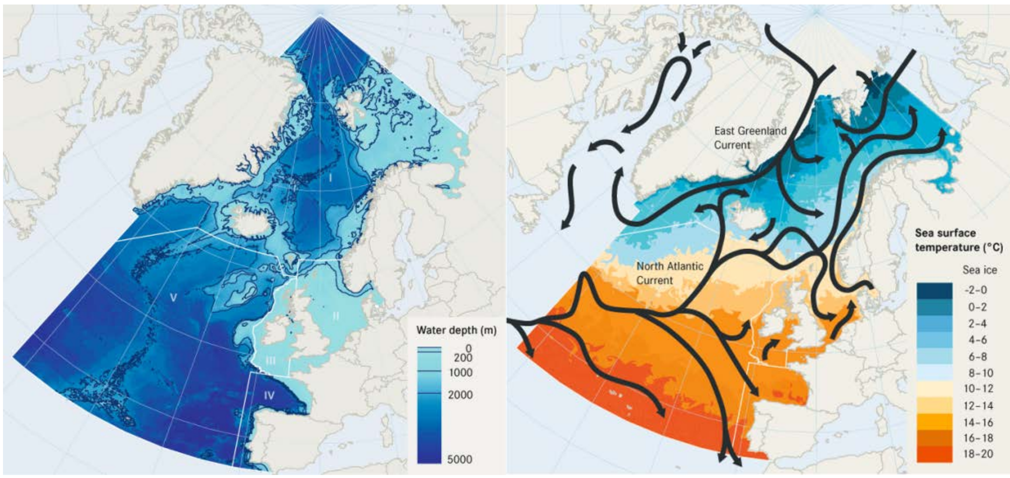

Figure 8. Left: the locations of the OSPAR area with subregions I–V. Right: mean annual sea surface temperatures (and main near-surface currents) within the OSPAR area. Maps from OSPAR.

The second challenge is even more fundamental, relating to uncertainty of the appropriateness of the concept of indicator species for the detection of OA impacts. Such an approach undoubtedly has merit in focusing biological monitoring effort where species X is known to be particularly sensitive to pollutant Y (or bioaccumulates that pollutant), hence complementing–or providing a more cost-effective alternative to–chemical monitoring effort, particularly for the detection of local, acute impacts. But we are not yet at an equivalent stage of understanding of the specificity of OA impacts, with its biological consequences being much less certain than its chemical consequences (Gattuso *et al*., 2012).

While some species will undoubtedly be affected more than others, the most sensitive and vulnerable components of the marine biota may not yet have been identified; and hence missed by an indicator-based biological monitoring programme. Under such circumstances, there is a strong rationale for linking chemical OA monitoring as closely as possible with a broad suite of measurements of biodiversity and ecosystem health, with that data collected for other purposes and hence also serving other functions.

Nevertheless, some candidate indicator species and groups to detect OA impacts have been provisionally identified by the Study Group (Table II). Their appropriateness for this purpose will be discussed with scientists who are familiar with these particular taxa. A thorough understanding of the seasonal and spatial (horizontal and vertical) distribution patterns of each selected taxon will be required to ensure that appropriate sampling methodologies can be applied, and valid interpretations of observed future changes in abundances or physiological processes (e.g. growth rates, calcification) can be made. This underscores the importance of existing time-series that have records of the phenology, population dynamics and other attributes of potential indicator species within their sampling domain(s). Their data will provide a long-term context within which changes in distribution, abundance and physiological condition, potentially associated with OA, may be interpreted.

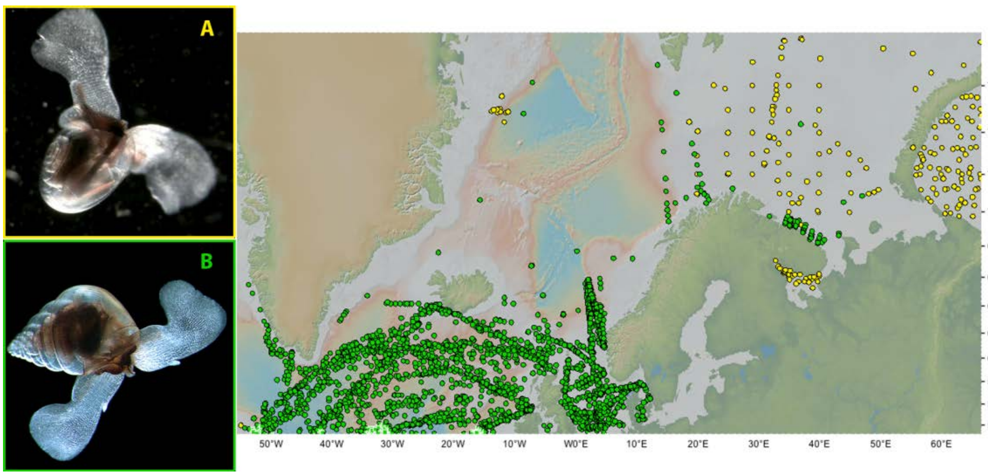

Figure 9. The distribution patterns of two species of the cosomate pteropods belonging to the genus *Limacina*. A: *Limacina helicina* (yellow points). B: *L. retroversa* (green points). Distribution data from the Ocean Biogeographical Information System (OBIS). Images of pteropods from Russ Hopcroft, University of Alaska; Fairbanks/NOAA.

When considering potential indicator organisms, it is important to bear in mind that changes in abundance *per se* would not provide unambiguous evidence of a response to OA. Most planktonic and benthic organisms (with the exception of long-lived and sessile cold-water corals), have high temporal and spatial variances in abundance, influenced by a wide range of physico-chemical and biological factors, and attribution of drivers responsible for long-term trends is not straightforward, even for relatively well-studied groups. Thus any signal due to OA (that may be relatively modest on a decadal time-scale, although likely to affect large areas) must be detected against this high natural variance.

Statistically significant correlations (both positive and negative) between the abundance of calcifying plankton and pH/pCO_2 have already been reported for the Northeast Atlantic, based on Continuous Plankton Recorder data. However, such correlations are not thought to represent causal relationships (McQuatters-Gollop *et al.*, 2010; Beaugrand *et al.*, 2012).

The above discussion strongly implies that the development of simple, abundance-based traffic-light indicators (e.g. healthy/non problem; of concern/potential problem; threatened/problem; as used elsewhere in OSPAR Coordinated Environmental Monitoring Programmes) is probably impracticable for OA impact detection. Instead, very careful, statistically sound examination of temporal trends in abundance in concert with other biological and physico-chemical data, including analysis of spatially and temporally contiguous carbonate chemistry measurements, will be needed to provide robust, defensible evidence for the future impacts of OA.

If biological OA monitoring effort is to be focused on a relatively narrow range of indicator organisms, clear protocols for collection of unbiased quantitative samples, sample processing and preservation, and measurement metrics will need to be developed for those species. Since ship-based OA chemical monitoring (e.g. via hydrographic or fish stock assessment research cruises, or by Voluntary Observing Ships) may only allow limited additional biological sampling, it is essential that sampling errors are minimized. Thus sound protocols need to be in place so that personnel, who may be less familiar with the collection of biological data, are able to perform collections, processing and preservation correctly. It may not be possible or permissible to collect physical samples of all indicator taxa; for example, special conservation measures may apply in some national/international waters for cold-water corals (e.g. *Lophelia;* distribution shown in Figure 10), hence monitoring (via time-series) of such species/habitats would need to be photographically based. Additionally, careful collection of tissue samples and boron isotopic analysis (e.g. McCulloch *et al.*, 2012) may yield records of historical pH at depth.

