BEPSII Policy Brief

Biogeochemical Exchange Processes at Sea-Ice Interfaces

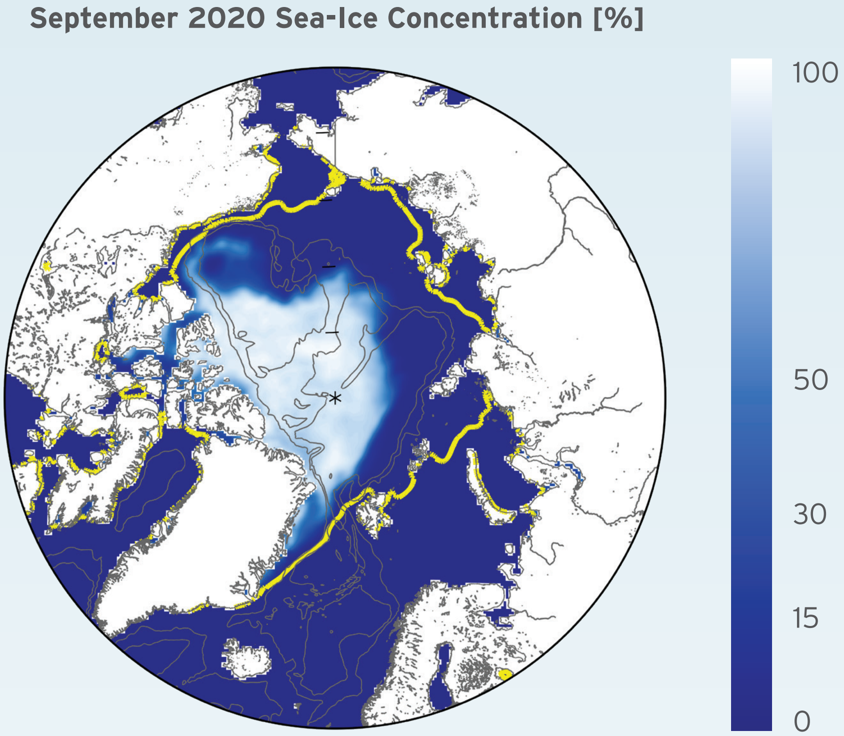
Effective Arctic climate change mitigation and adaptation strategies require consideration of biogeochemical and ecological impacts of sea-ice decline.

BEPSII Policy Brief: Key Messages

- Arctic sea-ice decline is one of the most prominent manifestations of global climate change.
- Sea-ice forms the basis of a thriving ecosystem that supports all four ecosystem service categories (habitat, provisioning, regulating, and cultural) and meets the criteria for Ecologically or Biologically Significant marine Areas (EBSAs).
- The decrease in sea ice is accompanied by:
    - increasing light penetration associated with earlier seasonal primary production;
    - increasing emissions of dimethylsulfide, an aerosol precursor;
    - increasing stress on sea-ice fauna, endemic fish, and megafauna;
    - increasing methane emissions; and
    - decreasing mercury deposition events.
- Global greenhouse gas emissions driving climate change are directly responsible for the demise of sea-ice ecosystems and its ecosystem services.
- Conservation measures can help protect some species and functions and should include explicit consideration of the sea-ice ecosystem.
- Reducing carbon emissions is the foremost mitigation measure able to slow the loss of the year-round sea ice, reduce the overall loss of sea-ice habitats, and thus preserve the unique ecosystem services provided by sea ice and their contributions to human-well being.
- Evaluating mitigation measures such as geoengineering operations to slow sea-ice melting must consider impacts on sea-ice and ocean biology and biogeochemistry.
- Reducing the uncertainties associated with the ecological and biogeochemical impacts of sea-ice decline requires long-term observing at multiple sites and enhanced process model development and downscaling.

(ABOVE) *Drifting pack ice sampling*
Photo: Andreas Wolden

Figure 1: Arctic sea ice concentration in September 2020. The historical (1979-2018) climatology for the September sea ice edge (15% sea ice concentration) is indicated in yellow.



Sea ice is a critical habitat that is fully integrated into the Arctic ecosystem. A recent community expert analysis (Steiner et al., 2021) concluded that the **sea-ice ecosystem qualifies as an Ecologically or Biologically Significant Area** (EBSA; Box 1), that **provides** all four categories of **ecosystem services** (Box 2).

