EUR-OCEANS Flagship workshop

EUR-OCEANS Flagship for Polar Ecosystem Change and Synthesis (PECS): Identifying key links between biogeochemical processes and foodweb structure

Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany

British Antarctic Survey, Cambridge, UK

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1. **Topic, focus, objective**

The EUR-OCEANS Flagship for Polar Ecosystem Change and Synthesis (PECS) and its first workshop: *Identifying key links between biogeochemical processes and foodweb structure,* follows on from work initiated during the EUR-OCEANS Foresight Workshop on 'Rapid Change in Polar Ecosystems' in 2010 (AWI, Bremerhaven, Germany, organized by Ulrich Bathmann and Eugene Murphy). The main scientific question that emerged from the Foresight Workshop was: "*How will change affect the structure and function of polar marine ecosystems and biogeochemical cycles?*" The main strategic recommendation that emerged most strongly was: "*The need to drive and coordinate European polar ecosystem research, with a particular focus on future change*." These key points form the core of the PECS Flagship and the first PECS workshop.

Understanding and predicting how polar regions respond to change is a globally relevant issue that requires circumpolar scale analyses and multi-nation cooperation. It is widely accepted that the risk posed by climate change is higher and more imminent for the polar oceans than almost any other large marine ecosystem. Assessment of polar ecosystem responses to change is required to support the management and protection of the ecosystem services and to predict feedbacks and effects on the Earth System. Furthermore, because of their sensitivity, contrasts and relatively simple structure, polar ecosystems serve as early indicators of climate change effects and are springboards for developing methods of global mitigation.

Hence, this workshop mainly focused on linking biogeochemical cycles and food web structure, which are both sensitive to climate change, in Arctic and Antarctic marine ecosystems by integrating the existing efforts of the European polar science community with those of the wider ICED community (Integrating Climate and Ecosystem Dynamics in the Southern Ocean; ICED is the Southern Ocean programme of the IGBP's IMBER programme (Integrated Marine Biogeochemistry and Ecosystem Research). The long-term goal of ICED is to: *Determine the major controls on the dynamics of Southern Ocean ecosystems and the potential for feedbacks as part of the Earth System*. See www.iced.ac.uk.)

This workshop was held to gather and harness expertise in order to improve our understanding of the links between biogeochemical processes and food web structure. It included presentations and discussions on a) Southern Ocean and Arctic Ocean food web structures, b) change in polar ecosystems, c) biogeochemical cycles; and d) linking these aspects together.

PECS Flagship objectives:

- **Comparative ecosystem studies** (incl. food web structure and biogeochemical processes) within and between the Southern and Arctic Oceans
- **Scenario testing** to predict polar ecosystem responses to change
- **Coordination and integration** of existing, planned and future polar process studies, monitoring, data syntheses and modelling to address the above issues
- **Coordination of EU polar ecosystem scientists** to address scientific objectives, and to enhance and expand the existing international network
- **Develop an EU strategy for polar marine ecosystem research**

PECS Workshop aims:

- Identify key links between biogeochemical processes and food web structure;
- Establish EU polar marine ecosystem scientist network and integrate this within EUR-OCEANS Consortium and ICED;
- Initiate European-centred polar marine ecosystem fieldwork coordination;
- Draft a Strategy for EU Polar Marine Ecosystem Research to influence funding calls.

2. Presentations

The complete workshop agenda is in Annex 3. After a welcome to all participants by Dieter Wolf-Gladrow, Eugene Murphy gave an introduction to the goals of the workshop. The series of talks started with the presentation on 'Changes in the physical settings in both Polar Regions' by Ursula Schauer (Arctic summer sea ice extent, Antarctic sea ice extent, warming and freshening of Antarctic Circumpolar Current (ACC) waters over 50 years, change in Arctic Ocean temperatures, heat transport through Fram Strait, freshening of Arctic Ocean surface waters). The cycling of biogenic elements was discussed by Dieter Wolf-Gladrow in his presentation 'Biogeochemical Cycles in Polar Oceans' (distribution of nutrients, dissolved inorganic carbon (DIC), total alkalinity (TA) in the Arctic Ocean and the Southern Ocean, the impact of ocean acidification and freshening on aragonite saturation level, Arctic Ocean primary production). Eugene Murphy, Rachel Cavanagh et al. presented 'Southern Ocean Ecosystem: The Structure of Foodwebs' based on previous work within ICED. Philipp Assmy discussed 'The structure of Arctic food webs (Part A): Phytoplankton and ice algae' followed by Katarzyna Blachowiak-Samolyk who gave the corresponding zooplankton perspective in her talk entitled 'The structure of Arctic food webs (Part B): Zooplankton trophic structure in the European Arctic - analyses based on traditional approach and size spectrum theory '. Ekaterina Popova compared various 'Arctic Ocean ecosystem modelling' approaches (based on a recently published article: Popova, E. E., A. Yool, A. C. Coward, F. Dupont, C. Deal, S. Elliott, E. Hunke, M. Jin, M. Steele, and J. Zhang (2012), What controls primary production in the Arctic Ocean? Results from an intercomparison of five general circulation models with biogeochemistry, J. Geophys. Res., 117, C00D12, doi:10.1029/2011JC007112). Christoph Völker gave 'Some thoughts on Southern Ocean ecosystem modelling' (use models to test hypotheses, icebergs as a source of iron, role of sea ice in initializing phytoplankton blooms, inclusion of algal physiology in models). Andrew Constable discussed 'Change in Southern Ocean ecosystems' (physical change, past perturbations by hunting of seals, whaling, and fisheries, impact on single species and ecosystems, time scales) in part based on the 'Southern Ocean Sentinel Workshop' (Hobart, 2012). Dieter Wolf-Gladrow presented a first outline of the paper 'Cycling of biogenic elements in polar oceans: identifying key links between biogeochemical processes and foodweb structure' that will be one of the major outputs of the PECS flagship programme. Bernard Quéguiner discussed 'Iron fertilization and the structure of planktonic communities in high nutrient regions of the Southern Ocean' based on investigations of natural iron fertilization by iron release from shelf sediments with comparisons with artificial iron fertilization experiments (summary of the publication by Quéguiner, in press – http://www.sciencedirect.com.biblioplanets.gate.inist.fr/science/article/pii/S0967064512001105). He proposed a conceptual scheme linking plankton seasonal evolution to export fluxes. Christine Klaas compared three iron fertilizations experiments in her presentation 'Response of pelagic ecosystems to iron addition: EisenEx, EIFEX, LOHAFEX ' (based in part on a recent publication by Smetacek, Klaas et al., Nature, 2012). She pointed out that several types of pelagic ecosystems exist in different regions of the Southern Ocean and that krill, amphipods or myctophids play an essential role in these ecosystems. The availability of two nutrients, namely silicic acid and iron, seem to correlate with the types of ecosystems and might even be responsible for structuring Southern Ocean pelagic ecosystems. Hauke Flores presented 'Ice matters: A preliminary comparison of Arctic and Antarctic under-ice communities and their function as a link between sea ice and the pelagic food web' (based in parts on Flores et al., PLoS ONE, 2012 and Flores et al., Mar Ecol Prog Ser, 2012). A summary of the second half of Day 1 was given by Dieter Wolf-Gladrow.