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	Candidate species	Quantitative basis for use as indicator?	Issues/comments
Cold-water corals	*Lophelia pertusa*	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
Pteropods (planktonic sea snails)	*Limacina* spp and other shelled pteropods	Abundance (taking account of other factors) 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)
Echinoderms (particularly some brittlestar species)	*Ophiothrix fragilis*	Abundance (taking account of other factors) 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*	Growth rate (using annual rings and changes in boron isotope composition)?	Technique not yet well-developed; sensitivity to OA uncertain
Coccolithophorids	*Braarudosphaera* Spp	Abundance (taking account of other factors) Calcification	High variability of responses of *Emiliania huxleyii* probably makes it unsuitable as an indicator; however, suitability of other species warrants further study
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 Calcification [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

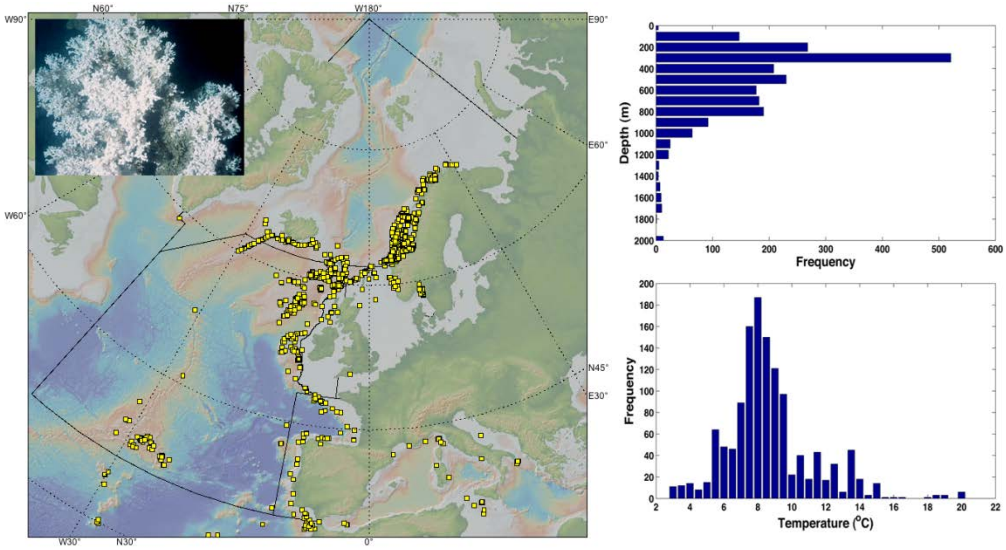

Figure 10. Observation locations of the cold-water coral *Lophelia pertusa* obtained from the Ocean Biogeographic Information System (OBIS). Data have not been screened for QC flags. The inset panels show histograms summarizing the depth distribution and temperature envelope associated with a subset of the mapped observations. By overlaying gridded pH or aragonite saturation (Ω) (e.g. from model-based maps; Artioli *et al.*, 2012) on the distribution data, it may be possible to identify regions of interest for more detailed monitoring.

As noted above, the interpretation of OA impacts and identification of appropriate indicator organisms may be confounded by climate change effects. Such effects are likely to include changes in water salinity (due to melting of ice and potentially changes in precipitation patterns), seasonal stratification and circulation/mixing (over a range of scales) as well as increased water temperature; with associated chemical consequences; e.g. reduced solubilities of CO_2 and carbonate. All these changes may influence the distribution, abundance and phenology of planktonic and benthic organisms. Such shifts have already been documented for zooplankton in the California Current (e.g. Roemmich and McGowan, 1995) and for phytoplankton, zooplankton and fish in the Northeast Atlantic (e.g. Beaugrand *et al.*, 2002; Perry *et al.*, 2005).

In general, warm-water phytoplankton and zooplankton taxa are smaller and less nutritious than their cold-water counterparts (Kattner and Hagen, 2009). Thus temperature-driven alterations in species composition of planktonic assemblages may have impacts on food quality (and hence body condition, growth and reproductive output) of higher trophic levels, even if total biomass of their prey species is unchanged. Such effects may either over-ride or interact with OA impacts, noting that these may be reduced or non-existent under conditions of high food availability (Thomsen *et al.*, 2012). Clearly, temperature effects must be carefully considered in the context of interpreting changes in community structure and function as a possible response to OA. Altered temperature and salinity may also affect metabolic rates, metabolic scope, and a myriad of other factors.

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; current dataflows

Current OA-relevant monitoring data are reported to a variety of data centres and incorporated in a range of data products making for a complex picture. Key repositories of global carbon data include PANGAEA and Carbon Dioxide Information Analysis Center (CDIAC). Data products include SOCAT (surface pCO_2 atlas) and GLODAP and these are discussed in more detail in Annex 6.

It is planned that European marine CO_2 (and other Greenhouse Gas) flux data will in the near future begin to be coordinated by the Integrated Carbon Observing System-Ocean Thematic Centre [ICOS-OTC is a European Scientific Infrastructure Project. http://www.icos-infrastructure.eu/home]. The ICOS-OTC will have its own data centre hosted by the University of Bergen.

8.2 Reporting OA data to ICES

The ICES-DataCentre (ICES-DC) is the primary repository of marine monitoring data for OSPAR and OSPAR rules require that Contracting Parties, (CPs), report their CEMP data to ICES (OA chemical parameters are currently voluntary parameters in the CEMP). Hans Mose Jensen of the ICES-DC gave a presentation to SGOA on data flows to the ICES-DC and outlined how chemical oceanography data could be reported to the ICES environmental database (ERF 3.2 format) or oceanographic database (IOF free format using BODC codes). An analysis of carbonate system data in the databases showed a substantial pH dataset but with little associated QA information and mostly relating to electrode determinations.

The requirements set out in an OSPAR OA monitoring programme and expected assessments outputs, which are currently in an early stage of development, will determine CPs reporting requirements to ICES. In discussions with ICES it was noted that monitoring data will be made available from various providers, including statutory monitoring laboratories, research institutes and university groups, in some instances through national data centres. In many instances the carbon dataset may be associated with hydrographic or environmental surveys so it is preferred to report them alongside these data. Moreover each ICES format has particular advantages, for example the oceanographic format is more suitable for (semi-)continuous data, such as from pCO_2 sensors, although the environmental database may have greater flexibility for retrieving and assessing discrete sample data. Consequently there is a need for defining reporting protocols for both routes of data entry to ICES.

An initial step would be to define the ERF 3.2 reporting codes for CPs reporting discrete sample data. OSPAR MIME 2011 carried out an initial review of ICES ERF 3.2 database codes relevant to carbonate parameters in the CEMP (Appendix 16 of the OSPAR CEMP Agreement 2010-1, as amended in 2012). These were not reviewed in detail at SGOA and it is suggested that this could be progressed at MCWG 2013 with a view to further defining the ERF3.2 reporting requirements.

8.2.1 Challenges for data reporting and integration

Given the multiplicity of data streams and repositories for ocean carbon data, in some cases dictated by the fact that data are reported as part of many different types of dataset (e.g. along with atmospheric data or ocean ecosystem data), it is important that various data centres have the facility to exchange relevant data. The ICES Cooperative Research Report on monitoring chemical aspects of Ocean Acidification (Hydes *et al*., 2013) recommends the attachment of an extensive meta-dataset reporting on methodology and analytical quality in line with the GO-SHIP Manual (Hydes *et al*., 2010) and CDIAC reporting formats. These metadata are at a level of detail not currently stored in either the ICES IOF or ERF3.2 formats. It is, however, possible in the ICES system to store a link to the metadata document in the ERF3.2 data, or require more information in the Cruise Summary Reports. If OSPAR data were to be gathered at ICES and submitted to other international organizations, a metadata form based on the CDIAC/GLODAP/Go-Ship manual, should be mandatory.

Consideration needs to be given as to how data from an expanding range of platforms can be accommodated. An example of such a problem is that currently in the UK BODC is unable to accept the "large" quantities of data produced by the Cefas data buoys. The major platform delivering data on ocean CO_2 fluxes are systems based on commercial ships which produce continuous data records when the ships are underway; these usually work on fixed routes. Research ships are also being fitted with continuous recording systems that will produce "random walk" data. BODC worked with Plymouth Marine Laboratory to set up a semi-automated system to harvest such datasets in real time by satellite communications. Data platforms such as data buoys and gliders are likely to play an increasing role in OA and CO_2 flux observations in the near future.

At present the quantities of CO_2 system surface and water column data that are produced are sufficiently "small" that they can be processed in efforts such a GLODAP where effort has been put into seeking out metadata.

SGOA should work to define data streams that will be involved, platforms, quantities of data and how quality control of the data will be carried out and the most appropriate ways of providing quantitative information on data quality. SGOA considered that core databases should include measured carbonate system parameters and not derived/calculated data (e.g. pH calculated from DIC and TA). To ensure harmonized approaches such derived parameters should be calculated at the assessment or data product synthesis stage.

A number of points require further discussion between the SGOA and the ICES DataCentre. The way forward will be e-mail exchanges leading to the production of preliminary plan during the ICES-MCWG meeting in March 2013 which will be held at ICES-HQ.

The following points require further discussion between SGOA and the ICES Data-Centre:

- Identify the OA data in the OSPAR area that should be visible via the ICES data system;
- Determine what extent of data exchange/harvesting with other OA data repositories (e.g. CDIAC) is desirable and achievable;
- Define the overall ownership, process and data products that SGOA require.

Within the above context the ICES data team set some questions for SGOA and some initial responses based on discussions at SGOA 2012 are given below. This discussion should be taken forward by SGOA with input from MCWG 2013.

