Steiner, N and Stefels, J 2017 Commentary on the outputs and future of Biogeochemical Exchange Processes at Sea-Ice Interfaces (BEPSII). *Elem Sci Anth,* 5: 81. DOI: https://doi.org/10.1525/elementa.272

COMMENTARY

Commentary on the outputs and future of Biogeochemical Exchange Processes at Sea-Ice Interfaces (BEPSII)

Nadja Steiner* and Jacqueline Stefels†

Biogeochemical processes associated with sea ice are still inadequately described and poorly represented in models, making it difficult to properly quantify the impacts of climate change in polar regions. Within the framework of the international Scientific Committee of Ocean Research (SCOR) working group 140, BEPSII, a community of sea-ice biogeochemical scientists established guidelines for the measurement of biogeochemical processes in sea ice, collated observed data, synthesized knowledge of sea-ice biogeochemical processes, and identified the feedbacks between biogeochemical and physical processes at the terrestrial-ocean-ice-snow-atmosphere interfaces and within the sea-ice matrix. Many of these results are presented in Elementa's Special Feature on BEPSII. By bringing together experimentalists and modelers, major improvements of sea-ice biochemistry models have been achieved which are anticipated to affect models on micro- to global scales. However, large gaps still exist in our understanding of detailed biogeochemical processes in sea ice, their seasonal evolution and their interactions with surrounding environments. The BEPSII community recommends continued focus on the development of reproducible methods and techniques for reliable inter-study comparisons, to enhance our understanding in areas where gaps have been identified via coordinated process studies combining modeling tools, laboratory experiments and field studies, and on the use of such studies to develop conceptual models helping us to understand the overall system.

Keywords: sea-ice biogeochemistry; BEPSII; sea-ice biogeochemistry measurement methods

Introduction

Near-future climate change is projected to have its strongest impact in polar regions due to direct changes in the surface area of ice sheets and open water and to subsequent feedbacks. Our understanding of these processes and the representation of these processes in models is still in its infancy. While sea ice will not completely disappear from polar regions, it is experiencing profound change in seasonality, especially in the Arctic with subsequent changes in its biogeochemical and physical properties (Stroeve et al., 2012a, b; Flato et al., 2013; Steiner et al., 2015).

Observations over the last 20 years have identified numerous, previously unknown biogeochemical processes occurring in the sea-ice zone, which spans 10% of the world ocean. These processes can occur within sea ice itself, or involve terrestrial-atmosphere-sea ice-ocean exchange of biogeochemical compounds. Sea-ice processes impact the underlying seawater and remote water masses through effects on marine productivity, nutrient stocks, and releases of brine and meltwater. Sea-ice processes also affect the atmospheric composition by controlling air-sea fluxes of gases and aerosols with the potential for significant climate feedbacks through direct and indirect (cloud) forcing mechanisms (**Figure 1**). Terrestrial processes can impact sea-ice and ocean processes by transporting nutrients and carbon via riverine input and coastal erosion. Higher trophic levels of polar ecosystems are dependent on sea ice. Indigenous communities in the Arctic are affected by changes in sea-ice biogeochemistry through cascading ecosystem effects (AMAP, 2017a, b, c). Changes in sea-ice structure and integrity will themselves impact the use of sea ice for cultural purposes and transportation.

Despite significant progress, our understanding of the biogeochemistry of the sea-ice zone remains limited. Observations are sparse due to technical and logistical limitations, and satellite remote sensing is insufficient for sea-ice biogeochemical parameters. Available historic observations have not been compiled into consistent and easily accessible databases. As a consequence, the representation of sea-ice zone biogeochemical processes in regional and Earth system models (ESMs) is extremely simple, and our confidence in understanding either the present importance of these processes or how they will respond to climatic change is limited. The Scientific

* Institute of Ocean Sciences, Department of Fisheries and Ocean Canada, Sidney, BC, CA

† University of Groningen, Groningen Institute for Evolutionary Life Sciences, Groningen, NL

Corresponding author: Nadja Steiner (nadja.steiner@dfo-mpo.gc.ca)