Flores, H., Atkinson, A., Kawaguchi, S., Krafft, B., Milinevsky, G., Nicol, S., Reiss, C., Tarling, G., Werner, R., Bravo Rebolledo, E., Cirelli, V., Cuzin-Roudy, J., Fielding, S., Van Franeker, J.A., Groeneveld, J., Haraldsson, M., Lombana, A., Marschoff, E., Meyer, B., Pakhomov, E., Van de Putte, A., Rombolá, E., Schmidt, K., Siegel, V., Teschke, M., Tonkes, H., Toullec, J., Trathan, P., Tremblay, N., Werner, T., 2012. Impact of climate change on Antarctic krill. Marine Ecology Progress Series 458, 1–19.

Flores, H., Van Franeker, J.A., Siegel, V., Haraldsson, M., Strass, V., Meesters, E.H.W.G., Bathmann, U., Wolff, W.J., 2012. The association of Antarctic krill Euphausia superba with the under-ice habitat. PloS one 7, e31775.

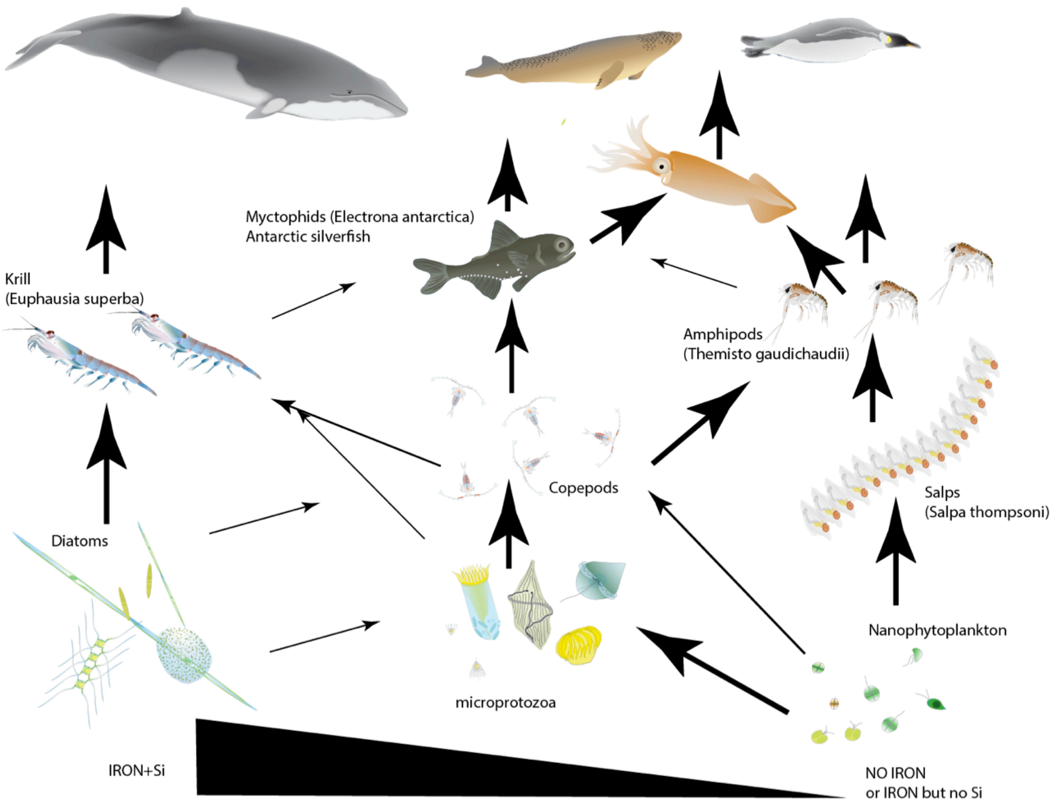

Fig. 1: Various types of Southern Ocean pelagic food webs and the role of iron and silicic acid in the functioning and structuring of these food webs was discussed by Christine Klaas.