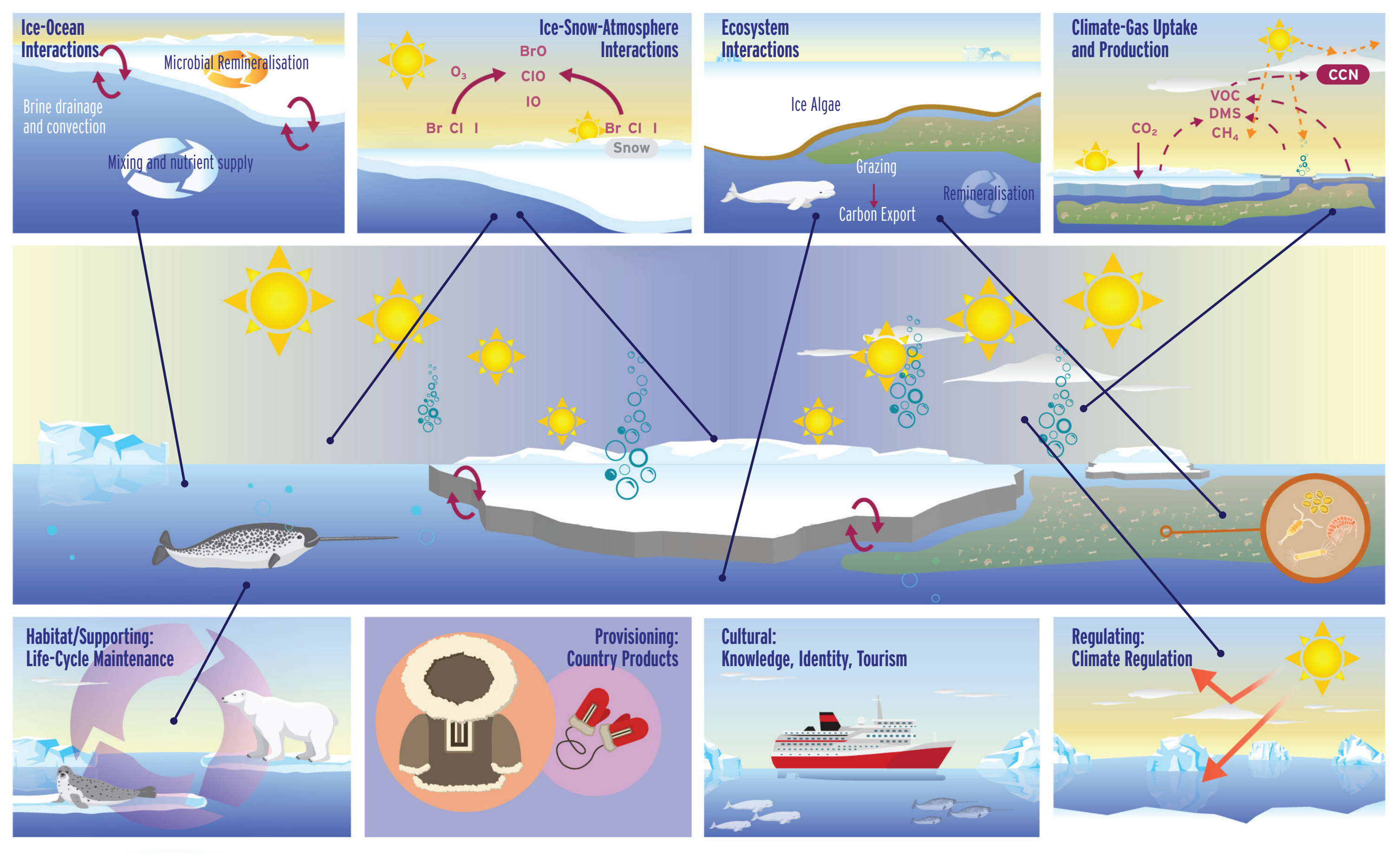
Box 1: The sea-ice ecosystem is an Ecologically or Biologically Significant Area (EBSA)

The Convention on Biological Diversity (CBD, 2008) defines an EBSA as "a geographically or oceanographically discrete area that provides important services to one or more species/populations of an ecosystem or to the ecosystem as a whole, compared to other surrounding areas or areas of similar ecological characteristics." EBSA designation is based on seven criteria. For sea ice, six of the criteria are ranked high, one criterion, biological productivity, is ranked medium (Steiner et al. 2021).

EBSA Criteria	Low	Med	High
Uniqueness or rarity			■
Special importance for life-history stages			■
Importance for threatened, endangered or declining species and/or habitat			■
Vunerability, fragility, sensitivity, or slow recover			■
Biological productivity		■	
Biological diversity			■
Naturalness			■

Box 2: Sea-Ice Ecosystems and Ecosystem Services

The concept of ecosystem services guides environmental decision-making by highlighting the multiple ways by which ecosystems support human well-being and how biophysical changes can affect humans. Ecosystem services are categorized into supporting, provisioning, cultural, and regulating services. Steiner et al. (2021) identified the following services that sea-ice ecosystems provide:



A variety of sea-ice ecosystem processes (top row) link the sea ice to the 4 different ecosystem service categories (bottom row).