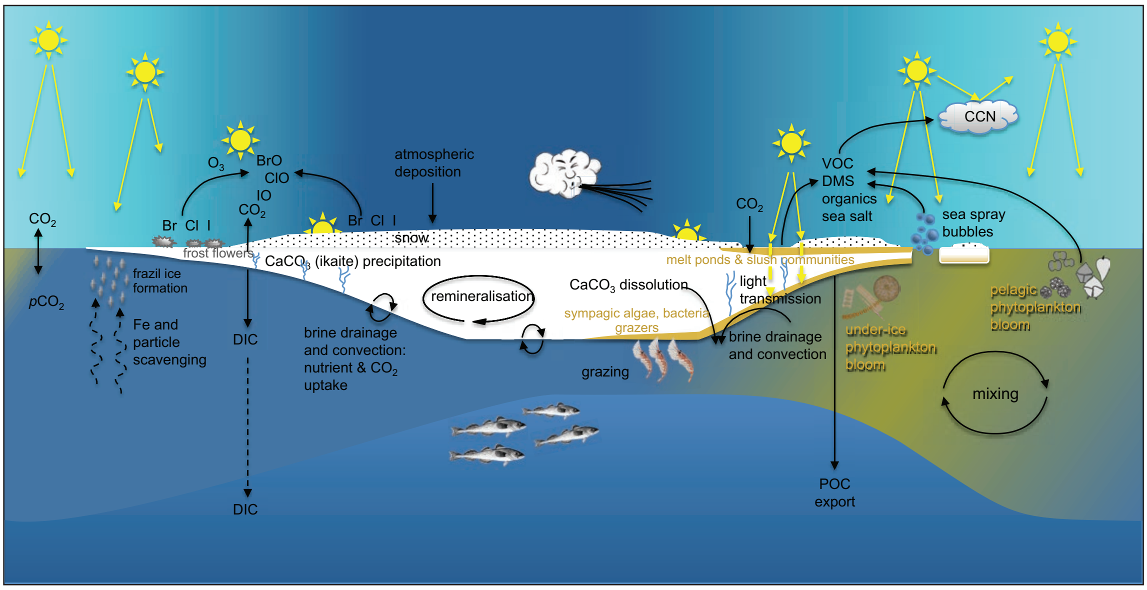

Figure 1: Schematic representation of biogeochemical processes at sea-ice interfaces and within sea ice over the seasons. DIC indicates dissolved inorganic carbon; POC, particulate organic carbon; VOC, volatile organic carbon; DMS, dimethylsulfide; and CCN, cloud condensation nuclei. DOI: https://doi.org/10.1525/elementa.272.f1

Committee of Ocean Research (SCOR) working group on Biogeochemical Exchange Processes at Sea-Ice Interfaces (BEPSII) is dedicated to study, review, evaluate and model these processes and exchanges in the sea-ice zone in both the Arctic and Antarctic.

Trying to understand the role of sea ice in the Earth's system means embracing a complex system of processes where processes at the microscale have far-reaching implications for the regional to global scale. A prerequisite to understanding this system is that the main processes and feedbacks at each and every scale be examined from an integrated perspective. Under the SCOR WG umbrella the BEPSII community tackled these challenges by concerted interaction between field scientists and modelers and brought together sea-ice specialists from multiple disciplines and modelers of sea-ice systems at the different scales, in order to address the following goals:

1) Standardize methods for data intercomparison;
2) Summarize existing knowledge in order to prioritize processes and model parameterizations;
3) Scale up processes from 1-D to Earth system models;
4) Analyze the role of sea-ice biogeochemistry in climate simulations.

BEPSII goals

In order to achieve the goals of BEPSII, activities were structured into three task groups, which have been working towards those goals over the last five years. Many of the outcomes are published in the BEPSII special feature of Elementa, as well as in other journals.

Methodologies and Intercomparisons

Task Group 1 on Methodologies and Intercomparisons identified three primary goals: compiling a methodological review, designing intercomparison and intercalibration projects, and working towards a guide of best practices. In order to evaluate currently available data on important parameters affecting sea ice physics and biochemistry and to make recommendations for further data collection needed for the validation of models, a thorough evaluation of existing and new methods is required. The need for this evaluation arises from the specific challenges involved in sea-ice studies: sea ice is a complex medium, including not only the sea-ice matrix, but also brines, gases and solid salt precipitates; and it exhibits substantial variability on all spatial and temporal scales. Miller et al. (2015) compiled a comprehensive review of the current state-of-the-art in sea-ice biogeochemical methods, including an assessment of their relative strengths and weaknesses, highlighting both the challenge and the complexity of measuring biological and chemical compounds in sea ice. While much progress has been made over recent years in figuring out how to measure and interpret the processes occurring in sea ice, many uncertainties remain with respect to the best practices of methods under different conditions. Miller et al. (2015) highlight the need for dedicated, collaborative field and laboratory studies, including expeditions that are focused solely on methods, to compare and intercalibrate the methods in use. The field of sea-ice biogeochemistry also provides experimental ground for new technological developments, new approaches and new methods, with a critical need for in situ probes (robust enough for long-term deployment in sea ice), to effectively answer many of the arising questions. Miller et al. (2015) also recommend that all future investigations include a core suite of ancillary measurements and employ a standard approach for sample identification and documentation. Our hope is to extend and update the compilation by Miller et al. (2015) over the coming years and to act on the group's vision to create an interactive online document providing a guide of best practices.