Paul Tréguer discussed 'The silica cycle in the Southern Ocean and in the Subarctic Pacific' (in part based on Tréguer and De La Rocha, The World Ocean Silica Cycle, Annu. Rev. Mar. Sci., 5:477-501, 2013). Evgeny Pakhomov discussed 'Antarctic food web analyses using stable isotopes and role of zooplankton'. Geraint Tarling presented 'Discovery 2010: Spatial and temporal variability in a Southern Ocean ecosystem (based in part on the recently published special issue: Tarling et al. (2012) Discovery 2010: Spatial and temporal variability in a dynamic polar ecosystem. Deep-Sea Research II 59-60). Ksenia Kosobokova discussed the 'Structure and productivity of the zooplankton communities of the Arctic Ocean'. Katarzyna Błachowiak-Samołyk presented 'Zooplankton trophic structure in the European Arctic - analyses based on traditional approach and size spectrum theory'. Eva Leu discussed the 'Importance of sea ice algae and phytoplankton as food source for zooplankton'. In his presentation 'Polar Ecosystems in the 21th Century' Victor Smetacek discussed various global change issues including warming, extreme weather events, sea level change and non-sustainable fisheries that would all impact marine ecosystems as well as future challenges for the scientific community in addressing these issues and their solutions both scientifically and in terms of public awareness. Paul Tréguer gave a brief report from the European Institute for Marine Studies's Arctic Workshop held in Plouzané. Key issues were summarized by Eugene Murphy and Dieter Wolf-Gladrow.

Stefan Hain (AWI) gave an 'Introduction to the German Arctic Research Strategy' published in 2012 by the German Government under the title 'Rapid Climate Change in the Arctic: Polar Research as a Global Responsibility'. (available under: www.fona.de/de/publikationen.php). Last but not least, Lars Henning (AWI) discussed 'Research funding possibilities and perspectives' within the European Union.

3. Summary of major discussion points from plenary and breakout sessions

In the first plenary session we discussed the similarities and differences between the northern and southern polar regions. For further discussion we limited the (officially undefined) extent of the Southern Ocean to the position of the Antarctic Polar Front. For the northern polar region no agreement could be reached, however, a restriction to the Arctic Ocean would be too narrow. The region north of 50°N might be the right choice because it includes the Arctic Ocean, Bering Sea, Greenland Sea, and Labrador Sea.

Sea ice extent and changes

The Southern Ocean is characterized by a large seasonal variation in sea ice extent and a large fraction of young (first year) ice. Until the beginning of the 1990s large regions of the Central Arctic Ocean were ice covered even in summer and multi-year ice was quite abundant. During the last two decades Arctic Ocean summer sea-ice extent decreased dramatically and a large proportion of multi-year ice was lost; thus the Central Arctic Ocean sea ice variations show more and more similarities to those observed in the Southern Ocean's Weddell Sea (both roughly 2.8 million km^2 in size). The dramatic change in sea ice extent in the Arctic Ocean has far reaching consequences for marine ecosystems and cycling of elements. The Antarctic has areas of both ice reduction and expansion, with the overall sea-ice extent changing little (even slightly increasing). However, the warming and sea-ice loss observed around the Antarctic Peninsula is comparable in speed to changes in the Arctic Ocean.

Physical dynamics of water masses

A peculiar feature in the Southern Ocean is the increase of westerly winds over the last two decades driven by the destruction of stratospheric ozone ('ozone hole') and increasing levels of greenhouse gases. This can be measured as a positive trend of the Southern Annular Mode (SAM) index. The impact of stronger wind forcing on Southern Ocean circulation and mixing is still controversially discussed by physical oceanographers. There are indications that changes in ocean circulation might have severe consequences for the cycling of CO_2 (LeQuéré et al., 2007) probably involving variations of the physical as well as the biological carbon pumps.

Nutrient limitations

Strong nutrient limitations play an essential role both in the Southern Ocean and the Arctic Ocean. The Southern Ocean includes the largest of the world's high-nutrient low-chlorophyll (HNLC) regions due to iron limitation, whereas nitrate and phosphate are in ample supply. Silicic acid concentrations are very high in upwelling waters south of the Antarctic Circumpolar Current (ACC) but decrease to limiting levels towards the Antarctic Polar Front. In the Arctic Ocean, nitrate is most often the limiting nutrient while surface dissolved iron can be well above 1 nmol L^{-1} and thus 5 to 10 times higher than in most open ocean areas of the Southern Ocean. Differences in mixed layer depths (stratification) and vertical nutrient distributions can explain the occurrence of deep chlorophyll maxima in the Arctic Ocean and the high values of vertically integrated biomass in the Southern Ocean.

Primary production: nutrient or light limitation?

The type of limitation (nitrate and/or light) will influence the development of primary production (PP) in the Arctic Ocean. Satellite-based estimates point to an increase of PP with decreasing summer sea ice. An extrapolation to an ice-free Arctic Ocean would lead to a doubling of PP compared to current values; this prediction is, however, not very robust as state-of-the art biogeochemical ocean general circulation model simulations give either different results or results similar to each other but for different reasons (nutrient versus light limitation).

Sea ice habitats

Sea ice, in both polar oceans, provides an important habitat for ice algal communities, heterotrophic protists, bacteria, and ice-associated macrofauna. It also constitutes a key habitat for a number of warm-blooded predators. . Organisms in sea ice find initially high nutrient concentrations in high-salinity brine channels and can escape predation by larger zooplankton. Extremely high concentrations of small organisms in sea ice may be an important factor in evolution. The contribution of ice algae to PP in the Arctic Ocean is not well constrained but increases with increasing latitude. Regionally integrated estimates vary by one order of magnitude but are much lower than depth-integrated PP in the water column. In ice-covered areas and during early spring, however, ice algae can sometimes contribute the bulk of the primary production. Sea ice algal assemblages in both polar oceans are generally quite similar, although dominated by different pennate diatom species (e.g. *Nitzschia frigida* in the Arctic and *N. stellata* in the Southern Ocean). The centric diatom *Melosira arctica* which grows in extensive, long mats attached to the underside of sea ice plays an important role in the Central Arctic Ocean.