SUPPORTING SERVICES in the form of habitat, including feeding grounds and nurseries for microbes, meiofauna, fish, birds and mammals, as well as life-cycle maintenance.

PROVISIONING SERVICES through harvesting of country foods and the supply of potential medicinal products and genetic resources.

CULTURAL SERVICES, such as inspiration and attraction for cultural activities, tourism and research and the base for Indigenous and local knowledge systems, cultural identity and spirituality.

REGULATING SERVICES through control of the planetary radiative balance, via the production of biogenic aerosols, atmospheric cleansing and the release or uptake of climate-relevant gases such as carbon dioxide and dimethylsulfide.

Polar bear, Eastern Fram Strait
Photo: Hauke Flores

Sea-Ice Ecosystems and Climate Change

The Arctic Ocean sea-ice is rapidly changing. The area covered is decreasing in both summer and winter, the Arctic Ocean is projected to be completely ice-free in summer within 2-4 decades and the remaining ice will be thinner, more dynamic and more fragile.

Recent assessments prepared by the BEPSII community (Lannuzel et al. 2020) highlight:

Increasing light penetration through thinner ice initiates **earlier** seasonal **algal production.** This earlier growing season may be accompanied by an **increase in ice algae and phytoplankton biomass, augmenting the emission of dimethylsulfide** (cloud precursor produced by algae). Sea-ice loss may also **deliver more methane** (a strong greenhouse gas) **to the atmosphere**, but warmer ice may release fewer halogens, resulting in **fewer mercury deposition events.** The net changes in atmospheric **carbon dioxide absorption** by the Arctic Ocean are **still highly uncertain.**

> Expanding anthropogenic activities can cause additional direct and indirect impacts through multiple pathways.

Variations in the timing of sea-ice formation and melt could cause **major disruptions of Arctic food web structure**. The growth of **sea-ice associated algae and the species that feed directly on those** algae **may increase** in some places, because of greater light available through the ice. However, **the effects on ice-associated mammals and birds are predominantly negative** mainly due to decreased ice cover and stability and linkages to food supplies, subsequently **impacting human harvesting and cultural services.** Expanding anthropogenic activities such as exploration and development, tourism, commercial harvesting and shipping can

(ABOVE) *Ice algae at the bottom of an ice core in the Canadian Arctic. Photo: Brent Else*

(BELOW) *Arctic cod (*boreogadus saida*). Photo: Hauke Flores*

cause additional direct and indirect impacts through multiple pathways (Steiner et al. 2021).

The **most effective way to mitigate these disruptive changes** in the Arctic sea-ice system **is to reduce greenhouse gas emissions**. As summarized by Miller et al. (2020), proposed **climate interventions** (i.e., geoengineering) **to restore Arctic sea ice would have cascading side effects** on sunlight transmission, gas and aerosol exchanges, ocean mixing, and primary production not only in the Arctic but also beyond. Evaluation of any such proposed intervention must consider these unintended consequences.

Despite large uncertainties in the assessments we have summarized here, disruptive changes are certainly expected, warranting **intensified modelling efforts and long-term observations** at representative sites across the Arctic (fixed-point ocean observatories and dedicated repeat stations, e.g. following the approach of the distributed biological observatory, www.pmel.noaa.gov/dbo/).

Qikiqtarjuaq, Nunavut, Canada
Photo: Nadja Steiner

Sea-Ice Ecosystems and Conservation

Conservation represents a key tool in climate change adaptation and mitigation through maintenance and potential restoration of ecosystem functions and services.

Ikaahuk (Sachs Harbour), NWT, Canada
Photo: Nadja Steiner

The recent BEPSII review (Steiner et al. 2021) highlights:

- The Convention on Biological Diversity (CBD) biodiversity goal calls for 10% of marine areas to be protected by 2020 and, in 2016 the members of International Union for the Conservation of Nature approved a 30% goal by 2030. Less than 10% ocean area is currently protected.
- Marine Protected Area (MPA) goals are increasingly expanding beyond the protection and restoration of a few species to the restoration of ecosystem functions and services and maintenance of long term ecosystem health.
- Recognizing the sea-ice ecosystem as an EBSA provides a reference to identify conservation needs and can guide the designation of MPA coverage in polar regions.
- The disappearance of sea ice is a direct consequence of global warming. While conservation measures help to protect species and ecosystems from additional, mostly localized human induced stressors, they do not address the global issue of climate change itself and must be combined with international efforts on emission reduction.

The disappearance of sea ice is a direct consequence of global warming.

- If conservation objectives of existing and proposed MPAs identify the linkage to global warming as the human stressor impeding the MPA's ability to conserve, then, collectively, MPAs could advance international regulations on emissions and climate change.
- The co-planning and co-management of Arctic marine conservation areas with Inuit organisations and communities and the inclusion of Inuit traditional knowledge in future decision making can play a significant role in biodiversity conservation and the protection of cultural heritage.