While the need for method intercalibration studies was strongly highlighted within the BEPSII research community, performing actual experiments was kept to a minimum during the timeframe of the SCOR working group. However, an intercomparsion of ice-melt methods indicated that for brackish sea-ice samples fast direct melting results in biologically more accurate results than slow buffered melting (Rintala et al., 2014). In preparation for more logistically demanding experiments, the BEPSII group dedicated much time to identifying components, needs and potential locations for such experiments, as well as outlining procedures for intercalibration studies. A new proposal for networking support was accepted by SCOR in September 2016 (SCOR Working Group 152, Measuring Essential Climate Variables in Sea Ice, ECV-Ice). The group's intention is to perform such intercalibration studies in the near future.

Data Collation and Management

Task Group 2 on Data Collation and Management was occupied with two primary goals: producing new data inventories by collation of existing data, and providing recommendations for standardized protocols and databases. The collation of datasets is a tedious process that requires not only a dedicated leader, but also the participation and collaboration of many individuals in the science community. Within the BEPSII framework several datasets have been compiled. The first dataset on Antarctic pack-ice Chlorophyll-*a* (Chl-*a*, Meiners et al., 2012), showed that integrated sea-ice Chl-*a* peaks in early spring and late austral summer, with the vertical distribution of sea-ice algal biomass depending on ice thickness. The dataset on Antarctic sea-ice macronutrients (Fripiat et al., 2017) indicates that the sea-ice microbial community is highly efficient at processing nutrients but with a dynamic quite different from that in oceanic surface waters, which calls for focused future investigations. The Antarctic sea-ice iron data (Lannuzel et al., 2016) highlights the active extraction of iron from seawater into sea ice, which results in concentrations at least an order of magnitude higher than in the underlying seawater. The various forms in which iron exists behaved differently when scaled to sea-ice salinity, which suggests distinct, spatially and temporally decoupled processes as drivers for iron distributions in sea ice.

A synthesis of the relationship between sea-ice bacterial community structure and biogeochemistry (Bowman, 2015) indicates a strong, variable relationship with Chl*a* and provides taxonomic support for some observed metabolic processes, as well as underexplored processes such as sulfur oxidation and nitrogen fixation. An analysis of the temporal and spatial variability in sea-ice carbon:nitrogen ratios on Canadian Arctic shelves (Niemi and Michel, 2016) demonstrated that the Redfield ratio has limited applicability over the four- order of magnitude range of biomass concentrations observed in first-year sea ice on Arctic shelves. A data synthesis of microalgal biodiversity and productivity in sea ice (van Leeuwe et al., 2017) identified consistent patterns in biodiversity: flagellates characterize surface communities, interior communities consist of mixed communities and pennate diatoms dominate bottom layers. van Leeuwe et al. (2017) also point out that seasonality has a significant impact on the distribution of algal groups and that the role of sea-ice communities in seeding pelagic blooms remains enigmatic. These results are highly relevant for modeling studies. Efforts are underway to collate measurements for additional variables in both the Arctic and Antarctic. All Antarctic data sets are stored in the Australian Antarctic Data Centre (AADC, http://data.aad.gov.au/aadc/seaice/).

BEPSII researchers strongly recommend the use of common data sheets to help create consistent observational data sets that include the necessary ancillary data. Several such sheets have been developed by the Antarctic Sea-ice Processes and Climate (ASPeCt) expert group and are available from the AADC. To facilitate the collation, quality assurance and analyses, a variety of new MATLAB scripts to read information from standardized data-entry forms (i.e., ASPeCt-Excel sheets) have been developed, and are available through the BEPSII home page (https://sites.google.com/site/bepsiiwg140/home).