- Will everyone report to CDIAC? Not all OA data are reported to CDIAC. CDIAC contains carbonate system data, including CO_2 flux data as it incorporates data for atmospheric gases. Some projects report data to PANGAEA (See Annex 6). ICES database holds other OSPAR monitoring data and ICES as the facility for storing biological data.
- Would there be any value/possibility in extending the CDIAC reporting if it does not currently cover SGOA needs? CDIAC holds atmospheric and oceanic trace gas data and climate data. However it is not a marine ecosystem database and is unlikely to be suitable for reporting OA impacts monitoring data.
- What format, codings does CDIAC use? For further discussion.
- Will SGOA be adopting/using existing codings/vocabs i.e. BODC, PARAM etc.? Where appropriate this would seem the most practical approach.
- What would be the most appropriate way to report/link to ICES i.e. which format: ERF/IOF, etc.? Initial discussions at SGOA suggest that the option to report in both formats should be available.
- Does SGOA intend to make the data publically available through ICES, or another website? For further discussion.
- What would be the products of an assessment be and would they then be available with the data? For further discussion. See Section 9.

8.3 Next steps and recommendations

1) A detailed plan of action with respect to the range of data streams to be produced by an OSPAR OA monitoring programme is needed. The OA monitoring strategy to be produced should help frame this discussion.
2) Data submission routes from data producers and national data centres to the ICES-DC need to be clarified and hurdles identified. Similarly the relationship of the ICES-DC in the context of global OA programme needs to be agreed.
3) SGOA should establish links with any data initiatives established under the global OA observation network. In the first instance contact should be made with Hernan Garcia (NOAA & US NODC).
4) For work within the OSPAR context, the ICES DataCentre should be seen as the locus of data assembly activities. Discussions with the ICES data managers suggested that the ICES system would require some changes to be fully functional with respect to the assembly of the new data but that the system was sufficiently flexible to accommodate the required changes. The above needs to consider the likely set of parameter codes ICES, BODC and others that might be involved.
5) An appropriate data reporting manual should be produced to help new groups with the reporting of data and access to translation of parameter codes in use with ICES and globally.

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

The terms of reference for SGOA require a first assessment of available data and this is envisaged for year three (2014). Group members spent some time discussing available datasets and how the data could be assimilated to provide assessment of the current status and prediction of future impacts on vulnerable species and ecosystems. It quickly became clear that the group did not have the available funding resources to undertake a full-scale assessment at this time. In addition it was felt that it was only practical to concentrate on an assessment of the currently available chemical data within the OSPAR area with existing resources.

In addition to lack of sufficient funding, it was established that ICES is not currently in a position to easily synthesize data from the various carbonate chemistry data portals. Current data holdings, consisting of separate cruise files, such as those served by the Surface Ocean Carbon dioxide Atlas (SOCAT), Carbon Dioxide Information Analysis Center (CDIAC), Global Ocean Data Analysis Project (GLODAP) and other databases are unsuitable for inclusion in an assessment without significant effort to identify good QC data and discard data without metadata. The size of datasets could be reduced significantly by using gridded data of monthly means if these datasets are recommended as being suitable (see ToR 10c). It was felt that a considerable part of the historic ICES pH data could not be used, as they have few metadata and questionable QC and it may be difficult to identify suitably high quality data.

There is an underlying requirement to identify tasks and levels of effort required to do an initial assessment. Therefore, the group then considered what could realistically be achieved given the above constraints and two potential products were proposed.

1) With reference to data currently available from GLODAP/SOCAT and other sources identified from 10c, to undertake a high-level literature review, this could be used to expand on the initial assessment of the variability of the carbonate system across the OSPAR area published in Section 2 of the "Chemical aspects of ocean acidification monitoring in the ICES Marine area" (Hydes *et al*., in Review).
2) Although the group would like to produce maps of spatial and seasonal variability and trends over the whole OSPAR region, this was not considered practical. Therefore, in year two, the group aim to put together maps for areas with cold-water corals/calcareous algae habitats (e.g. Figure 10) with reference to available data maps of Ω_{arag} and depth. The incorporation of modelling products could then be incorporated to identify future risks to these vulnerable ecosystems. It was noted that maps from GLODAP of carbonate system parameters would not available before early 2014.

An additional recommendation from the group was to concentrate effort on regions where long-term chemical and biological time-series exist and to encourage the focus of additional monitoring in these areas.

9.1 Actions

1) All group members to identify gaps in data before next meeting, once datasets have been identified from 10c;

2) Need to decide on actual data we need for assessment and get it into a database format that we can easily use for future assessments, cf. MIME format;

3) Explore the possibility of securing small project funding to assist with the data synthesis and assessment based on the fact that OA will potentially lead to ecological and thus societal impacts within the OSPAR region. This additional funding is necessary to provide more comprehensive assessments of potential problems.

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11 Identification of Terms of Reference for 2013

The SGOA 2013 Terms of Reference (Annex 3) remain the same for 2012 with the exception of removal of item c) Finalize Guidelines for Measuring the Carbonate System. This item was completed at SGOA 2012.

12 Recommendations and actions

Recommendations from SGOA 2012 are provided in Annex 4.

The following actions items were identified for follow up at SGOA 2013.

Actions	Who	SGOA 2012 Report Section
Contact the chairs of WGMPE, WGOH, WGBEC and WGBE to make them aware of the work of SGOA and invite them to consider if and how they may input to this topic.	Mark Benfield	1
Invite a physical-biogeochemical-ecosystem modeller to join SGOA. Follow up on suggested candidates.	Evin McGovern	1
Contact Luis Valdes to see if a suitable physical oceanographer can be identified to participate in SGOA.	Mark Benfield	1
Provide update of national OA monitoring activities to SGOA 2013.	All SGOA	3
Prepare an outline for an OSPAR Monitoring and Assessment Framework and circulate to the group early 2013 with a view to completing a first draft for SGOA 2013.	Evin McGovern and SGOA	6
Act as a liaison between SGOA and Global Observation Network and circulate relevant information from that forum.	Phil Williamson	6
SGOA to prepare a summary of the findings of a number of current or imminent reports on impacts of OA.	SGOA Mark Benfield/ Phil Williamson to lead	5
Liaise with MCWG and ICES-DC to map OA-relevant data streams and identify reporting requirements and data exchange needs between different data centres.	Evin McGovern, David Hydes, Are Olsen, MCWG and ICES-DC	8
Contact Hernan Garcia (NOAA) to establish links and collaboration with data management initiatives under GOA-ON.	David Hydes, Phil Williamson	8
Critically review MIME2011 ERF 3.2.reporting codes for OA parameters and identify relevant ERF 3.2 reporting codes relevant to OA monitoring and reporting.	MCWG 2013 and ICES-DC	8
Review data available in GLODAP and SOCAT. SGOA members to identify additional OA data (especially in relation to areas of high vulnerability e.g. corals).	Are Olsen and SGOA	9
Identify potential small project funding to support a first assessment. Contact OSPAR and identify other possible sources.	Evin McGovern and SGOA	9

13 Date and venue of the 2013 meeting

It was provisionally agreed that SGOA 2013 would take place on October 7th–10th, 2013 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 Friday 14th December.

Annex 1: List of participants

Name	Address	Phone/Fax	E-mail
Mark Benfield Chair	Louisana State University Department of Oceanography and Coastal Sciences 2179 Energy, Coast & Environment Building Baton Rouge LA 70803 United States		mbenfie@lsu.edu
Melissa Chierici	Institute of Marine Research, Tromsø PO Box 6 9294 Tromsø Norway	Phone +47 77 60 97 54 Fax +47	melissa.chierici@imr.no
Claus Hagebro	ICES H.C. Andersens Blvd. 44–46 1553 Copenhagen V. Denmark	Phone +45 33386754 Fax +45 3393 4215	claus@ices.dk
David J. Hydes	National Oceanography Centre Southampton Waterfront Campus European Way SO14 3ZH Southampton United Kingdom		david.hydes@noc.ac.uk
Hans Mose Jensen	International Council for the Exploration of the Sea H. C. Andersens Boulevard 44–46 1553 Copenhagen V Denmark	Phone +45 Fax +45	hans.jensen@ices.dk
Jan René Larsen Observer	Arctic Monitoring and Assessment Programme Gaustadalléen 21 PO Box 8100 N-0349 Oslo Norway	Phone +45 2361 8177	jan.rene.larsen@amap.no
Evin McGovern Chair	Marine Institute Rinville Oranmore Co. Galway Ireland	Phone +353(0)91387253 Fax +353 (0)91387201	evin.mcgovern@marine.ie

