The Biogeochemical Exchanges in Arctic Sea Ice

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Arctic sea ice biogeochemistry plays a critical role in shaping the region's marine ecosystems. The biogeochemical exchanges within sea ice, including CO_2 efflux, brine drainage, and the release of reactive halogen species, represent complex processes that influence marine life and nutrient cycling. Solar radiation and the activities of microalgal communities further modulate these processes, enhancing the complexity of nutrient interactions. These processes have significant climatic implications, particularly through the operation of the biological carbon pump and the generation of climate-active gases. Additionally, phytoplankton blooms, both under ice and in open water, play a critical role in these biogeochemical cycles. Understanding these intricate processes is essential to predicting and mitigating the impacts of climate change on Arctic ecosystems.

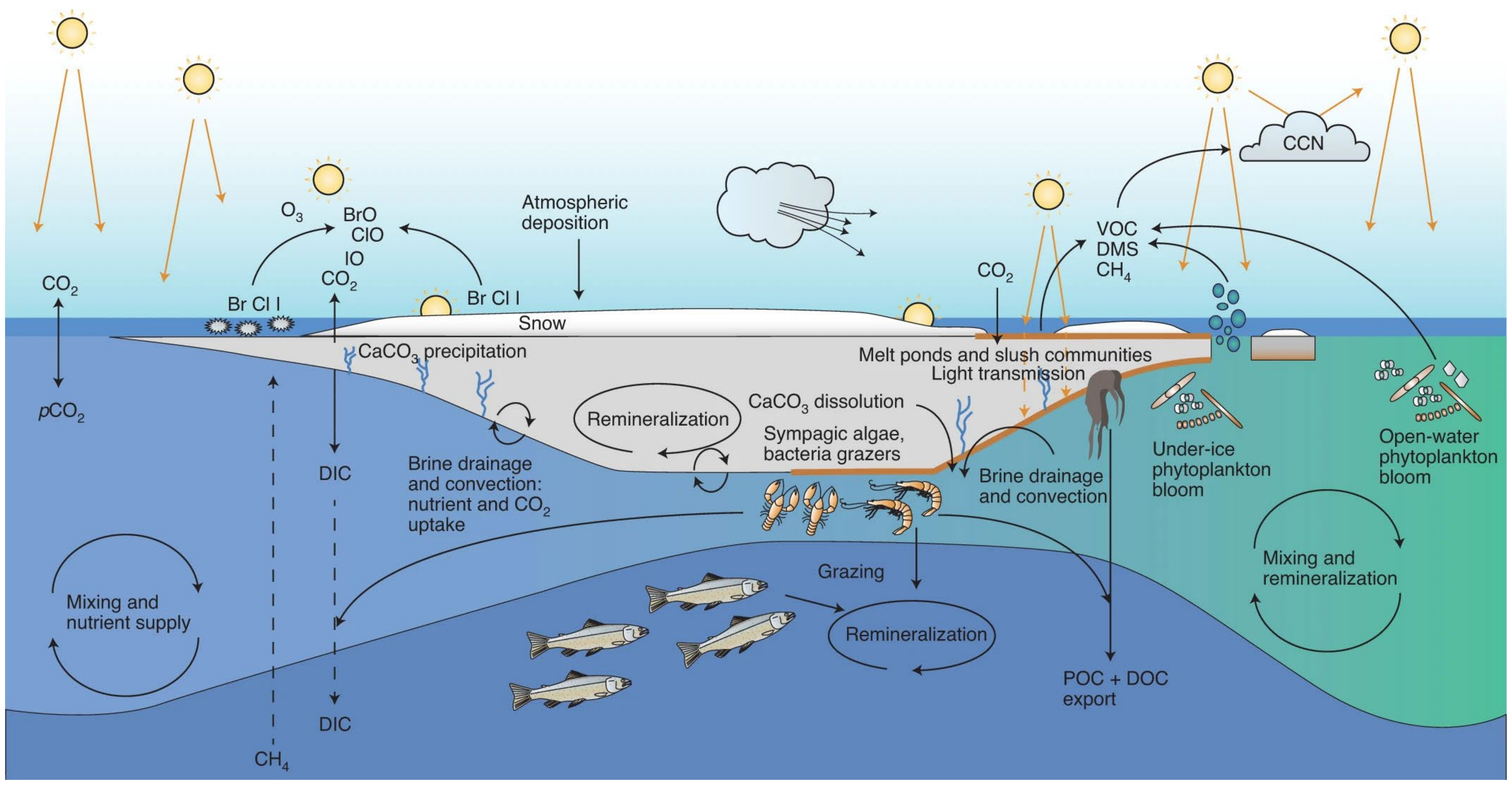

Fig. 1: Schematic of seasonal sea-ice biogeochemical processes in the Arctic Ocean. [1,2]