Process Studies and Modeling

Task Group 3 on Process Studies and Models worked on four products: recommendations from modelers to observers, review papers on major biogeochemical processes, intercomparison of 1-D models and publication of a review, and application of sea-ice biogeochemistry in regional models with links to global and regional climate modeling.

Improving model parameterizations requires communication between observers and modelers to both guide model development and improve the acquisition and presentation of observations. In addition to more observations, modelers need conceptual and quantitative descriptions of the biogeochemical processes in sea ice. Steiner et al. (2016) provide guidelines to help modelers and observers improve their communications and integration of measurements and modeling efforts. The paper provides details on the various types of modeling and compiles the needs for sea-ice biogeochemical modeling on different temporal and spatial scales. The aim is to provide a better understanding of what kind of observations modelers need, and consequently how field campaigns should be designed to support modeling efforts and how the results should be reported to help modelers to gain the most from the observations. A guide for modelers aiming at facilitating the implementation of sea-ice biogeochemical modules into existing ocean-ice models is provided by Tedesco and Vichi (2014).

In a concerted effort, experimentalists and modelers summarized existing knowledge on various biogeochemical and physical processes at the ocean-ice-snow-atmosphere interfaces and within sea ice. The results of this effort appear in several synthesis papers mentioned above (Meiners et al., 2012; Bowman, 2015; Niemi and Michel, 2016; Lannuzel et al., 2016; Fripiat et al., 2017; van Leeuwe et al., 2017). In addition to collating data and synthesizing the results, focus was placed on identifying gaps in model parameterizations of the related processes.

(Bowman, 2015) highlighted that an adequate modeling framework and studies that can resolve the functional dynamics of the sea-ice bacterial community, such as community gene-expression studies, are urgently needed to predict future change. Niemi and Michel (2016) emphasized the need for variable C:N stoichiometry in sea-ice biogeochemical models. van Leeuwe et al. (2017) indicated that seasonal succession in ice algal communities may need to be represented in models.

Physical processes emerged from evaluations of young Antarctic sea ice during its initial growth stages as the dominant mechanisms leading to the enrichment of dissolved and particulate iron, organic matter, and bacteria into young sea ice (Janssens et al., 2016). Within sea-ice brines, bacteria were observed to use compatible solutes for osmoprotection, transporting, storing, and cycling of these organic compounds as needed to withstand naturally occurring salinity shifts. The cycling activity (production of ammonia) was likely linked to nitrification (Firth et al., 2016). The cycling of the volatile organic compounds, dimethylsulfide (DMS), dimethylsulfoniopropionate (DMSP) and dimethyl sulfoxide (DMSO), in Antarctic spring ice was influenced strongly by short-term synoptic events, most likely due to due to the temperature impact on the connectivity and stability of the brine network (Carnat et al., 2016). Differences in ozone vertical profiles at Arctic coastal and inland sites could not be attributed to differences in locally occurring halogen chemistry, but instead were linked to interactions with open water between sea-ice floes (leads), causing increased vertical mixing and recovery of ozone (Peterson et al., 2016). The applicability of bio-optics for estimating photosynthesis rates of sea-ice algae in the Baltic Sea was assessed by Müller et al. (2016). In situ and temperature-controlled short-term radiotracer incubations identified a significant correlation between sea-ice temperature and intracellular iron uptake by Antarctic sea-ice algae as well as indications of luxury iron uptake (Lannuzel et al., 2017). Sea-ice tank experiments showed that sea ice is a source of CO_2 during ice formation and a sink during ice-melt periods, with a suggested role for gas-bubble formation to explain the measured outflux of CO_2 (Kotovitch et al., 2016).