Name	Address	Phone/Fax	E-mail
Shannon Meseck By WebEx	National Oceanic and Atmospheric Administration Aquaculture and Enhancement Division Milford Laboratory 212 Rogers Avenue Milford CT 06460 United States	Phone +1 203 882 6531 Fax +1	shannon.meseck@noaa.gov
Sólveig Ólafsdóttir	Marine Research Institute PO Box 1390 121 Reykjavík Iceland	Phone +3545752000 Fax +3545752001	solveig@hafro.is
Are Olsen	University of Bergen Geophysical Institute Allegaten 70 N-5007 Bergen Norway	Phone +47 55 23 84 84 Fax +47	are.olsen@gfi.uib.no
David Pearce	Centre for Environment, Fisheries and Aquaculture Science (Cefas) Lowestoft Laboratory Pakefield Road NR33 0HT Lowestoft Suffolk United Kingdom	Phone +44 1502 524 504 Fax +44	david.pearce@cefas.co.uk
Beth Phelan By WebEx	National Oceanic and Atmospheric Administration Ecosystems Processes Division James J. Howard Marine Sciences Laboratory 74 Magruder Road Sandy Hook Highlands NJ 07732 United States	Phone +1 732 872 3179 Fax +1	beth.phelan@noaa.gov
Marilynn Sørensen	International Council for the Exploration of the Sea H. C. Andersens Boulevard 44–46 1553 Copenhagen V Denmark		marilynn@ices.dk

Name	Address	Phone/Fax	E-mail
Katrin Vorkamp	Aarhus University Dept. of Environmental Science PO Box 358 Frederiksborgvej 399 DK-4000 Roskilde Denmark	Phone +45 8715 8483	kvo@dmu.dk
Pamela Walsham	Marine Scotland Science Marine Laboratory PO Box 101 375 Victoria Road Torry Aberdeen AB11 9DB United Kingdom	Phone +44 1224 876 544 Fax +44	Pamela.Walsham@scotland.gsi.gov.uk
Sieglinde Weigelt-Krenz	Bundesamt für Seeschiffahrt und Hydrographie Wüstland 2 22589 Hamburg Germany	Phone +49 40 3190-3310 Fax +49 40 3190-5000	sieglinde.weigelt@bsh.de
Phillip Williamson	University of East Anglia School of Environmental Sciences NR4 7TJ Norwich United Kingdom	Phone +44 1603 593111/+44 7749 092287	p.williamson@uea.ac.uk
Patrizia Ziveri	Universitat Autonòma de Barcelona Institut de Ciència i Tegnologia Ambientals Ed. Cn. UAB Campus 08193 Bellaterra Barcelona Spain	Phone +34 93 586 84 85 Fax +34	patrizia.ziveri@uab.cat

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) Background and scene setting:

- 5.1) Current OSPAR monitoring and assessment framework:
  - 5.1.1) Overview of OSPAR JAMP and Quality SR 2010 by Evin McGovern.
  - 5.1.2) Eutrophication and the common procedure by Evin McGovern.
  - 5.1.3) Hazardous Substance Monitoring in OSPAR by Martin Larsen.
- 5.2) OA Global Observation network by Phil Williamson.

6) Links to other ices working groups/activities:

- 6.1) Presentation from ICES DataCentre as to current data structures capabilities.

7) Review tor and discussion of approach for three year life of SGOA.;

8) Brief reports from members of national OA monitoring activity research activities;

9) Plenary presentations; specific projects/topics:

- 9.1) UKOA by Phil Williamson;
- 9.2) MEDSEA by Patrizia Ziveri;
- 9.3) Gloat V2 by Are Olsen;
- 9.4) OA monitoring activities of AMAP by Jan Rene Larsen;
- 9.5) Norwegian Coordinated assessment of OA by Melissa Chierici.

10) Main terms of reference:

- 10.1) 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:
  - 10.1.1) What questions should monitoring address and assessment?
  - 10.1.2) What are long-term data needs?
  - 10.1.3) How should data be assessed?
- 10.2) finalize guidelines for measuring carbonate system[3];
- 10.3) Collate chemical data and information on ocean acidification in the OSPAR Maritime Area:

[3] Building on the draft guidelines coming forwards from ICES Marine Chemistry Working Group (MCWG).

10.3.1) Identify datasets and put in place arrangements for collation of data;

10.3.2) Discuss with ICES DataCentre options for information exchange with project data centres and CDIAC.

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

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

10.6) Report current knowledge of biological effects of OA on plankton, and macrozoobenthos;

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

10.8) Make initial arrangements for a first assessment of all available data in the OSPAR maritime area.

11) Plenary discussion of draft report;

12) Any other business;

13) Recommendations and action list;

14) Date and venue of the next meeting;

15) Closure of the meeting.

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[4] 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).

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 7–11, October 2013 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) 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[5];

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.

SGOA will report by XX October 2013 for the attention of OSPAR and ACOM.

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

Supporting information

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

Annex 4: Recommendations

RECOMMENDATIONS	FOR FOLLOW UP BY
SGOA recommends that the Monitoring Guidelines for Chemical Aspects of Ocean Acidification (SGOA 2012 Report Annex 5) should be forwarded to OSPAR for adoption as a part of the JAMP guidelines.	OSPAR
SGOA recommends QUASIMEME should be encouraged to develop a proficiency-testing scheme for TA and DIC.	QUASIMEME

Annex 5: Draft monitoring guidelines for chemical aspects of ocean acidification

1. Introduction

Ocean acidification is an unavoidable consequence of increased atmospheric concentrations of CO_2 and the partitioning of CO_2 into seawater. CO_2 reacts with seawater to produce carbonate, bicarbonate and hydrogen ions. Since the industrial revolution the concentration of hydrogen ions in seawater has increased by 30%. Ecosystems in certain seas such as Arctic waters are potentially more vulnerable to these changes as they will tend to become undersaturated with respect to the carbonate minerals forming the shells of many organisms earlier than other areas. A range of other biological processes and functions are also likely to be affected by changes in pH (Gattuso and Hansson, 2011). Elsewhere it is important to consider that the concentration of hydrogen ions affects many biogeochemical processes such as the ratio of available ammonia to ammonium supporting primary production and the solubility of trace metals. Eutrophication may be closely linked to ocean acidification through the production of organic matter from CO_2 during primary production (Borges and Gypens, 2010; Provoost *et al.*, 2010; Cai *et al.*, 2011). The degree of ocean acidification may be assessed through the measurement of carbonate species in solution and the calculation of the saturation states of the shell forming carbonate mineral aragonite and calcite. At present a recommendation cannot be made for a minimum reliable approach to monitoring (such as measurement of pH during late winter immediately prior to the spring bloom during eutrophication-related surveys). This is because data of sufficient accuracy and precision for the assessment of acidification status is generally absent. We are at a stage where the collection of baseline data to look at regional and temporal differences through the year should be encouraged. It should be noted that work on Ocean Acidification complements the study and budgeting of marine CO_2 inventories and air-sea fluxes. Planning of the two activities should be coordinated.

2. Purposes

The measurement of carbonate species in seawater is carried out for the following purposes:

1) To monitor the spatial distribution of carbonate species concentrations within the maritime area. (In coastal areas high quality marine observations may need to be coupled to regular monitoring of major river inputs[A]).

2) To assess trends in the degree of ocean acidification due to anthropogenic influences by monitoring pH, other carbonate system parameters and carbonate mineral saturation, over periods of several years.

3) To provide information of sufficient spatial and temporal resolution to underpin the identification of biological impacts and future ecological risks through direct observation and the use of numerical models.

3. Quantitative objectives

The quantitative objectives must take into account the characteristics (e.g. variability) of the marine areas concerned.

It is intended that the region-specific temporal trend-monitoring programme should have the power (e.g. 90%) to detect a change in concentration (e.g. 0.02 pH) over a selected period (e.g. 10 years). To clarify the situation and to help define objectives, Contracting Parties should collect and undertake statistical analyses of new baseline datasets collected (collection of new data should meet the quality criteria required for the monitoring of ocean acidification). The representative monitoring stations chosen for this should be selected on the basis of numerical modelling results and cover the range of environments from nutrient rich estuaries to deep ocean water and around cold-water corals.

The spatial distribution of the monitoring programme should enable Contracting Parties to determine the representativeness of their monitoring stations with regard to spatial variability of carbonate parameter concentrations. This would include a definition of the extent of the monitoring area and understanding of how monitoring by different Parties is complementary. This should be done to enable a full assessment, which can be integrated across the whole OSPAR area.