Biota

- Changes in Arctic conditions affect ice algae and phytoplankton communities, impacting ecosystem-wide productivity and biodiversity.
- Despite cold conditions, high bacterial production occurs in sea ice, fueled by carbon from primary producers. Warming climate enhances heterotrophic activity.
- Warming impacts the biodiversity of metazoan consumer communities, leading to a shift from sympagic to pelagic producers and disrupting food webs.
- Cold-adapted species are declining while sub-polar species expand, affecting Arctic fauna. The biological carbon pump is expected to become less efficient, leading to a shift from carbon export to retention.

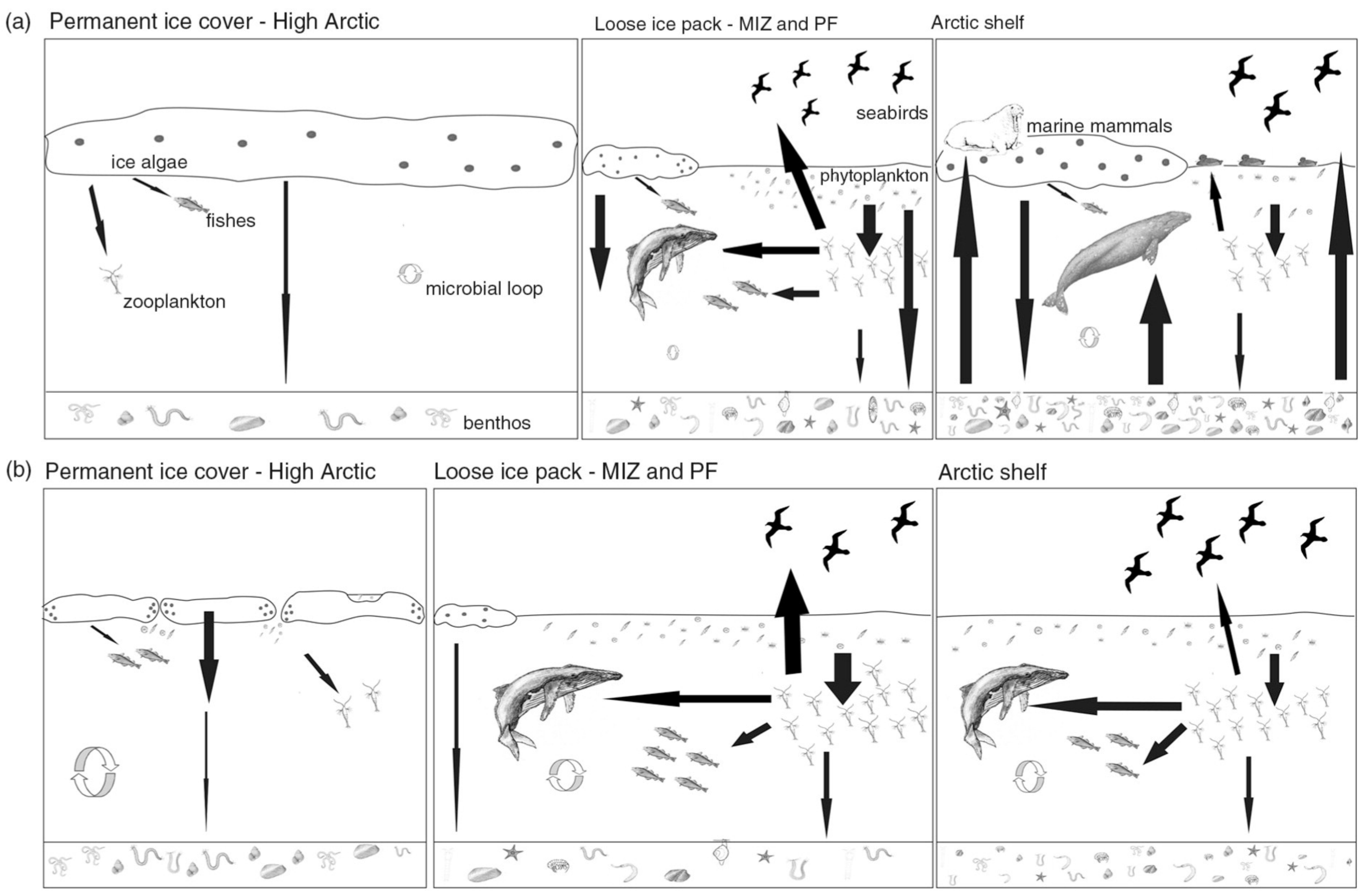

Fig. 3: (a) Current and (b) predicted food-web scenarios for the Arctic shelf, Marginal Ice Zone (MIZ) and Polar Front (PF), and the High Arctic with permanent ice cover. The size of the picture frame for (b) reflects the predicted changes of relative contribution of each area. [5]

Environmental conditions

- Light influences algal growth and bloom timing. Declining Arctic albedo exposes algae to more sunlight and UV radiation.