Such compilations and focused research efforts are essential to the development and improvement of model parameterizations and models, which eventually allow us to quantify our knowledge of the impact of sea-ice biogeochemistry on climate and how climate change feeds back to sea ice. Several model studies have been performed within BEPSII in an effort to improve specific processes affecting sea-ice biogeochemistry. These include the transfer of gases (O_2) within the sea-ice matrix in order to assess the O_2 budget under sea ice (Moreau et al., 2015), and the implementation of subgrid-scale snow thickness variability to improve the evolution of light transmission during the freeze-melt transition in spring, which is required for ice algal growth (Abraham et al., 2015). This parameterization is applied in Mortenson et al. (2017), who analyzed the impacts of mortality and photosynthetic parameterizations on the onset, maximum and decline of the sea-ice algae bloom for Resolute Passage in the Canadian Arctic Archipelago. Hayashida (2017) extended the model to include the sea-ice sulfur cycle, indicating the importance of sea-ice algal DMS contributions and sporadic DMS fluxes via openings in the ice in early spring. Yakshina and Golubeva (2017) examined the impact of ice-penetrating short-wave radiation on the formation of the subsurface temperature maximum, further highlighting the importance of adequate representation of radiative fluxes through ice on the under-ice ocean structure. A new implementation of a spatial sea-ice algae model with application to the northern Baltic Sea is presented in Tedesco et al. (2017). Procedures for multi-model intercomparisons of the seasonal cycle of sea-ice algal growth and decline have been developed and publication efforts are currently in progress.

There is an urgent need to translate relevant processes from small-scale models to global ESMs. As investment in development time for the insertion of new mechanisms into ESMs can be high, modelers not only need to develop simplified parameterizations, but also to develop small to intermediate scale models that are able to prioritize ice biogeochemistry to climate linkages. Vancoppenolle et al. (2013a) highlighted the role of sea ice in global biogeochemical cycles. Compilations of Earth system model results of projected future Arctic Ocean acidification (Steiner et al., 2013, 2014) and Arctic primary production (Vancoppenolle et al., 2013b) acknowledged the impact of sea ice on gas exchange, mixing and light, but do not explicitly include sea-ice biogeochemistry. An analysis of the future of the subsurface Chl*a* maximum in the Arctic (Steiner et al., 2015) includes higher resolution ice-ocean-ecosystem models, but only one model includes ice algae and the specific impacts thereof were not discussed. Nutrient uptake by ice algae and subsequent remineralization in the surface ocean will very likely affect the temporal evolution of the deep Chl*a* maximum. Grimm et al. (2016) and Moreau et al. (2016) included dissolved inorganic carbon (DIC) and total alkalinity (TA) into the sea-ice component of two different three-dimensional ocean-sea ice models to assess the sea-ice carbon pump (SICP, the separation and sequential release of DIC and TA during sea-ice growth and melt processes). Both studies indicate that the efficiency of the SICP is related to the concentration and the ratio of TA to DIC in sea ice relative to the oceanic TA and DIC conditions and to the export of brine-bound DIC to depth, which is larger in the Antarctic than in the Arctic. They concluded that climatic changes induce considerable variations in the strength of the SICP on a regional scale. However, on a global scale, the influence of the SICP on the air-sea CO_2 flux was suggested to be small. Impacts of biological processes on the carbon cycle were not included in these studies.

Summary and Outlook

To date, BEPSII has promoted the publication of scientific papers and reviews, conducted cross-cutting community workshops, initiated community model intercomparisons, and identified critical requirements for methodological developments, data-quality control and reporting protocols. BEPSII achieved many of its goals with respect to synthesizing available sea-ice biogeochemical research and establishing an active and coordinated community of sea-ice biogeochemical researchers. The need to continue the work within such a community with the winding down of the SCOR working group has been recognized by several other science and research organizations. BEPSII is now entering its second phase as a research community with support from the Surface Ocean Lower Atmosphere Study (SOLAS), the Climate and Cryosphere program (CLIC), the Scientific Committee of Antarctic Research (SCAR) and the International Arctic Science Committee (IASC) and will continue to seek support from international and national organizations.

In an effort to build upon the work initiated by SCOR WG 140, and the many findings and successes of the program, as evidenced by the contributions to this Special Feature in Elementa and to other journals, BEPSII has formulated new goals and objectives to:

1) develop dedicated consistent methodologies for sea-ice biogeochemical research;
2) establish effective sea-ice biogeochemical data-archiving approaches and databases;
3) foster process studies to determine impacts on ecology and biogeochemical cycles;
4) foster technological developments and international knowledge transfer towards large-scale, autonomous and high-frequency sampling of sea-ice biogeochemical parameters;
5) improve the representation and evaluation of sea-ice biogeochemistry in regional and Earth system numerical models;
6) synthesize and integrate observational and modeling efforts;
7) continually revise and renew scientific foci, teams, and objectives; and
8) develop conceptual models describing sea-ice interactions in or with the Earth system.

These new goals will be addressed by five task groups, each focused on one of the goal-encompassing topics that follow.