Food web structure

Phytoplankton blooms in polar oceans are dominated (in terms of biomass) by relatively few diatom species and the colony-forming haptophytes of the genus *Phaeocystis*. The Southern Ocean harbours a high degree of endemic species, in particular heavily silicified diatoms of the iron-limited ACC that make up the siliceous sediments surrounding Antarctica (opal belt). The sediments north of the seasonal ice zone consist mainly of frustules of the silica-sinking diatom *Fragilariopsis kerguelensis* while *Chaetoceros* spores contribute a large part to the surface sediment in the Scotia Sea. Although ubiquitous from the ACC to the coastal current blooms of *Phaeocystis antarctica* occur regularly only in the Ross Sea. Phytoplankton assemblages in the Arctic Ocean are similar to those in boreal and temperate oceans due to its connectivity with the North Atlantic and North Pacific. Coastal blooms that form over the extensive Arctic shelves are dominated by weakly silicified diatoms and *Phaeocystis pouchetii*. The low productive, picophytoplankton dominated Central Arctic Ocean is determined by perennial ice cover and strong haline stratification which limit light and nutrient availability. Reduction in summer sea ice extent and increased freshening in a warming Arctic will lead to changes in phytoplankton community composition, as already shown for the Canadian Basin, with cascading ramifications for carbon flux and food web dynamics. Coccolithophores can be found in both polar oceans, but never grow to bloom proportions except in adjacent subpolar regions (for example, Patagonian shelf). Nitrogen-fixing cyanobacteria generally play a minor role in polar oceans, however, a recent study has shown that cyanobacteria introduced by river plumes along Arctic shelves may fix nitrogen in the Arctic Ocean. Nitrogen fixation was also observed near the Kerguelen Islands.

The classical view of the Southern Ocean food chain 'diatoms-krill-whales' is based largely on the observations dating from the earlier days of polar research carried out under British leadership in the Scotia Sea and around South Georgia. Recent compilations of zooplankton observations carried out by the international community (including large data sets from the former Soviet Union) have shown that (1) the largest biomass of krill occurs in the Atlantic sector and in particular in the Scotia Sea, (2) krill density exhibits large interannual variation, and (3) krill biomass decreased dramatically between 1970 and 2000 and has not recovered thereafter (Atkinson et al., 2004).

In large parts of the Southern Ocean, alternative food pathways, such as the copepod-myctophid-top predator link, play an essential role (compare Fig.1).

The lush life around and on the island of South Georgia (large colonies of elephant and fur seals and penguins) is in part supported by the advection of krill and is largely dependent on recruitment further south and west (Antarctic Peninsula, ice covered Weddell Sea). This situation is similar to the Arctic Ocean ecosystem that profits from the advection of large amounts of the copepod *Calanus finmarchicus* from the North Atlantic.

Modelling

The simulation of polar marine ecosystems and the cycling of elements are challenging for both hemispheres. The Arctic Ocean is strongly forced by inflow of water masses from the Atlantic and the Pacific and the topography (many islands, shallow shelves) requires a fine resolution. Freshwater inflow by large rivers plays a significant role. Physical models are unable to properly simulate the strong stratification and shallow mixed layers of the central Arctic Ocean. This in turn affects the simulation of primary production. Further, models have to take into account denitrification in shelf regions. The flow in the Southern Ocean is dominated by upwelling in the south, northward Ekman transport partially compensated by southward transport via mesoscale eddies that are generated by instabilities of the ACC, and by subduction/mode water formation at the Antarctic Polar Front. Models able to resolve mesoscale eddies and to simulate biogeochemical processes with some complexity (including iron) are still computationally expensive, hence, only short-term integrations (years to decades) are currently feasible.

Break-out groups

Two break-out groups were formed. The main topics discussed are listed below.

In the `bottom-up´ break-out group the following topics were discussed: (1) Nutrient cycling in the Arctic and the Southern Ocean. (2) Pre-conditions for algal blooms (nutrients, fresh water input, lateral advection, mixing, vertical advection, coastal upwelling, maximum winter values). (3) Patterns of nutrient distribution. (4) Denitrification processes. (5) Riverine input of nutrients. (6) Primary production (PP): How will it change? How to simulate PP? (7) Phytoplankton assemblage: size spectra, key species, toxic species, invasive species (Why no blooms of coccolithophorids in cold regions?). (8) Ocean acidification. (9) Freshening (Arctic Ocean): cyanobacteria, aragonite undersaturation.

In the `top-down´ break-out group the following topics were discussed: (1) Fundamental differences in biogeographic processes (advective versus endemic system). (2) Does food quality and quantity differ (can this be used to predict types of zooplankton communities?)? (3) Comparative food web analysis (functional group and species analogues in Arctic and Antarctic). (4) Size structure/size spectra approaches: are they useful for intercomparison of Arctic and Antarctic ecosystems? (5) Is there top down control of phytoplankton (scale issues)? (6) Regionalisation approaches – predictors of species/functional communities. (7) Is match-mismatch equally important in both poles? (8) How is diel vertical migration affected? (9) Development of synthesis tables.