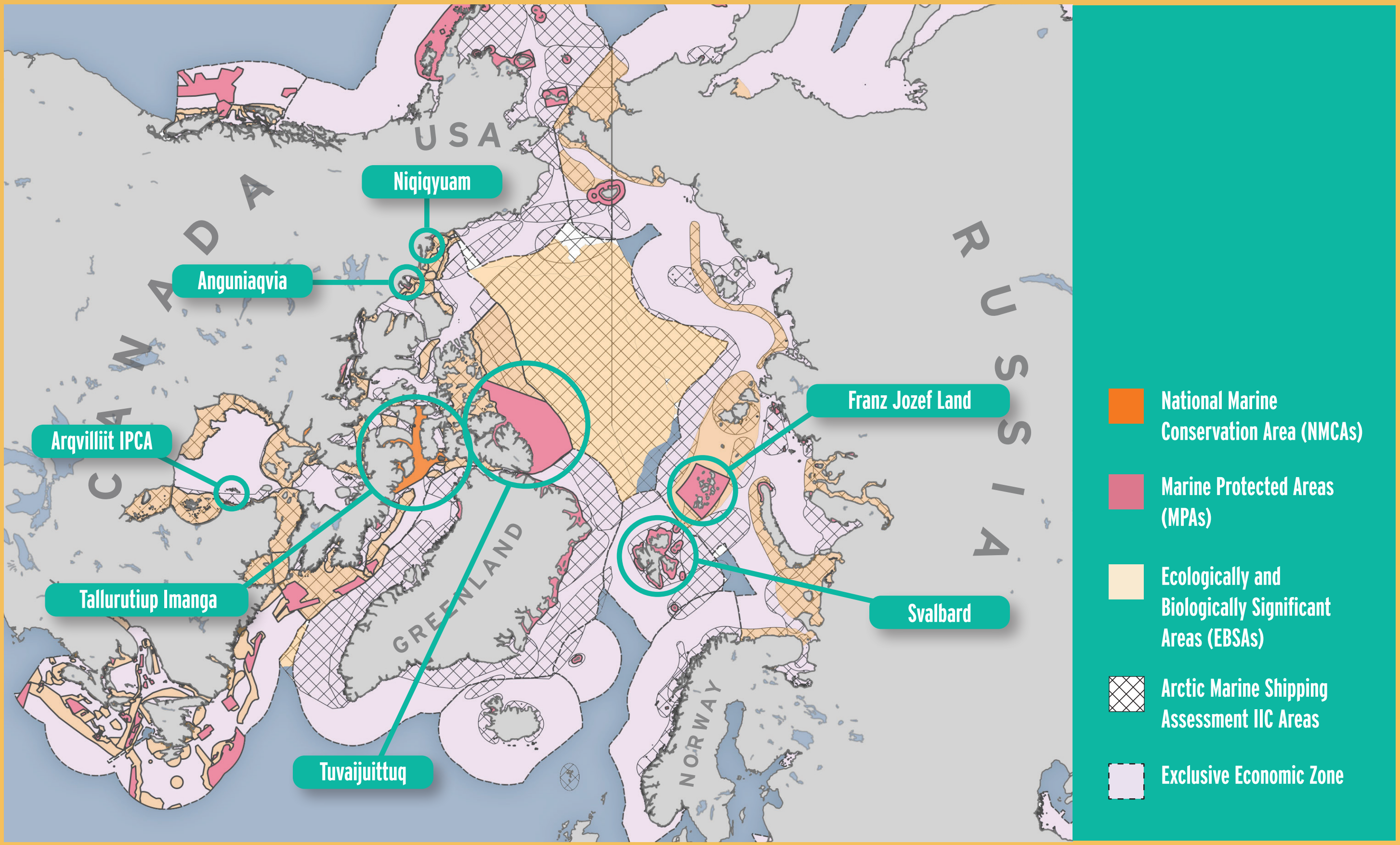


Figure 2 Map of the Arctic, indicating areas of heightened ecological and cultural significance ("Recommendation IIC areas") as identified in the Arctic Marine Shipping Assessment (AMSA) (CAFF, 2017), ecologically and biologically significant areas (EBSAs), marine protected areas (MPAs), including the new sea-ice-related Tuvaijuittuq MPA, as well as other conservation efforts with key Inuit involvement and leadership, e.g. Tallurutiup Imanga National Marine Conservation Area (NMCA) and the Arqvilliit Indigenous Protected and Conserved Area (IPCA).

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Contact

Policy brief prepared by the BEPSII steering committee and community members. BEPSII is an international research community studying sea-ice biogeochemical processes.

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