Methodologies

Method intercalibration studies, a need strongly highlighted in the BEPSII research community, will be developed within the SCOR working group ECVice. Currently planned for intercalibration are techniques to measure gas concentration in sea ice. Respective experiments will be performed at the Roland von Glasow ice tank facility at the University of East Anglia. Techniques to measure primary production in sea ice are also planned for intercalibration. A first experiment will be conducted in Japan in 2018, and Cambridge Bay in the Canadian Arctic Archipelago is currently being evaluated as a location for an extended experiment in 2019. Also included are assessments of tracer incubation protocols for general metabolic rate determinations in sea ice (e.g., bacterial production, nutrient transformations) and methods to estimate bacterial production and abundance, DNA/RNA, biomass, nutrients, taxonomy, and storage of ice cores for later analysis. Special emphasis will be put on the nutrient-chlorophyll paradox in productive sea ice. An initial experiment to intercalibrate methods and devices to sample, process, store, and analyze trace metal concentrations in sea ice is in progress for the Ross Sea, Antarctica, where duplicate cores were collected using three different coring devices. Finally, techniques for light measurements within and under sea ice are under discussion. The task group will design experiments and collate results from ice tank facilities and field campaigns to investigate and possibly isolate specific biogeochemical processes currently not represented in models and pursue the vision of creating a guide of best practices in an interactive online document. All of these efforts aim at unifying observational procedures and methods to enhance reproducibility and comparability among internationally conducted polar field projects.

Technology and Data Collation

Many biogeochemical sensors that have been developed for temperate or open-ocean conditions need to be adjusted for use in polar conditions. Remotely controlled platforms will allow to circumvent accessibility issues (e.g., under sea ice). Coordinated development and validation will expand our capability for biogeochemical measurements in sea-ice environments. BEPSII as a program is ideally suited to support in-situ platform and sensor development and validation. BEPSII as a community of researchers also continues to pursue its initial work on historical data collation and analysis. Efforts are currently in progress to collate datasets for Antarctic fast ice Chl*a*, Arctic sea-ice Chl*a*, Antarctic sea-ice DIC/TA, sea-ice ^{18}O-H_2O, Antarctic sea-ice particulate and dissolved organic carbon and Arctic sea-ice nutrients. Additional effort will be extended towards tools and protocols for gene-based community assessments and international networking on laboratory ice-tank facilities.

Modeling and Observational Process Studies

One of the BEPSII efforts is to design consistent and reproducible time-series process studies for multidisciplinary projects, so as to improve the usefulness and efficacy of observational data for models. Other process studies and analyses will focus on ridge-associated processes, the impact of biochemistry on physical ice properties, light transmission and ecological responses, and sea-ice algal phenology. Studies on the interactions between snow and sea ice is a collaborative action with IGAC's Cryospheric Atmospheric Chemistry (CATCH). An important task is to upscale localized process studies to regional scales, which includes studies of representativeness and patchiness of observations.

Continued development and intercomparison of 1-D models will allow to select for parameterizations of relevance that warrant implementation in regional or global models. The inclusion of sea-ice biogeochemistry in regional models is currently expanding, and intercomparisons of 3-D models are being planned within the framework of the Forum of Arctic Modeling and Observational

Synthesis (FAMOS) and within the SCAR scientific research program Antarctic Climate Change in the 21st Century (AntClim^{21}).

Syntheses

One essential component of synthesizing processes and developing model parameterizations is the development of conceptual process models that describe linkages of biogeochemical processes to exchanges between sea ice and surrounding environments, including sea ice-pelagic-benthic coupling, sea ice-pelagic-terrestrial coupling, and atmosphere-snow-sea ice coupling. For many of the interactions involving the sea-ice environment our understanding across multiple space and time scales is very limited. There are clear needs to discuss linkages in a multi-disciplinary environment, address open questions and unknowns via specific testing in field projects, hypotheses testing also with models, and model intercomparison projects. BEPSII will also establish links to related processes on a paleoclimatic timescale via the Past Global Changes (PAGES) working group on sea-ice proxies (SIP).

Many of the linkages and functional interactions among the biological communities associated with sea ice are insufficiently known. These include interactions within the microbial foodweb, seeding of pelagic primary and secondary production, and cascading links to higher trophic levels. Identifying and analyzing these and other linkages are crucial to inferring the impacts of changing Arctic and Antarctic environments on polar ecosystems and biodiversity and to improving confidence in ecosystem models.