Final discussion

In the final discussion three major questions were raised: (1) How do `physics´ (circulation, mixing, wind forcing, etc.) and biogeochemistry influence food web structure in polar regions? (2) What is the effect of food web structure in polar regions on cycling of elements? (3) How does climate change and exploitation of marine resources impact marine biogeochemistry and food web structure in polar regions? In order to answer these big questions further smaller questions were formulated, namely: (1.1) Are there differences between the two polar areas? (1.2) What are relevant physical, biological, chemical, biogeochemical processes? (1.3) What phytoplankton species form the base of polar food webs? (2.1) How does food web structure affect the biological pump? (2.2) How does food web structure alter the nutrient dynamics? (2.3) What are major processes and dominant species? (3.1) How will the system function when all sea ice is gone? (3.2) What is the impact of fisheries on the whole ecosystem?

4. Relevance to the EUR-Oceans Consortium objectives (EOC)

The aims and objectives of this Flagship activity are directly in line with the main scientific objective of the EUR-Oceans Consortium: 'understanding the key challenging biogeochemical processes and developing robust scenarios of the future state of marine ecosystems'. This has also been our focus, albeit restricted to the polar regions. As outlined above, however, the potential consequences of change in polar ocean ecosystems are global in their reach. This workshop contributed to the development of the long-lasting, integrated and multidisciplinary effort necessary to understand these consequences.

The Flagship meets other objectives of the EOC including the promotion and coordination of 'Top-level scientific research on the impacts of anthropogenic and natural forcing on ocean ecosystems', and 'Optimal use of shared technical infrastructures and scientific facilities' through the coordination of fieldwork by European institutions.

The outcomes of this workshop are strongly linked to the overarching EOC scientific priorities: (1) to investigate 'impacts of climate change on the biogeochemical cycles of a changing ocean', and particularly (2) 'to build scenarios of the impact of climate/global change on marine ecosystems'.

Links /synergies / added value with respect to existing programmes or projects

There is a strong historical basis of European research on polar ecosystems. European scientists have had a leading role in developing globally important analyses of these ecosystems and in driving and steering international activities to address challenges of major significance for Europe (e.g. within IPCC, CCAMLR, SCAR, IGBP and IPY). European national operations already invest a significant budget into polar research. Building on the coordination of research that has developed under these programmes and through EUR-OCEANS will further enhance the legacy of the European research effort in the polar regions. This workshop strengthened existing links between EUR-OCEANS and ICED scientists and ensured to further develop research in polar marine ecosystems. The workshop also built upon recent work of ICED and its sub-programme Sentinel, which is developing a suite of biological monitoring sites and predictions for climate change on Southern Ocean ecosystems.

5. Outputs/Recommendations

The workshop was unusual in bringing together scientists who tend to work in either of the polar regions. The joint discussions from different perspectives shed light on both systems and may lead to new insights and detailed comparisons of certain aspects. Examples are (a) the role of amphipods in both systems, (b) support of ecosystems in the Arctic Ocean and at South Georgia by inflow of large amounts of zooplankton, and (c) architectural similarities in generalized food web structures in Arctic and coastal Antarctic regions These discussions should be continued through joint sessions at scientific meetings, and through future related events through the Flagship and European network. The delegates strongly recommend that marine ecosystem research, focused on both the Arctic and Antarctic, should be a high priority for current and future European research.

- Polar Marine Ecosystems Research: Strategic directions for the EU Research Area:

The rapid change in the Arctic Ocean and at the Antarctic Peninsula is a harbinger of large climatic changes in many other regions of the planet. Polar regions can be considered as a test bed of how well we will be able to make future predictions and respond to the challenges. Changes in polar regions will affect other regions including Europe. An ice-free Arctic Ocean will provide new economic opportunities from shipping goods to exploitation of resources (oil, gas, minerals) with risks of pollutions and political conflicts. Changes in the Southern Ocean may have impacts on fisheries and global cycling of elements and thus climate. Recently Germany developed a research strategy for polar regions. Because of the increasing importance of polar regions for global change and global economy we strongly recommend the development of a joint European research strategy for polar regions.

A coordinated, multidisciplinary strategy will maximise the impact of EU research and funding; improve research integration and coordination; ensure dissemination of knowledge, education and outreach to stakeholders; and ensure high level EU contribution to world class research. One key output of the workshop is a short text indentifying priorities for further scientific investigation by the European polar research community. This strategy paper is focused on polar marine ecosystems and will be distributed within the European scientific communities and be used to inform decision makers. The next steps are currently being planned and we will aim to organize a one-day thematic workshop in Brussels (compare Annex 7: **Polar Marine Ecosystems Research: Strategic directions for the EU Research Area).**

- Manuscripts:

1) State-of-the-art knowledge of the links between marine biogeochemistry and the structure and functioning of polar marine ecosystems will be summarized in a paper together with the formulation of open questions and suggestions for future research bringing together European polar scientists (Wolf-Gladrow et al., in prep.).

2) A manuscript reviewing circumpolar Southern Ocean food webs was further developed during the workshop and the discussion sessions greatly advanced its progress (Cavanagh et al., in prep.)

- Fieldwork coordination:

The fieldwork plans of the participants were presented and will be included in the interactive fieldwork map on the ICED web page (http://www.iced.ac.uk/science/fieldworkmap.htm; compare Annex 6) to facilitate and strengthen collaborations and strategic fieldwork planning. Each cruise or long-term monitoring site will be accessible via this Google Earth interface and will be linked to a more detailed description of sampling strategy and methodology. This will enable scientists all over Europe (and beyond) to collaborate and share samples and infrastructure and to build the basis for future strategic planning. Key regions were identified during the Foresight Workshop in 2010 and we recommend that research in under-sampled or model regions will be furthered in the framework of the above-mentioned Polar Marine Ecosystems Research Strategy.

