COMMENTARY:

Collapsing Arctic coastlines

Michael Fritz, Jorien E. Vonk and Hugues Lantuit

A holistic and transdisciplinary approach is urgently required to investigate the physical and socio-economic impacts of collapsing coastlines in the Arctic nearshore zone.

Arctic permafrost coasts account for 34% of Earth's coasts[1]. Coastal erosion rates as high as 25 m yr^{-1} (refs 2,3) together with the large amount of organic matter frozen in permafrost[4,5] are resulting in an annual release of 14.0 Tg (10^{12} grams) of particulate organic carbon into the nearshore zone[6,7]. This carbon flux is in the same order of magnitude as the yearly contribution from all Arctic rivers, or the vertical net methane (CH_4) emissions from terrestrial permafrost[8]. Arctic nearshore zones (shallower than 20 m water depth) represent about 20% of the shelves and 7.5% of the Arctic Ocean — a much greater proportion than for the rest of the Earth, where the nearshore zone occupies only 1.4% of the world's ocean area[9,10]. Rapid environmental changes that occur in the Arctic nearshore zone are systematically under-studied, because icebreaking research vessels avoid these shallow waters, and there is very limited shore-based research infrastructure. However, this zone is the primary recipient of increasing fluxes of carbon and nutrients from thawing permafrost. We highlight the crucial role the nearshore zone plays in Arctic biogeochemical cycling, as the fate of the released material is determined in this location. It may (i) degrade into greenhouse gases, (ii) fuel marine primary production, (iii) be buried in nearshore sediments or (iv) be transported offshore (Fig. 1).

Fluxes from coastal erosion are expected to drastically increase due to the combined effect of declining summer sea-ice cover on the Arctic Ocean, longer and warmer thawing seasons, and the rising sea level allowing waves to hit the coast higher and longer during the ice-free season. Unlike large rivers, where decadal to centennial discharge fluctuations can be constrained to a ±10% window[11,12], coastal erosion fluxes have the potential to increase by an order of magnitude on the same timescale[13]. Such increases would result in drastic impacts on global carbon fluxes and their climate feedbacks, on nearshore food webs, and on local communities, whose survival still relies on marine biological resources.

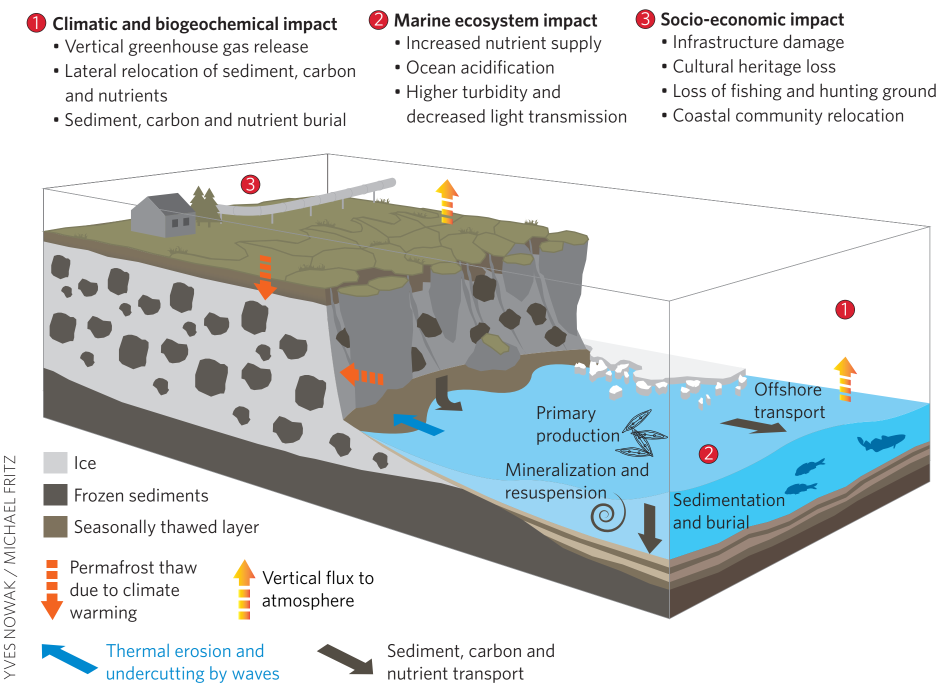

Figure 1 | Impact of thaw and erosion of Arctic permafrost coasts. (1) Climatic and biogeochemical consequences are due to vertical and lateral carbon mobilization onshore, in the nearshore zone and offshore. (2) Marine ecosystem perturbations are mainly due to release of nutrients, pollutants, carbon and sediments to the nearshore zone, where they are: (i) fuelling primary production, (ii) changing chemical and optical properties such as increased ocean acidity and turbidity, (iii) buried in seafloor sediments, or (iv) transported offshore. The quantities of these fluxes, however, are as yet unknown. (3) Socio-economic impacts in the coastal zone include infrastructure damage, loss of cultural heritage, fishing and hunting grounds, and the threat of coastal community relocation.