4. Sampling strategy

Monitoring should consider all four measurable carbonate species (Dickson, 2010) measured as Total Dissolved Inorganic Carbon (DIC), Total Alkalinity (TA), Partial Pressure (of dissolved) Carbon Dioxide (pCO_2), and hydrogen ion concentration measured as pH[B] (Dickson *et al.*, 2007). The following supporting parameters are required for calculation of final individual concentrations of components of the carbonate system, which are not measurable directly such as the concentration of carbonate ions (CO_3^{2-}): temperature, salinity, silicate and phosphate.

The equilibrium chemistry of the carbonate system has been studied extensively (see Dickson, 2010) and the equilibria have been precisely quantified so that if two components of the system are measured the other two can be calculated with known level of error that varies with the choice of the pair and the concentration levels being worked at (Hydes *et al.*, 2010). Well-tested software (e.g. CO2SYS and SEACARB[C]) is available for carrying out the required calculation.

At the present state of development of analytical methods and supporting reference materials, the most reliable methods for work with samples are measurements of DIC and TA, which are supported by Reference Materials[D]. For underway sampling high frequency (<5 minutes) measurements with high precision and accuracy (<2 μatm) can be achieved for the measurement of pCO_2 (measurements can be referenced against WMO approved gas standards[E]). For assessment of ocean acidification, in some areas where only measurements of pCO_2 are available they can be coupled to estimates of TA from salinity (Lee *et al*., 2006) to give an estimation of pH. In such cases, the relationship between salinity and TA for that area should be established.

Prior to establishing long-term monitoring Contracting Parties should undertake wide ranging measurements to define the levels of variability across their marine areas before defining a minimum effective programme for observations in their areas. This should take into account and be coordinated with the plans of other Contracting Parties and their own existing programmes for monitoring other parameters (eutrophication being the likely most complementary activity).

Guidelines for monitoring are set out below in line with existing guidelines for the monitoring of eutrophication. For the parallel assessment of air-sea fluxes for the establishment of annual air-sea fluxes, year-round monitoring of pCO_2 needs to be done with repeat visits sites on at least a monthly basis in representative areas (to be defined from numerical models).

4.1 Monitoring for purposes 1 and 2

In coastal seas monitoring of carbonate parameters should take place along salinity gradients in order to determine the scale of local influences resulting from variations in riverine inputs of carbonate species. Equally, monitoring in shelf seas should be sufficiently extensive take account of inputs and the oceanographic characteristics of each region, particularly the in-flow of ocean water across the shelf break.

TA-salinity relationships for a coastal area can provide information about internal and external processes involved in regulating TA concentrations such as variability of riverine inputs and denitrification. A linear relationship indicates that physical mixing is the dominant process regulating the TA concentration, while non-linearity indicates the additional influence of chemical and/or biological processes. Several sources of freshwater or offshore water may add complexity to TA-salinity mixing diagrams, and temporal variability of the TA concentrations of the sources may contribute additional scatter and variability to the relationship.

The temporal trend monitoring strategy should ensure that sufficient data are collected in order to confirm that the maximum winter DIC concentrations was detected in given year.

All carbonate data should be reported with accompanying data for the salinity and *in-situ* temperature of the sample because the values *in-situ* pCO_2 and pH are sensitive particularly to changes in temperature. Normalization of data to a particular salinity can help is identifying if a change in concentrations is related to change in water mass properties.

After sampling, the supporting parameters should be inspected to assess the level of algal activity at the time of sampling (e.g. chlorophyll-a and dissolved oxygen) with respect to daily and annual cycles in production and decay to assess the error bar that should be attributed to data when included in temporal trend studies.

For ocean acidification monitoring in off shelf waters key areas include Arctic Seas and vulnerable habitats such as cold-water coral reefs.

Measurements are required in subsurface waters as these can be used for calculation of the accumulation anthropogenic carbon in the water (e.g. Tanhua *et al*., 2007).

4.2 Monitoring for purpose 3

Monitoring for purpose 3 is intended to identify where biological effects due to ocean acidification occur. For purpose 3, the sampling strategy for the carbonate system should be linked to appropriate biologically orientated surveys e.g. studies of corals, molluscs and embryonic life stages of certain groups of organisms. From a biological perspective there is a need to capture data on the spatial and temporal variation in the carbonate system of the waters surrounding the particular potentially sensitive organisms.

5. Sampling

5.1 Equipment

Water samples for analysis of DIC/TA can be collected using a rosette frame or hydro-bottles clamped to a hydro-wire and lowered to the prescribed depth. Use of a rosette sampler is preferred combined with an accurate and precise profiling probe for measurement of temperature (±0.05), salinity (±0.005) and pressure (a "CTD" profiler). Additional subsamples should be taken from water bottles and analysed for salinity, nutrients, dissolved oxygen and chlorophyll-a. Sampling from an underway water supply may also be possible but the procedure should be validated.

Samples for DIC/TA should be collected directly into Pyrex glass bottles with gas tight stoppers, leaving a 1% headspace, and the samples poisoned by the addition of Mercuric Chloride if the samples are to be stored (Dickson *et al.*, 2007; SOP 1). For rosette sampling the priority for the order of drawing samples is: samples for DIC/TA should be taken after CFC, oxygen and pH samples but before nutrient and salinity samples, to minimize the CO_2 exchange across the free surface that forms in the hydro-bottle as it drains.

5.2 Contamination

Sampling should be undertaken in such a way that any ship's discharges are avoided. Sampling bottles on the rosette and sample storage bottles should remain closed when not in use.

Sample storage bottles should be thoroughly rinsed with sample before filling. A tube attached to the sample collection bottle running to the base of the sample storage bottle should be used to minimize the possibility of gas exchange during sampling.

6. Storage and pretreatment of samples

6.1 Storage

Bottles that are gas tight should be used for sample storage. Normally Pyrex bottles of 250 or 500 ml capacity are used and sealed with a greased ground glass stopper held in with a retaining band. Samples poisoned with mercuric chloride (Dickson *et al*., 2007; SOP 1) should be stored in a cool and dark environment. Samples can be stable for at least one year if collected carefully.

It is recommended that laboratories should conduct systematic studies of the stability of their samples. As part of these tests exchange samples between laboratories should be done to separate errors due to degradation of samples from measuring errors.

6.2 Pretreatment

Unnecessary manipulation of the samples should be avoided; however filtration with GF-F filters may be used for TA samples from turbid waters. No recommendation can be given for DIC samples. An accepted filtration method that minimizes the gas exchange for DIC samples has not been published.

7. Analytical procedures

The methods for the determination of the four carbonate species are described in detail in Dickson *et al.* (2007). The preferred methods are (1) TA - acid base titration with the endpoint calculated by Gran fit; (2) DIC - addition of phosphoric acid with quantification of the evolved CO_2 by coulometry; (3) pCO_2 underway samples - equilibration of gas stream with the surface water and determination of the equilibrated mole fraction of CO_2 in the gas stream by infrared spectrometry at a known gas pressure; (4) No recommendation can currently (2012) be given on a technique for direct measurements of pH and laboratories using direct measurements of pH should validate that the measurements obtained are fit for purpose for their target sampling area.

8. Analytical quality assurance

The quality assurance programme should ensure that the data are fit for the purpose for which they have been collected, i.e. that they satisfy levels of precision and accuracy compatible with the objectives of the monitoring programme.

Regular collection of duplicate samples should be undertaken. Specific technical information on QA and QC is provided by Dickson *et al.* (2007; SOPs 21, 22 and 23). Reference Materials (RM) are available for TA, DIC, pH (TRIS) and reference gases for pCO_2 (see above). Recommendations and Matlab tools for pCO_2 QC procedures have been developed as part of the Surface Ocean CO2 Atlas (SOCAT) and CARINA projects and are available at http://www.socat.info/publications.html (see Olsen. A. and D. Pierrot, 2010).

When possible in addition to routine use of RMs, the data should be checked for cruise-to-cruise consistency, where possible, by comparing samples from the deep-ocean with near-steady CO_2 chemistry (>2000 meters for instance), by comparing DIC/TA relationships to Salinity, and/or relationships between DIC and nitrate, phosphate and oxygen (Tanhua *et al.*, 2010; http://cdiac.ornl.gov/oceans/2nd_QC_Tool/).

A system of regular intercomparisons between the concerned laboratories should be organized.

9. Reporting requirements

Data for TA and DIC should be reported in units of $\mu mol\ kg^{-1}$. Data for the CO_2 should be reported as the partial pressure pCO_2 in units of micro-atmospheres. Data for pH should be reported with details of the pH scale to which the measurement is referenced; normally this should be the total scale (Dickson, 2010).

