frontiers | Frontiers in Marine Science

TYPE Editorial
PUBLISHED 09 June 2025
DOI 10.3389/fmars.2025.1627187

OPEN ACCESS

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RECEIVED 12 May 2025
ACCEPTED 23 May 2025
PUBLISHED 09 June 2025

CITATION
Kohlbach D, Desforges J-P and Espinel-Velasco N (2025) Editorial: Current and future threats to marine zooplankton in changing polar oceans and their potential for adaption and coping.
Front. Mar. Sci. 12:1627187.
doi: 10.3389/fmars.2025.1627187

Editorial: Current and future threats to marine zooplankton in changing polar oceans and their potential for adaption and coping

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KEYWORDS

climate change, sea ice, anthropogenic pollution, vulnerability vs. resilience, Arctic Ocean, Southern Ocean

Editorial on the Research Topic
Current and future threats to marine zooplankton in changing polar oceans and their potential for adaption and coping

Marine zooplankton such as krill, copepods, amphipods and other small crustaceans play a crucial role in polar ecosystems: They form the foundation of the food web, serving as a primary food source for larger marine animals like fish, whales, and seabirds while consuming vast amounts of algae and other small heterotrophic prey, transferring carbon (= energy) up the food chain (Thorpe, 2024). Additionally, zooplankton play an important role in nutrient cycling, as they contribute to the vertical transport of organic material when they migrate between the surface and deeper waters and also in the form of marine snow (dead/dying animals, fecal matter) sinking to the seafloor fueling benthic communities (Halfter et al., 2020; Bridier et al., 2021). Their presence and migration patterns can also impact carbon sequestration, influencing the polar regions' role in the global carbon cycle (Steinberg and Landry, 2017). As such, marine zooplankton are essential not only for the survival of higher trophic levels but also for the overall health, structure and functioning of polar marine ecosystems.

Marine zooplankton are continuously and increasingly exposed to the impacts of anthropogenic climate change, which poses both immediate and long-term threats to e.g., food-source availability, distribution, reproductive success and ultimately survival (Le Moullec and Bender, 2022; Bargagli and Rota, 2024). Stressors such as rising seawater

temperatures, ocean acidification, and shifts in sea-ice dynamics are altering the environmental conditions that zooplankton are adapted to (Espinel-Velasco et al., 2023). Warmer waters and longer open-water seasons can affect the timing and abundance of ice algal and phytoplankton blooms, disrupting the food supply for zooplankton, whose lifecycles are oftentimes perfectly embedded between sympagic (ice-associated) and pelagic primary production peaks (Søreide et al., 2010; Renaud et al., 2024). Many species depend on ice-associated algae as a food source in both hemispheres (Kohlbach et al., 2016, 2018), a dietary resource that will likely have a more spatio-temporally restricted availability in the sea ice-retreating decades to come. These environmental changes are likely to cause a shift in zooplankton distribution, with some species migrating northwards seeking cooler waters while others may face habitat loss (Kuletz et al., 2024). While some zooplankton may exhibit short-term resilience through adaptive behaviors, such as altered migration patterns or shifts in reproductive timing, their ability to cope with these rapid environmental changes might be limited in the long term and our understanding of potential coping mechanisms is still in its infancy. Long-term survival will depend on the pace of change and the ability of zooplankton populations to evolve and adapt genetically or successfully conquer and inhabit regions closer to their natural living conditions. If these environmental stresses continue to accelerate, as it is expected, the overall structure and productivity of polar marine ecosystems could be severely impacted (Johnston et al., 2022). Additionally, and partly facilitated by changing environmental settings, the increasing presence of anthropogenic pollutants, such as persistent organohalogenated chemicals, heavy metals and microplastics (Xie et al., 2022), can have adverse effects on marine animals' behavioral patterns and overall body condition (Dietz et al., 2019; Bargagli and Rota, 2022; Borgå et al., 2022).

In this Research Topic, we aimed to identify and examine the role of marine zooplankton in polar food webs and how the *status quo* is being altered by climate and environmental change. We collected five original research papers exploring innovative tools to study polar zooplankton dynamics under rapid change. Two papers apply state-of-the-art molecular techniques such as DNA metabarcoding and RNA sequencing to understand diet and stress responses, one paper uses field data to explore timing of reproductive development in Antarctic krill, one paper models zooplankton community dynamics under climate-change scenarios, and the last paper reviews our current understanding of metal sources and fate in zooplankton of Arctic marine food webs.