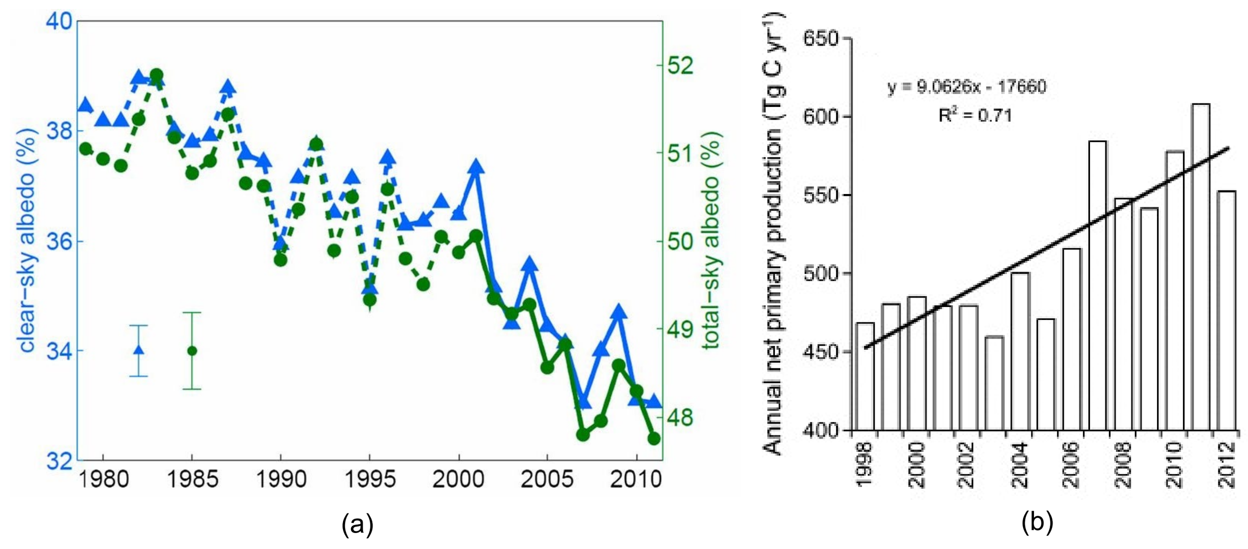

Fig. 2: (a) Arctic albedo has decreased by 4–6% from 1979 to 2011 [3], (b) likely increasing light for ice algae and phytoplankton [4].

- Nutrients for algal growth come from seawater and the atmosphere. Factors like ice temperature and salinity, surface-water stratification, and more open water impact nutrient availability.
- Sea ice, especially first-year ice, provides a habitat for sympagic algae. Climate warming could alter sea ice permeability and colonization space, affecting sympagic productivity.

Climate-active gases

- Sea ice acts as a source of CO_2 in autumn and winter due to high brine pCO_2 and precipitation of $CaCO_3$, but as a CO_2 sink in spring and summer due to brine dilution, $CaCO_3$ dissolution, and the biological carbon pump driven by algal productivity. Changes in ice coverage and type can alter CO_2 transfer.
- Decreasing sea-ice cover likely increases CH_4 efflux to the atmosphere.
- Shifts in sea ice and environmental conditions can enhance the release of DMS, a compound influencing radiation exchange between Earth's atmosphere and space.
- Reactive halogen species from sea ice contribute to ozone depletion. The shift to open waters and warmer sea ice conditions will likely decrease these events.

Conclusion

Changes in Arctic environmental conditions, biota, and climate-active gases interlink to impact local biodiversity, carbon cycling, atmospheric chemistry, and global climate systems. The Arctic Ocean is transitioning from a carbon export to retention system.

References:
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[2] Steiner N, Stefels J. Commentary on the outputs and future of Biogeochemical Exchange Processes at Sea-Ice Interfaces (BEPSII). Elementa: Science of the Anthropocene. 2017;5:81.
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[5] Kędra M, Moritz C, Choy ES, David C, Degen R, Duerksen S, et al. Status and trends in the structure of Arctic benthic food webs. Polar Research. 2015;34(1):23775.