- European polar network:

All workshop delegates joined the EU polar marine ecosystem network, to work on increasing EU representation and to maintain strong Arctic-Antarctic links. Further involvement is encouraged, the first step is to sign up via the ICED website http://www.iced.ac.uk

The above outputs will provide major input into the EUR-OCEANS Consortium and ICED, and in turn will feed into CCAMLR, IPCC, IMBER and other relevant international programmes.

Next steps for the PECS Flagship

- Submit workshop **manuscripts**
- Develop the **mapping tool** to include Arctic and EU activity layers
- Prepare for **Thematic Workshop** in Brussels to influence Horizon 2020
- Explore new ways of **expanding participation and activities** of the **European network**
- Strengthen **Arctic-Antarctic community links**

Appendix and agenda

Annex1: Organizers

Prof. Dieter Wolf-Gladrow, Dr. Judith Hauck, Dr. Christoph Völker, Alfred Wegener Institute for Polar and Marine Research, Postfach 12 01 61, D-27515 Bremerhaven, Germany, email: Dieter.Wolf-Gladrow@awi.de, phone: +49 (0)471 4831 1824

Prof. Eugene Murphy, Dr. Rachel Cavanagh, Dr. Nadine Johnston, Natural Environment Research Council, British Antarctic Survey, High Cross, Madingley Road, Cambridge, CB3 0ET, UK, email: ejmu@bas.ac.uk, phone: +44 (0)1223 221614

Annex 2: Participants

Participants: Philipp ASSMY, Katarzyna BLACHOWIAK-SAMOLYK, Rachel CAVANAGH, Andrew CONSTABLE, Hauke FLORES, Nadine JOHNSTON, Judith HAUCK, Christine

KLAAS, Ksenia KOSOBOKOVA, Eugene MURPHY, Eva LEU, Evgeny PAKHOMOV, Ekaterina POPOVA, Bernard QUEGUINER, Ursula SCHAUER, Victor SMETACEK, Geraint TARLING, Paul TREGUER, Christoph VÖLKER, Dieter WOLF-GLADROW

Guests: Eduard BAUERFEIND, Astrid BRACHER , Mario HOPPEMA, Catherine LALANDE, Katja METFIES, Barbara NIEHOFF, Eva-Maria NÖTHIG, Ilka PEEKEN, Ingo SCHEWE, Volker STRASS

(please see affiliation in Annex 4)

Annex 3: Agenda of the workshop

The workshop was divided into four main compartments over three days:

1. **Introduction** (0.5 days): this comprised presentations by invited speakers to provide an overview on climate change in polar regions, the structure of Southern Ocean and Arctic Ocean food webs and biogeochemistry, and summaries of change in these ecosystems.

2. **Linking biogeochemical cycles and food web structure** (1.5 days): This session was started with a set of presentations from workshop delegates with a particular emphasis on the role of zooplankton in biogeochemical cycles. Presentation topics included, among others, a) relevant information about zooplankton in the two regions, b) key aspects of biogeochemical cycles, c) why we need improved linkages of these aspects, d) what we know about the different roles of zooplankton in these systems, and e) how we can improve models in this respect.

3. **Integration** (0.5 days): Discussion session – the integration part of the workshop discussed and collated key points from the workshop with particular emphasis on identifying similarities and differences between Arctic and Antarctic ecosystems and biogeochemistry.

4. **Perspectives and challenges for polar research** (0.5 days): This section focused on developing a *Strategy for European Polar Marine Ecosystem Research*. This included discussions on a) EU field-work plans, b) creation of European network of Polar research scientists and c) ways to develop further funding.

Monday, 26.11.2012

Day 1: 09:00 – 13:00: Introductory session (overview talks)

14:00 – 18:00: Linking biogeochemical cycles and food web structure (presentation of manuscript outline, discussion session, presentations by delegates, poster session)

Tuesday, 27.11.2012

Day 2: 09:00 – 13:00: Linking biogeochemical cycles and food web structure (presentations by delegates)

14:00 – 18:00: Linking biogeochemical cycles and food web structure (Break-out groups and plenary to summarize discussion session)

Wednesday, 28.11.2012

Day 3: 09:00 – 13:00: Integration (discussion session)

14:00 – 18:00: Perspectives and challenges for polar research (presentation of planned fieldwork, planning of future research and funding strategy)

Annex 4: Participant list EUR-OCEANS Flagship Workshop 26-28th November 2012, Bremerhaven

First name	Surname	Country of residence	Institution
Philipp	Assmy	Norway	Norwegian Polar Institute
Eduard	Bauerfeind	Germany	Alfred-Wegener-Institute for Polar and Marine Research
Katarzyna	Blachowiak-Samolyk	Poland	Institute of Oceanography of the Polish Academy of Science
Astrid	Bracher	Germany	Alfred-Wegener-Institute for Polar and Marine Research
Rachel	Cavanagh	United Kingdom	British Antarctic Survey
Andrew	Constable	Australia	Australian Antarctic Division
Hauke	Flores	Germany	Alfred Wegener Institute for Polar and Marine Research
Judith	Hauck	Germany	Alfred Wegener Institute for Polar and Marine Research
Mario	Hoppema	Germany	Alfred Wegener Institute for Polar and Marine Research
Nadine	Johnston	United Kingdom	British Antarctic Survey
Christine	Klaas	Germany	Alfred Wegener Institute for Polar and Marine Research
Ksenia	Kosobokova	Russia	P.P. Shirshov Institute of Oceanology, Russian Academy of Sciences
Catherine	Lalande	Germany	Alfred Wegener Institute for Polar and Marine Research
Eva	Leu	Germany	Alfred-Wegener-Institute for Polar and Marine Research