Outreach

As Arctic sea ice retreats, human activities such as subsistence fisheries and hunting, tourism, resource extraction and shipping change or accelerate. Most human activities affect biogeochemical processes either directly, as through the deposition of contaminants on ice and into the ocean, or indirectly through atmospheric and oceanic warming and ocean acidification. Changes in sea ice and sea-ice algal production directly impact species that rely on sea ice as their habitat and source of food, e.g., zooplankton species and higher trophic levels such as polar cod *Boreogadus saida* (Kohlbach et al., 2016, 2017), but also affect the exchange, uptake, release and production of climate-active gases. Hence, BEPSII is assessing links of sea-ice biogeochemical processes and impacts to stakeholders and policy makers via involvement in the Arctic Council's Arctic Monitoring and Assessment Program (AMAP), the International Arctic Science Committee (IASC), and the Scientific Committee of Antarctic Research (SCAR).

BEPSII is building capacity by strongly supporting early career scientists and students. Efforts include the organization of a field school anticipated for summer 2019, travel support to annual meetings, and encouragement to take on leadership roles in synthesizing available information within their field of expertise with mentoring from senior scientists. BEPSII results and work plans are made available to the scientific community and the public via Facebook (https://www.facebook.com/SCOR.BEPSII), Twitter (@BEPSII_seaice) and the BEPSII website (https://sites.google.com/site/bepsiiwg140/home).

Concluding remarks

The manuscripts presented in Elementa's Special Feature on BEPSII summarize our collated knowledge of sea-ice biogeochemical processes and measurement techniques at the time and provide an introduction and resource for new as well as established researchers in the field. The publications highlight sea ice in polar regions as an important medium for biogeochemical processes which can have large impacts on local and regional scales. Sea-ice biogeochemical research has a highly collaborative international nature as indicated by the multi-national authorship of the manuscripts (sometimes representing over ten countries). This also indicates that many open questions require multi-national contributions to address the particular research problem. The material presented points out gaps, uncertainties and critically missing pieces which we hope will inspire and drive continued, focused research combining field observations, laboratory experiments and model studies and aid in the writing of proposals to support this research. Scientists with an interest in sea-ice biogeochemistry are invited to join our community and contribute to our ongoing endeavor to quantify the role of sea ice in polar ecosystem services – from biodiversity impacts to climate change – and help us to communicate these globally-relevant issues.

Acknowledgements

We gratefully acknowledge the BEPSII steering committee for their leadership and vision, and all members of the BEPSII research community for their expertise and enthusiasm which made SCOR working group 140 on Biogeochemical Exchange Processes at Sea-Ice Interfaces (BEPSII) a successful and enduring program. We thank all authors, editors and reviewers for their contributions, time and support to make this special feature so special.

Funding information

This article is a product of the Scientific Committee on Ocean Research (SCOR) working group 140 on Biogeochemical Exchange Processes at Sea-Ice Interfaces (BEPSII). The initiation of the BEPSII network took place during a workshop organized under the aegis of the European COST Action 735 ('Tools for Assessing Global Air-Sea Fluxes of Climate and Air Pollution Relevant Gases'; a SOLAS-related activity). NS acknowledges salary funding from Fisheries and Oceans Canada.

Competing interests

The authors have no competing interests, as defined by Elementa, that might be perceived to influence the research presented in this manuscript.

Author contributions

- Contributed to conception and design: NS, JS
- Drafted and/or revised the article: NS, JS
- Drafted and/or revised the figure: JS
- Approved the submitted version for publication: NS, JS

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How to cite this article: Steiner, N and Stefels, J 2017 Commentary on the outputs and future of Biogeochemical Exchange Processes at Sea-Ice Interfaces (BEPSII). *Elem Sci Anth,* 5: 81. DOI: https://doi.org/10.1525/elementa.272

Domain Editor-in-Chief: Jody W. Deming, University of Washington, US

Knowledge Domain: Ocean Science

Part of an *Elementa* Special Feature: Biogeochemical Exchange Processes at Sea-Ice Interfaces (BEPSII)

Submitted: 18 July 2017 **Accepted:** 06 December 2017 **Published:** 27 December 2017

ELEMENTA Science of the Anthropocene

Elem Sci Anth is a peer-reviewed open access journal published by University of California Press.

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