By applying state-of-the-art biomolecular techniques, the diet of Arctic amphipods during the phytoplankton-poor polar night has been studied by Dischereit et al.. Metabarcoding revealed a surprisingly diverse dietary composition including gelatinous zooplankton and fish. These findings provide novel and exciting insights since jellyfish were typically considered a trophic dead-end with little nutritional value.

In Martinez-Alarcón et al., RNA sequencing was used in an experimental approach to study the impact of different temperature treatments on *Themisto* spp., key amphipods in Arctic food webs. Results showed that thermal stress impacts gene expression of species differently, suggesting species-specific regulatory capacities to temperature increase. Their findings are important to our understanding of the potential to cope with rising seawater temperatures and likelihoods of range shifts for marine amphipods in a warming Arctic.

In Steinke et al., the impacts of climate and environmental variability on the timing of reproductive development in female Antarctic krill around the Antarctic Peninsula is studied. Pronounced variability in maturation status among multi-annual measurements was observed and Southern Annular Mode and the Multivariate El Niño Index were identified to be the most prominent drivers of this variability. Results of this work are especially useful for management of krill fisheries and species reliant on krill as part of their diet.

Hibino et al. used a modeling approach to infer the effect of sea-ice cover on the zooplankton distribution in the Pacific Arctic Ocean. Under significant warming scenarios, generalized dissimilarity models (GDM) projected that zooplankton communities in high latitudes will be more affected by altered timings of sea-ice melt seasons and consequently changes in annual primary production than those on the southern shelf (northern Bering Sea to southern Chukchi Sea). The authors provide evidence that Arctic warming is not likely to uniformly yield high primary productivity.

In a Mini-Review by Halsband et al., sources and transfer of metals within Arctic marine ecosystems are elucidated with a focus on bioavailability of different compounds and their potential for toxicity in marine copepods. Updated information on zooplankton responses to metal exposure in combination with other stressors, including increased temperature and lower pH, is provided and a number of research gaps are identified. Suggestions for future research foci, such as improved understanding on intra- and interspecific differences in metal toxicity, are discussed.

Overall, the five papers in this Research Topic explore leading issues in polar marine ecosystems, such as rising ocean temperatures, shifts in sea-ice dynamics, and climate change influences on pollution exposure and effects. Understanding these ecological dynamics is critical to assessing the vulnerability *vs.* resilience of marine zooplankton populations to ongoing environmental stress of varying sources. Investigating the capacity of zooplankton to cope with such changes—through physiological adaptation, behavioral and trophic plasticity, or shifts in distribution—is critical to evaluate whether these responses are sufficient to maintain their ecological roles in rapidly changing polar ecosystems.

Author contributions

DK: Conceptualization, Investigation, Project administration, Writing – original draft, Writing – review & editing. JD: Conceptualization, Investigation, Project administration, Writing – original draft, Writing – review & editing. NE-V: Conceptualization, Investigation, Project administration, Writing – original draft, Writing – review & editing.

Funding

The author(s) declare that financial support was received for the research and/or publication of this article. DK is currently funded by the German Helmholtz Association Initiative and Networking Fund (Helmholtz Young Investigator Group Double-Trouble, VH-NG-20-09). NEV was funded by the RESTORESEAS project (BiodivRestore Transnational Cofounder Call/Swedish Environmental Protection Agency 2022-00025).

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declare that Generative AI was used in the creation of this manuscript. Authors used ChatGPT to rephrase certain statements for better flow/readability of sentences.

Publisher's note

References

Bargagli, R., and Rota, E. (2022). Microplastic interactions and possible combined biological effects in Antarctic marine ecosystems. *Animals* 13, 162. doi: 10.3390/ani13010162

Bargagli, R., and Rota, E. (2024). Environmental contamination and climate change in Antarctic ecosystems: an updated overview. *Environ. Sci.: Adv.* 3, 543–560. doi: 10.1039/D3VA00113J

Borgå, K., McKinney, M. A., Routti, H., Fernie, K. J., Giebichenstein, J., Hallanger, I., et al. (2022). The influence of global climate change on accumulation and toxicity of persistent organic pollutants and chemicals of emerging concern in Arctic food webs. *Environ. Sci.: Processes Impacts* 24, 1544–1576. doi: 10.1039/D1EM00469G