Katja	Metfies	Germany	Alfred-Wegener-Institute for Polar and Marine Research
Eugene	Murphy	United Kingdom	British Antarctic Survey
Barbara	Niehoff	Germany	Alfred Wegener Institute for Polar and Marine Research
Eva-Maria	Nöthig	Germany	Alfred-Wegener-Institute for Polar and Marine Research
Evgeny	Pakhomov	Canada	University of British Columbia
Ilka	Peeken	Germany	Alfred-Wegener-Institute for Polar and Marine Research
Katya	Popova	UK	National Oceanography Centre
Bernard	Quéguiner	France	Aix-Marseille University, Mediterranean Insitute of Oceanography
Ursula	Schauer	Germany	Alfred Wegener Institute for Polar and Marine Research
Ingo	Schewe	Germany	Alfred Wegener Institute for Polar and Marine Research
Victor	Smetacek	Germany	Alfred Wegener Institute for Polar and Marine Research
Volker	Strass	Germany	Alfred-Wegener-Institute for Polar and Marine Research
Paul	Tréguer	France	European Institute for Marine Studies, Brest
Geraint	Tarling	UK	British Antarctic Survey
Christoph	Völker	Germany	Alfred Wegener Institute for Polar and Marine Research
Dieter	Wolf-Gladrow	Germany	Alfred Wegener Institute for Polar and Marine Research

Annex 5 ICED home page (http://www.iced.ac.uk/)

Integrating Climate and Ecosystem Dynamics in the Southern Ocean

ICED is an international multidisciplinary programme launched in response to the increasing need to develop integrated circumpolar analyses of Southern Ocean climate and ecosystem dynamics.

ICED has been developed in conjunction with the Scientific Committee on Oceanic Research (SCOR) and the International Geosphere-Biosphere Programme (IGBP), through joint support from the Integrated Marine Biogeochemistry and Ecosystem Research (IMBER) and Global Ocean Ecosystem Dynamics (GLOBEC) programmes.

The ICED vision is to develop a coordinated circumpolar approach to better understand climate interactions in the Southern Ocean, the implications for ecosystem dynamics, the impacts on biogeochemical cycles, and the development of sustainable management procedures.

ICED Science

The ICED Science Plan and Implementation Strategy sets out an ambitious programme to address not only the significant scientific challenges of integrating Southern Ocean ecosystem, climate and biogeochemical research at a circumpolar level, but also the challenge of bringing together a multidisciplinary group of international scientists to ensure effective cooperation and communication in addressing the objectives of ICED.

The ICED Network

To become involved please complete our online form. We aim to improve Southern Ocean science integration, and to strengthen links with Arctic and non-polar scientists to understand the role of polar ecosystems in the Earth System. We encourage a wide range of scientists to join us.

For more information contact ICED.

What's New?

EUR-OCEANS Consortium Flagship on Polar Ecosystem Change and Synthesis (PECS) and EU Strategy

We have received European funding for this 2-year Flagship programme. Our first workshop was held in November 2012 and outcomes included a Strategy for European polar marine ecosystem research. Preparations are underway for a Thematic Workshop on Polar Ecosystems in Brussels. If you would like more information please contact ICED.

ICED Food Web Modelling Paper

The results of the ICED food web modelling workshop has been published in *Progress of Oceanography*.

Annex 6: http://www.iced.ac.uk/science/fieldworkmap.htm

Fieldwork Map

Improving Southern Ocean fieldwork coordination

ICED has identified the coordination of Southern Ocean fieldwork as a major priority. A coordinated approach to fieldwork will help to realise the full potential of planned field effort and will allow targeting of future circumpolar research across all relevant disciplines including ecology, physics and biogeochemistry.

ICED is developing an interactive map to display information on Southern Ocean field activities. This initiative will provide a central focus for fieldwork planning and coordination activities in the Southern Ocean, across all disciplines.

Advances in fieldwork mapping

Initial attempts to map field efforts during IPY provided a useful start point to begin fieldwork coordination. We have now begun to develop these ideas further by making use of the latest virtual globe and data sharing technologies to include information entered via the web using a system of virtual forms for data entry that uploads directly to Google Earth.

Each project and long-term monitoring site will initially be represented by a placemark. The placemark will link to more detailed information about each project. We plan to develop this to display cruise tracks (planned and completed). The map will enable information to be brought together and visualised in an accessible way for observing, coordinating and planning future Southern Ocean fieldwork.

Viewing the fieldwork map

You can view an embedded version of the Google Earth map here.

You can also download a version of the map to view in Google Earth on your computer. Download Google Earth here. To view the current version of the ICED map open this Google Earth file. We are now building on this with a view to fieldwork planning for ecosystem studies across the entire Southern Ocean. We also aim to develop an Arctic view as part of our European Flagship Project.

Once you have installed Google Earth on your computer, follow these simple instructions to display your project details on the map.

This project is currently linked with the Southern Ocean Observing System (SOOS). We are in the process of forming other programme links.

For more information about this project contact ICED.

Annex 7:

Polar Marine Ecosystems Research: Strategic directions for the EU Research Area

Polar marine ecosystems are a critical aspect of global sustainability research and should be a high priority for Europe and Horizon 2020 because:

- They are integral to the Earth System, influencing global climate and biogeochemical cycles and maintaining unique biodiversity and ecosystem services;

- Their international political and economic significance is rising; there is mounting pressure for expansion of fisheries to provide food security and, in the Arctic, exploitation of oil, gas and minerals;

- They are undergoing unprecedented, dramatic and rapid climate-driven changes affecting regional environments and peoples, with far reaching consequences for the rest of the globe;

- They provide unique historical records and insights, serve as a barometer of the current state of the planet and act as an indicator for future change;

- Assessment of their responses to change is crucial for effective stewardship and predicting effects on the Earth System.