Data reporting should be in accordance with the latest ICES reporting formats, together with information on methods used, detection limits, reference values and any other comments or information relevant to an ultimate assessment of the data. In order to establish the acceptability of the data, they should be reported together with summary information from recent control charts, including dates, sample sizes, means and standard deviations. **For monitoring data only directly measured values should be reported.** This avoids any uncertainty about how calculated value was arrived at. During the subsequent assessment other parts of the carbonate system will be calculated. If these data are in its turn archived any derived values should be flagged to indicate how the values were arrived at. Pesant *et al.* (2010) propose a system of secondary flagging for this purpose.

10. Summary tables

Table 1. Generally accepted levels of error associated with each method based on Dickson (2010).

		Ref Method	State of art	Other
	Total dissolved inorganic carbon μmol kg^{-1}			
(A)	Acidification / vacuum extraction / manometric determination	1.0		
(B)	Acidification / gas stripping / coulometric determination		2-3	
(C)	Acidification / gas stripping / infrared detection			4
(D)	Closed-cell acidimetric titration			10+
(E)	Auto-analyser colorimetric			5+
	Total alkalinity μmol kg^{-1}			
(F)	Closed-cell acidimetric titration		2-3	
(G)	Open-cell acidimetric titration	1-2		
(H)	Other titration systems			2–10
	pH			
(I)	Electrometric determination with standard TRIS buffer.		0.005	0.01–0.03
(J)	Spectrophotometric determination using *m*-cresol purple	0.003		
	pCO_2 μatm			
(K)	Direct - equilibrator infrared determination of pCO_2		2	
(L)	Indirect - membrane colorimetric determination of pCO_2			2–10
(M)	Direct - membrane infrared determination of pCO_2			1–10

Table 2. Present status of Reference Materials for the quality control of oceanic carbon dioxide measurements based on Dickson (2010).

Analytical Measurement n	Desired Accuracy [1]	Uncertainty [2]	Availability
DIC	± 1 μmol kg^{-1}	± 1 μmol kg^{-1}	since 1991 [3]
TA	± 1 μmol kg^{-1}	± 1 μmol kg^{-1}	since 1996 [3]
pH	± 0.002	± 0.003	since 2009 [4]
Mole fraction of CO_2 in dry air	0.5 μmol $mole^{-1}$	± 0.1 μmol $mole^{-1}$	since 1995 [5]

1) Based on considerations outlined in the report of SCOR Working Group 75 (SCOR, 1985). They reflect the desire to measure changes in the CO_2 content of seawater that allow the increases due to the burning of fossil fuels to be observed. (SCOR. 1985. Oceanic CO_2 measurements. Report of the third meeting of the Working Group 75, Les Houches, France, October 1985.)

2) Estimated standard uncertainties for the Dickson SIO reference materials.

Sterilised natural seawater certificated using a definitive method based on acidification, vacuum extraction, and manometric determination of the CO_2 released. Available from UC San Diego (http://andrew.ucsd.edu/co2qc/).

3) Certificated using a definitive method based on an open-cell acidimetric titration technique (Dickson *et al.*, 2003). Available from UC San Diego (http://andrew.ucsd.edu/co2qc/).

4) Standard buffer solutions based on TRIS in synthetic seawater (Nemzer and Dickson, 2005; DeVallis and Dickson, 1998). Available from UC San Diego (http://andrew.ucsd.edu/co2qc/). These are now available, in at present limited quantities, from Dickson's laboratory for the validation of locally prepared buffers. Dickson *et al.*, 2007, SOP 6a describes the preparation of buffers using 2-amino-2-hydroxy-1,3-propanediol (TRIS) and 2-aminopyridine (AMP) in synthetic seawater.

5) For calibration of continuous pCO_2 measurement systems, cylinders of air certificated on the basis of non-dispersive infrared spectrometry are available from NOAA/ESRL, (http://www.esrl.noaa.gov/gmd/ccgg/refgases/stdgases.html).

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Endnotes

[A] River monitoring is needed for (1) understanding of the variability of river inputs and the drivers of this variability (2) to give better parameterization of river inputs in numerical models of marine acidification (e.g. Blackford *et al.*, 2006).

[B] Confusion can arise due to the existence of several different pH scales. pH is an operationally defined concept and there are four different scales (US National Bureau of Standards (NBS), free scale, total hydrogen ion scale, seawater scale), which result in significantly different numerical values. The recommended scale for use in seawater related calculation is the total hydrogen ion scale. It is critical that the scale used is reported as part of the metadata when data are deposited in a database.

[C] CO_2 system calculation software can be down loaded from (1) http://cdiac.ornl.gov/ftp/co2sys/ (2) Lavigne H. and Gattuso J.-P. 2011. seacarb: seawater carbonate chemistry with R. R package version 2.4. http://CRAN.R-project.org/package=seacarb (3) http://neon.otago.ac.nz/research/mfc/people/keith_hunter/software/swco2/

[D] Dickson Lab http://andrew.ucsd.edu/co2qc/

[E] NOAA Carbon Cycle Greenhouse Gases Group (CCGG http://www.esrl.noaa.gov/gmd/ccgg/refgases/stdgases.html) is currently responsible for maintaining the World Meteorological Organization mole fraction scales for CO_2, CH_4, and CO.

Annex 6: Carbon data centres

International data centres of importance for ocean carbon cycle research for the OSPAR region are PANGAEA and CDIAC. PANGAEA is a data publisher for earth and environmental data and is hosted by the Alfred Wegener Institute for Polar and Marine Research (AWI) and the Center for Marine Environmental Sciences (MARUM), University of Bremen. The World Data Center for Marine Environmental Sciences (WDC-MARE) uses PANGEA as its data archive and data distribution system. Large European EU-projects like CARBOOCEAN, CARBOCHANGE and EPOCA use WDC-MARE/PANGEA as their main repository, and it includes data from volunteer observing ships (VOSs), hydrographic cruises and perturbation experiments. PANGEA is a member of the World Data System of the International Council for Science (ICSU-WDS), which build on the former ICSU WDCs. The WDS will be a common globally interoperable distributed data system.

CDIAC, Carbon Dioxide Information Analysis Centre, is the climate data and information analysis centre of the US Department of Energy. CDIAC is widely used by the global ocean CO_2 research community and holds data from both VOS and hydrographic cruises. Whereas CDIAC previously was considered default data centre also by the European community, awareness on European funding and visibility has led to more widespread usage of PANGAEA.

Apart from these, there are several data centres that operate at institutional and national level, for instance the British Oceanographic Data Centre (BODC) and the Norwegian Marine Data Centre, which do not by default interoperate with PANGAEA or CDIAC.

The community is turning towards the data product systems SOCAT, and GLODAP for data archiving and publication, since these provide integrated, quality controlled and well-documented data.

The Surface Ocean CO_2 Atlas (SOCAT) is a global ocean carbon cycle research community initiative assembling, harmonizing, quality controlling and publishing surface CO_2 fugacity (fCO_2, similar to partial pressure, pCO_2, but taking into account the non-ideal nature of CO_2) data from the global ocean. The SOCAT project was initiated in 2007 and the first product release (of v1.5) took place in 2011. SOCAT involves some 50–100 scientists from around the globe, these are organized into seven regional groups and a global coordination group. The regional groups assign two types of quality flags to the data. A “cruise flag” is given to each cruise; this designates the expected quality of the data and depends on the degree of documentation and sampling protocols. In addition a WOCE flag is assigned to each fCO_2 data point, in order to mark questionable or bad data. Two types of products have been created, the global set of QC’d fCO_2 data (Pfeil *et al*., 2012) and a set of gridded monthly mean values with minimal spatial and temporal interpolation (Sabine *et al*., 2012). The SOCAT data products and individual files are available through CDIAC and through PANGAEA. SOCAT data can also be interactively sub sampled and retrieved through NOAA/PMELs Live Access Server and the Ocean Data View software. SOCAT homepage and data links can be accessed at www.socat.info. SOCAT is currently evolving into a routine effort and version 2 is scheduled for release mid-2013.