Bridier, G., Olivier, F., Chauvaud, L., Sejr, M. K., and Grall, J. (2021). Food source diversity, trophic plasticity, and omnivory enhance the stability of a shallow benthic food web from a high-Arctic fjord exposed to freshwater inputs. *Limnol. Oceanogr.* 66, S259–S272. doi: 10.1002/lno.11688

Dietz, R., Letcher, R. J., Desforges, J.-P., Eulaers, I., Sonne, C., Wilson, S., et al. (2019). Current state of knowledge on biological effects from contaminants on arctic wildlife and fish. *Sci. Total Environ.* 696, 133792. doi: 10.1016/j.scitotenv.2019.133792

Espinel-Velasco, N., Gawinski, C., Kohlbach, D., Pitusi, V., Graeve, M., and Hop, H. (2023). Interactive effects of ocean acidification and temperature on oxygen uptake rates in *Calanus hyperboreus* nauplii. *Front. Mar. Sci.* 10. doi: 10.3389/fmars.2023.1240673

Halfter, S., Cavan, E. L., Swadling, K. M., Eriksen, R. S., and Boyd, P. W. (2020). The role of zooplankton in establishing carbon export regimes in the southern ocean–a comparison of two representative case studies in the subantarctic region. *Front. Mar. Sci.* 7. doi: 10.3389/fmars.2020.567917

Johnston, N. M., Murphy, E. J., Atkinson, A., Constable, A. J., Cotté, C., Cox, M., et al. (2022). Status, change, and futures of zooplankton in the Southern Ocean. *Front. Ecol. Evol.* 9. doi: 10.3389/fevo.2021.624692

Kohlbach, D., Graeve, M., Lange, B., David, C., Peeken, I., and Flores, H. (2016). The importance of ice algae-produced carbon in the central Arctic Ocean ecosystem: Food web relationships revealed by lipid and stable isotope analyses. *Limnol. Oceanogr.* 61, 2027–2044. doi: 10.1002/lno.10351

Kohlbach, D., Graeve, M., Lange, B., David, C., Schaafsma, F., van Franeker, J., et al. (2018). Dependency of Antarctic zooplankton species on ice algae-produced carbon suggests a sea ice-driven pelagic ecosystem during winter. *Glob. Change Biol.* 24, 4667–4681. doi: 10.1111/gcb.14392

Kuletz, K. J., Ferguson, S. H., Frederiksen, M., Gallagher, C. P., Hauser, D. D., Hop, H., et al. (2024). A review of climate change impacts on migration patterns of marine vertebrates in Arctic and Subarctic ecosystems. *Front. Environ. Sci.* 12. doi: 10.3389/fenvs.2024.1434549

Le Moullec, M., and Bender, M. L. (2022). "Impacts of global warming on Arctic biota," in *Global Arctic: An introduction to the multifaceted dynamics of the Arctic* (Cham, Switzerland: Springer), 211–228.

Renaud, P. E., Daase, M., Leu, E., Geoffroy, M., Basedow, S., Inall, M., et al. (2024). Extreme mismatch between phytoplankton and grazers during Arctic spring blooms and consequences for the pelagic food-web. *Prog. Oceanogr.* 229, 103365. doi: 10.1016/j.pocean.2024.103365

Søreide, J., Leu, E. V., Berge, J., Graeve, M., and Falk-Petersen, S. (2010). Timing of blooms, algal food quality and *Calanus glacialis* reproduction and growth in a changing Arctic. *Glob. Change Biol.* 16, 3154–3163. doi: 10.1111/j.1365-2486.2010.02175.x

Steinberg, D. K., and Landry, M. R. (2017). Zooplankton and the ocean carbon cycle. *Annu. Rev. Mar. Sci.* 9, 413–444. doi: 10.1146/annurev-marine-010814-015924

Thorpe, R. B. (2024). We need to talk about the role of zooplankton in marine food webs. *J. Fish Biol.* 105, 444–458. doi: 10.1111/jfb.15773

Xie, Z., Zhang, P., Wu, Z., Zhang, S., Wei, L., Mi, L., et al. (2022). Legacy and emerging organic contaminants in the polar regions. *Sci. Total Environ.* 835, 155376. doi: 10.1016/j.scitotenv.2022.155376