EU polar marine ecosystem scientists recognise that:

- We have extensive (and expanding) networks of EU scientists with the ambition and experience[a] to advance polar marine ecosystem research through international, multidisciplinary collaborations;

- Horizon 2020 provides a timely opportunity to unite and harness this collective expertise to address key questions about the Polar Regions and their role in the Earth System;

- The EU should capitalise on its extensive investment and success to date, raising its level of excellence and strengthening its leadership and international partnerships in polar marine ecosystem research.

To advance knowledge of polar marine ecosystems and their influence on global cycles, we

recommend that:
Polar marine ecosystem research is focused on the Arctic *and* the Antarctic

- Rapid changes in the Arctic are clearly a high priority for the Northern Hemisphere. However, from a scientific and Earth System perspective, parallel Southern Ocean research is also crucial;

- The Arctic is warming and sea ice is rapidly receding, with the record minimum Arctic ice extent reached in 2012. The Antarctic has areas of both ice reduction and expansion, and the Antarctic Peninsula is one of the most rapidly warming parts of the planet. Significant ecological responses to such changes are being documented and the consequences need to be understood;

- Physical dynamics of Southern Ocean water masses are rapidly changing due to atmospheric variations (e.g. ozone and greenhouse gases) and are in turn affecting the physical and biological carbon pumps;

- As the oceans continue to absorb anthropogenic CO_2 and become more acidic, the survival of shelled organisms (incl. algae and invertebrates) will be affected. Ocean acidification (decrease of pH, reduced saturation level for calcium carbonate minerals) is especially strong in cold waters, and evidence of dissolution in Antarctic marine snails has already been reported;

- Southern Ocean ecosystem studies provide some of the longest continuous scientific observations on record; much more extensive than from the Arctic. Together these give an historical context predicting change and for effective stewardship of these regions;

- The Southern Ocean is one of the few areas where there is sufficient knowledge across a range of spatial, temporal and trophic scales (e.g. from microbes to whales, from local to circumpolar scales) to understand whole ecosystem operation. These analyses also have relevance to Arctic and global ocean ecosystems;

- Both regions have rapidly expanding EU and globally important fisheries. Their effective management, underpinned by ecological research, will allow for sustainable development;

- Through comparative studies of both oceans, we will rapidly advance knowledge about the Polar Regions, their influence on global cycles and ecosystems, their responses to change, and their effective stewardship.

Polar marine ecosystem research should be focused on these over-arching priority questions:

- What are the main drivers of ecological responses to change (including oceanographic forcings at different scales, direct effects on individual species, indirect effects through the food web and harvesting)?

- What is the role of these ecosystems in polar (and global) nutrient cycles, how are key processes linked, and how will these be affected by change?

- How should change be accounted for in the sustainable management of resources in the polar oceans?

Key scientific activities, working towards integrated end-to-end ecosystem analyses, should include:

- Multidisciplinary international research cruises in key regions of both polar oceans;

- An international network of long-term multidisciplinary observations (including moorings, gliders and predator-mounted oceanographic instruments) in both polar oceans;

- Comprehensive data mining, syntheses and management;

➢ A concerted modelling effort to improve the scientific basis and proficiency of models in projecting the response of polar marine ecosystems to environmental change and their feedbacks to the Earth System.

To achieve European and international leadership and collaborations in this field we recommend that:

A clear strategy for integrated European polar marine ecosystem research is developed

➢ A coordinated, multidisciplinary strategy (linked to the European Polar Board) will maximise the impact of EU research and funding; improve research integration and coordination; ensure dissemination of knowledge, education and outreach to stakeholders; and ensure high level EU contribution to world class research.

The EU polar marine ecosystem communities are now poised to unite for unparalleled scientific integration in understanding and predicting future change, working towards an Earth System perspective. The EU can capitalise on its investment and success, raising its scientific excellence and strengthening its leadership in this globally relevant research. Outputs will address major scientific and socio-economic concerns on climate change, food and employment security. We strongly recommend that marine ecosystem research, focused on both the Arctic and Antarctic, is a high priority for Horizon 2020. We are keen to present further details to support the above.

Rachel Cavanagh[1], ***Nadine Johnston***[1], ***Eugene Murphy***[1], ***Paul Tréguer***[2] *and* ***Dieter Wolf-Gladrow***[3], on behalf of the EUR-OCEANS Consortium Flagship for Polar Ecosystem Change and Syntheses (PECS)

[1] British Antarctic Survey, Cambridge, CB3 0ET, UK, Contact email: rcav@bas.ac.uk, phone: +44 (0)1223 221400; [2] European Institute for Marine Studies, Brest, France; [3]Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany

[a]The Framework Programmes (e.g. FP6 EUR-OCEANS NoE and its legacy the EUR-OCEANS Consortium, including PECS) have enabled multidisciplinary networks of EU polar scientists to lead globally important analyses of polar ecosystems and drive international activities addressing significant science challenges (e.g. Integrating Climate and Ecosystem Dynamics in the Southern Ocean, ICED, programme). These partnerships were strengthened during the International Polar Year (2007-8, planned by the International Council for Science), providing a unique multidisciplinary snapshot of the poles. These activities have provided a legacy of partnerships that will allow us to achieve far more than that of any single nation or discipline.