Environment and society

Currently, most Arctic research is focused on permafrost in tundra and boreal landscapes and on the potential vertical greenhouse gas fluxes resulting from gradual permafrost thaw[4]. Although emission scenarios from gradual permafrost carbon degradation are urgently needed to better constrain Earth system models, impacts of accelerating coastal erosion on nearshore ecosystems are immediate and irreversible. Arctic warming and sea level rise account for the observed coastline collapse as an abrupt form of permafrost degradation that leads to the rapid release of large amounts of previously frozen organic carbon to the nearshore zone. The fate of this permafrost carbon, however, has never been properly quantified. Eroding coasts will also liberate more nutrients such as nitrogen and phosphorus into an ocean that is considered limited in nitrogen or phosphorus[14]. This limitation paradigm might not hold true in the Arctic nearshore zone. Higher nutrient fluxes should be expected to lead to substantial impacts on primary production: for example, by summer algal blooms and oxygen depletion in shallow waters. The mineralization of organic carbon in the water might also strengthen ongoing ocean acidification[15], leading to conditions in which some carbonate species essential to the coastal food web will not survive (Fig. 1).

Increasing erosion will also add to the list of ongoing socio-economic issues already initiated by the rapid environmental change in the Arctic. These impacts are felt at the coast even though their source may be located far offshore or in the terrestrial hinterland, for example, through the long-distance transfer of pollutants (such as mercury) into the Arctic Ocean via rivers[16]. Collapsing coasts will add to this pollution load by releasing heavy metals in greater quantities into nearshore waters and food webs. Quantifying the potential impacts of increasing erosion on coastal ecosystems is crucial for the food security of northern residents living in Arctic coastal communities[17]. Knowledge is needed on how the traditional hunting and fishing grounds might be impacted by high loads of sediment and nutrients released from eroding coasts, and to what extent coastal retreat will lead to a loss of natural habitat. Ultimately, losing land to the sea is also a threat to cultural heritage passed on from the early explorers and indigenous peoples (Fig. 1). Studies on environmental and socio-economic threats in the Arctic coastal zone[17] have so far mostly been limited to considering perturbations of aquatic ecosystems and damage to industrial as well as municipal infrastructure. The multifaceted impacts of environmental change on local communities, ecosystem services, and socio-economic dynamics have not yet been quantified at the circum-Arctic scale.

Looking ahead

Currently, knowledge of the Arctic carbon and nutrient budgets is incomplete and thus hampers the incorporation of lateral material transfer into Earth system models. For example, the released quantities of nutrients such as nitrogen or phosphorus and the contribution of dissolved organic carbon from coastal erosion are literally unknown[18], although they are assumed to dramatically change sediment and nutrient pathways in the nearshore zone[19]. Ultimately, the availability and quality of marine food resources depends on the viability of aquatic ecosystems as a whole.

Large icebreaking research vessels avoid the shallow and inaccurately charted waters of the Arctic coast, so this transition zone is systematically under-studied. A network of research stations on the coast is needed to provide platforms for ship-based observations with small nearshore vessels and for long-term monitoring of change. Quantifying fluxes of organic carbon, nutrients, and contaminants is required, both in nearshore deposits and in the water column through both sediment coring and systematic oceanographic monitoring. Ultimately, this will allow the assessment of transport and degradation pathways of sediment and organic matter derived from erosion. There is a need to follow the complete pathway, which is multi-directional and includes atmospheric release, lateral transport, transitional retention in the food web, and ultimate burial in seafloor sediments (Fig. 1). Such an holistic approach requires a transdisciplinary research programme, for example under the EU Framework Programme for Research and Innovation Horizon 2020. From the beginning, the scientific community needs to be involved, as do stakeholders in policy and planning, and the local communities who will have to live with the consequences of climate change in this vulnerable land–ocean continuum in the Arctic. ❐

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References

1. Lantuit, H. *et al. Estuar. Coast* **35,** 383–400 (2012).
2. Jones, B. M. *et al. Geophys. Res. Lett.* **36,** L03503 (2009).
3. Günther, F. *et al. Cryosphere* **9,** 151–178 (2015).
4. Schuur, E. A. G. *et al. Nature* **520,** 171–179 (2015).
5. Hugelius, G. *et al. Biogeosciences* **11,** 6573–6593 (2014).
6. Vonk, J. E. *et al. Nature* **489,** 137–140 (2012).
7. Wegner, C. *et al. Polar Res.* **34,** 24964 (2015).
8. Koven, C. D. *et al. Proc. Natl Acad. Sci. USA* **108,** 14769–14774 (2011).
9. Eakins, B. W. & Sharman, G. F. *NOAA National Geophysical Data Center* (NOAA, accessed 15 May 2016).
10. Laruelle, G. G. *et al. Hydrol. Earth Syst. Sci.* **17,** 2029–2051 (2013).
11. *Arctic Climate Issues 2011: Changes in Arctic Snow, Water, Ice and Permafrost* SWIPA 2011 Overview Report (AMAP, 2012).
12. Wagner, A., Lohmann, G. & Prange, M. *Global Planet. Change* **79,** 48–60 (2011).
13. Zhang, K., Douglas, B. C. & Leatherman, S. P. *Climatic Change* **64,** 41–58 (2004).
14. Popova, E. E. *et al. J. Geophys. Res. Oceans* **117,** C00D12 (2012).
15. Semiletov, I. *et al. Nat. Geosci.* **9,** 361–365 (2016).
16. Fisher, J. A. *et al. Nat. Geosci.* **5,** 499–504 (2012).
17. Ford, J. D., McDowell, G. & Pearce, T. *Nat. Clim. Change* **5,** 1046–1053 (2015).
18. Fritz, M. *et al. Cryosphere* **9,** 737–752 (2015).
19. Vonk, J. E. & Gustafsson, O. *Nat. Geosci.* **6,** 675–676 (2013).

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