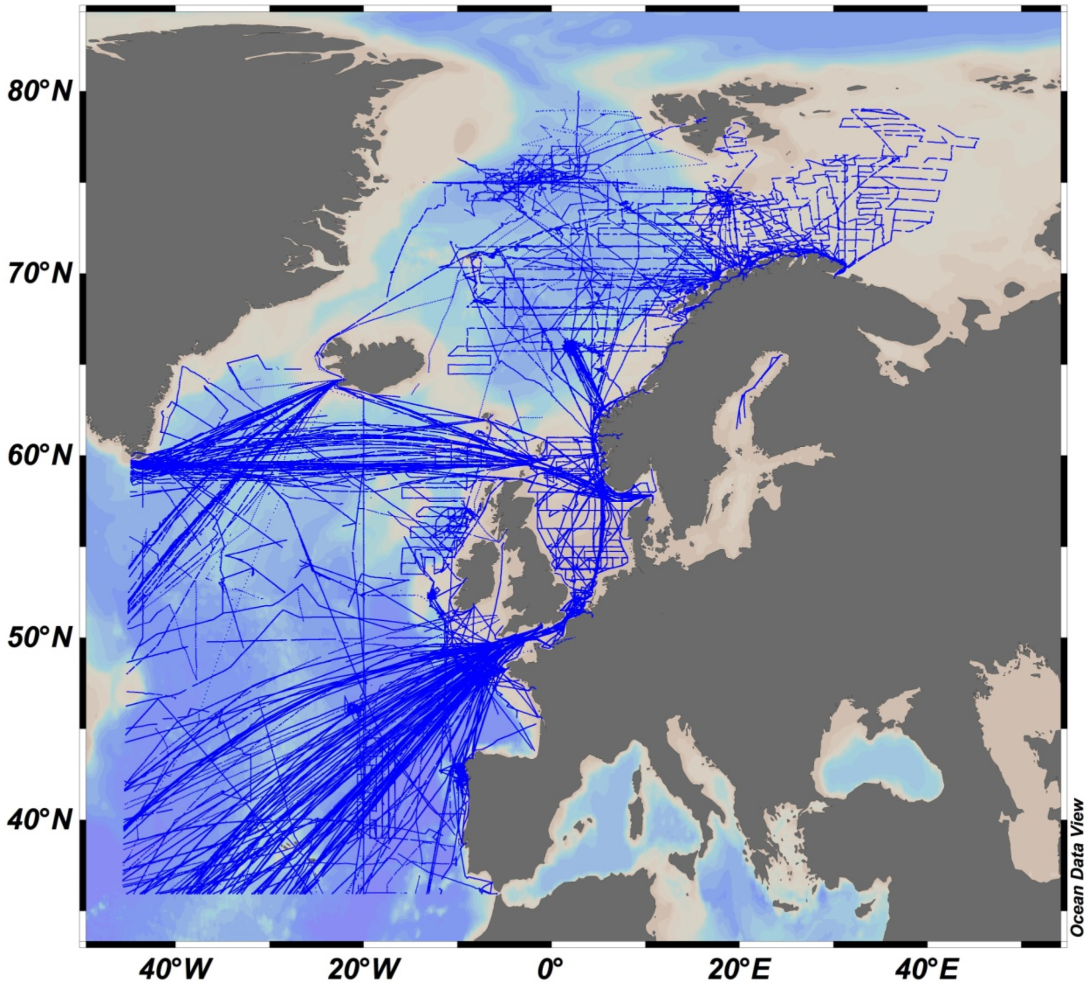

Figure 1. Positions of SOCATv1.5 (Pfeil *et al.*, 2012) surface ocean fCO_2 data in the OSPAR region.

The Global Ocean Data Analysis Project (GLODAP) was initiated in the early 2000s and involved primarily the US ocean carbon research community, assembling the WOCE-JGOFS interior ocean carbon data along with data from other selected cruises, into one single, well documented and bias corrected database. GLODAP v1.2 was released in 2004 (Key *et al.*, 2004, Sabine *et al.*, 2005, http://cdiac.ornl.gov/oceans/glodap/) and contains data from ca. 120 cruises from all of the global oceans, apart from the Arctic. In the late 2000s the CARINA (CARbon in the Atlantic) project, as part of the EU-IP CARBOOCEAN, carried out a similar exercise, focusing on Arctic, Atlantic and Southern Ocean data that for various reasons were not included in GLODAPv1.1 (Tanhua *et al.*, 2010). The CARINA data collection contains data from almost 190 different cruises. Currently a similar collection for the Pacific is being finalized; PACIFICA will contain data from around 300 cruises.

An international team of experts led by Are Olsen (NO) and Robert M. Key (US) is currently amalgamating these three synthesis products into a new interior ocean carbon data product with global coverage, GLODAPv2. In addition to the data included in GLODAPv1.1, CARINA and PACIFICA, data from the CLIVAR and other recent surveys will be added to this data product. Tentative release is set to late 2013. The community, as coordinated through the IOCCP, intends to keep this effort running on a routine basis in future.

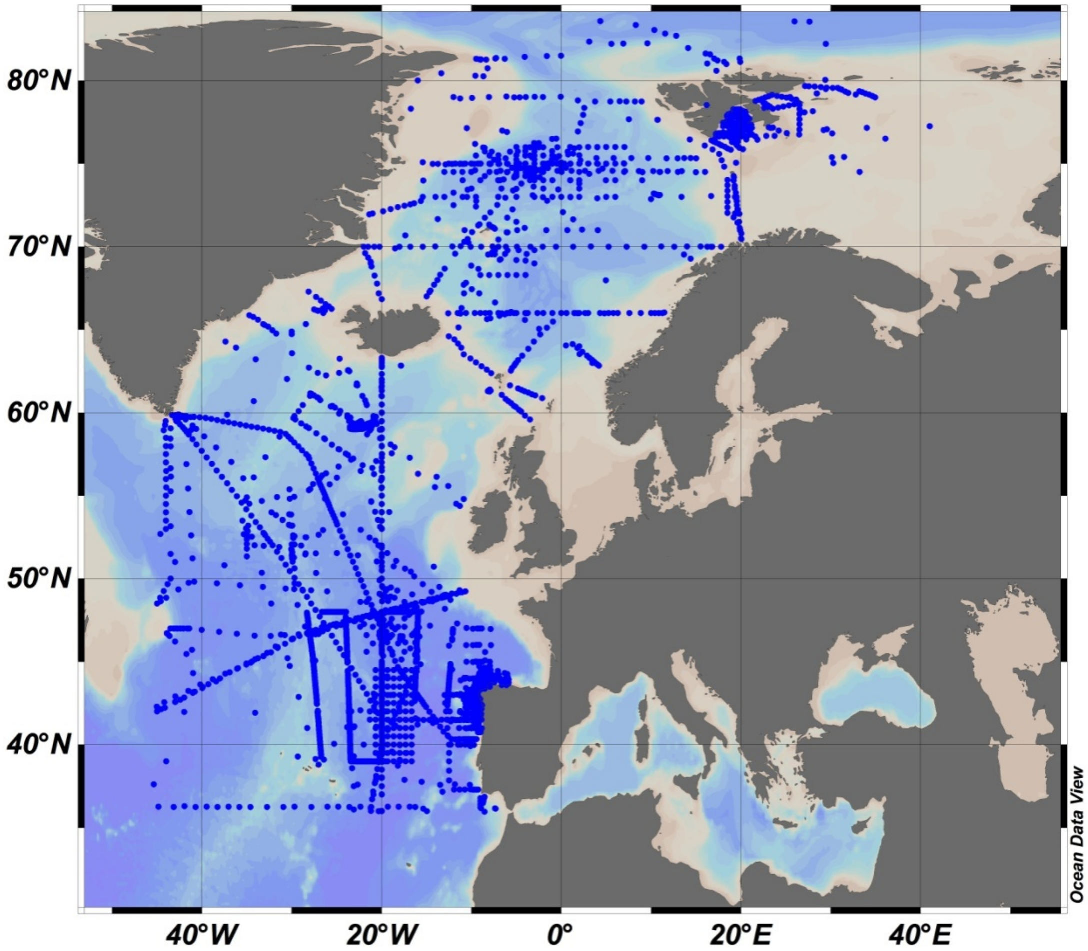

Figure 2. Positions of CARINA (Tanhua *et al.*, 2010) interior ocean carbon data in the OSPAR region.

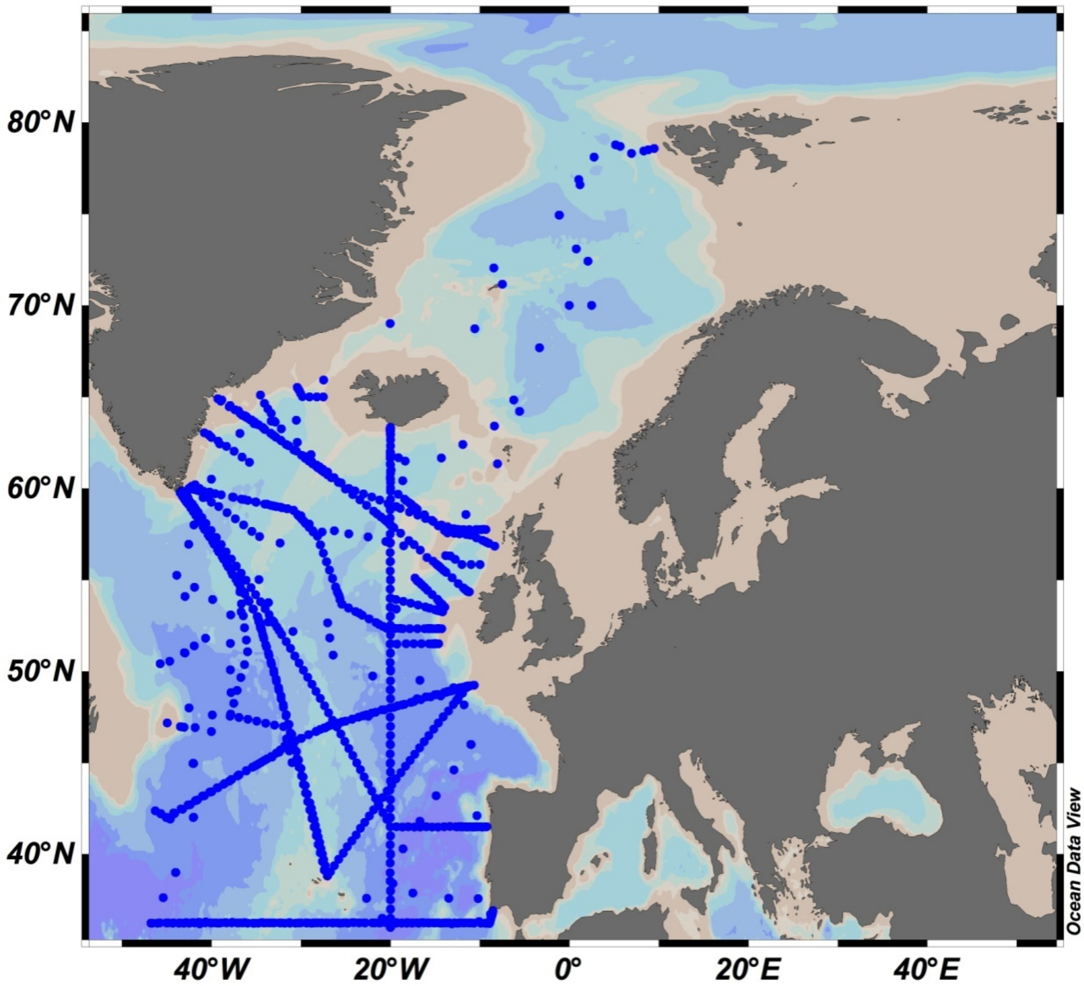

Figure 3. Positions of GLODAPv1.1 (Key *et al.*, 2004) interior ocean carbon data in the OSPAR region.

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Sabine, C. L., R. M. Key, A. Kozyr, R. A. Feely, R. Wanninkhof, F. J. Millero, T.-H. Peng, J. L. Bullister, and K. Lee. *Global Ocean Data Analysis Project: Results and Data*. ORNL/CDIAC-145, NDP-083. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, US Department of Energy, Oak Ridge, Tennessee, 110 pp, 2005.

Tanhua, T., A. Olsen, M. Hoppema and V. Gouretski. (Eds.) CARINA: a consistent carbon-relevant database for the Arctic, Atlantic and Southern Oceans, *Earth System Science Data*, Special issue, 2012.

Links

CDIAC	http://cdiac.ornl.gov/
PANGAEA	http://www.pangaea.de/about/
WDC-MARE	http://www.wdc-mare.org/
SOCAT	http://www.socat.info/
GLODAP	http://cdiac.ornl.gov/oceans/glodap/
CARBOCEAN	http://www.carboocean.org/
CARBOCHANGE	http://carbochange.b.uib.no/
CLIVAR	http://www.clivar.org/
EPOCA	http://www.epoca-project.eu/

Annex 7: 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.

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		SOO	Underway pCO_2	2010
France		Plymouth–Roscoff		SOO	Underway pCO_2	
France		ASTAN (48°46'N; 3°56'W)		FS Mooring	pCO_2	2009–
France / Ifremer		MAREL (48°22'N; 4°33'W)	?	FS Mooring	pCO_2	2003–
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		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	?	?

Country/Institute	PI	Area	OSPAR/HELCOM region	Platform/type	Parameters	Period
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 & 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& MI	Ward	Irish Shelf and off-shelf	OSPAR III & V	RV Celtic Explorer	Underway pCO_2	2009–2011
Ireland / NUI Galway& MI	O'Dowd/Ward	Mace Head Coastal Atmospheric research station	OSPAR III	FS Buoy	pCO_2	2008–2009
Ireland / NUIG & MI	McGovern / Cave	Irish Shelf and off-shelf	OSPAR III & V	RV Research Cruises	TA, DIC	2008–
Ireland / NUIG & 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?	?
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: 1/year
Norway/ IMR	Chierici	Gimsøy-NW	Norwegian Sea	IMR research vessels	water column DIC, TA, nutrients	start 2010–2012, 2–4 times annually: 2013–2016: 1/year

Country/Institute	PI	Area	OSPAR/HELCOM region	Platform/type	Parameters	Period
Norway/ IMR	Chierici	Svinøy-NW	Norwegian Sea	IMR research vessels	water column DIC, TA, nutrients	start 2010–2012, 2–4 times annually: 2013–2016: 1/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: 1/year
Norway/ IMR	Chierici	Bjørnøya-Sørkapp	Barents Sea (SW)	IMR research vessels	water column DIC, TA, nutrients	start 2013 to 2016: 1/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: 1/year
Norway/ IMR & FRAM centre (OA Flagship)	Chierici/Fransson (NPI)	Fram Strait	Arctic Ocean/Greenland Sea	RV Lance	water column DIC, TA, nutrients	start 2011 ongoing
Norway/ IMR & 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 / UiB & Bjerknes	Johannessen	75° N transect	OSPAR I	RV Research cruises	DIC, TA	2003, 2006, 2008?
Norway / UiB & Bjerknes	Skjelvan/Johannessen	OWS M	OSPAR I	FS WS Monthly profiles	DIC, TA	2001–2009
Norway / UiB & Bjerknes	Skjelvan/Johannessen	OWS M	OSPAR I	FS WS Continuous	pCO_2	2005–2009
Norway / UiB & Bjerknes	Skjelvan/Johannessen	OWS M	OSPAR I	FS Buoy Continuous	pCO_2	2011
Norway / UiB & Bjerknes	Johannessen/Olsen/Lauvset	Nordic Seas	OSPAR I	RV G. O. Sars (research vessel)	Underway pCO_2	ongoing
Norway / UiB &	Johannessen/Olsen/Omar	Aarhus–Nuuk		SOO (Nuka Arctica)	Underway pCO_2	2005–

Country/Institute	PI	Area	OSPAR/HELCOM region	Platform/type	Parameters	Period
Bjerknes						
Norway / UiB & Bjerknes	Johannessen/Omar	Bergen–Amsterdam	OSPAR II	SOO / weekly	Underway pCO_2	2005–2009
Norway / UiB & Bjerknes	Johannessen/Omar	North Sea	Sleipner	RV G. O. SARS	Underway pCO_2	June 2012
Norway / UiB & 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
Spain / IIM	Rios / Perez	OVIDE, Iberian Peninsula-Greenland	OSPAR V	RV Research cruise	Underway pCO_2, pH, TA	2002–2012
Spain / IIM	Rios / Perez	Spain–Antarctic	OSPAR V	SOO	Underway pCO_22	2000–2009
Spain / ULPGC	Davila	English Channel–Durban	OSPAR V	SOO various ships	Underway pCO_2	2005
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 Baltic		SOO	Underway pCO_2	2010

Country/Institute	PI	Area	OSPAR/HELCOM region	Platform/type	Parameters	Period
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–
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), 2/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_2Transects (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) & monthly (E1)	TA/DIC	2008–

Country/Institute	PI	Area	OSPAR/HELCOM region	Platform/type	Parameters	Period
UK /PML	Mountford / Kitidis	English Channel (E1, L4)	OSPAR II	Weekly (L4) & monthly (E1)	Underway pCO_2Transects (Plymouth Quest)	
UK "Ellett Line"	Reid / Hartman	Greenland–UK	OSPAR I & III	Scientific cruise	Hydrography	2008 2010 2011
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

Note: Reproduced from Hydes *et al*. (ICES CRR) In press. This table is based on information received by MCWG and SGOA and does not purport to be definitive or complete.