Developing an Aggregate Exposure Pathway for Arctic Copper Pollution: Protocol and First Steps

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- **Copper** is an important **resource, nutrient, and pollutant;** and demand is expected to **increase significantly** in coming decades.
- The **Norwegian Arctic** (Fig. 1) is an important ecosystem that is likely to undergo **significant economic** and **ecological shifts** as the **climate changes and melting ice opens up new areas for shipping, fishing, and exploitation of mineral resources.**
- Though a well-studied **classical stressor**, there is only a limited picture of how **copper occurs** — naturally and anthropogenically — in the environment, how it moves geographically and between compartments, and how biota are exposed to it.
- We are using the **Aggregate Exposure Pathway (AEP)** concept to build a comprehensive understanding of **copper pollution in the Norwegian Arctic,** based on a weight-of-evidence assessment of **diverse sources of exposure information.**

Figure 1: Study area for papers in literature review, highlighted in green (land) and sky blue (seas, oceans). International Hydrographic Organization (IHO) definitions were used in mapping extents of named oceans, seas, and subseas.

Criteria for inclusion:
- Measured copper concentrations
- In study region (Fig. 1)
- In English
- Full text available
- Aquatic ecosystems and copper sources to these ecosystems

Methods

We used four methodological frameworks (Fig. 2):

- The Aggregate Exposure Pathway (Teeguarden et al., 2016) models exposure states and transitions for understanding total ecotoxicological exposure to target tissues.
- EFSA's Weight of Evidence guidelines (EFSA, 2017) to handle diverse evidence on copper's environmental occurrence and flow.
- A systematic literature review (see search string below) of Web of Science and PubMed following PRISMA 2020 guidelines (Page et al., 2021), excluding less relevant aspects like risk of bias assessment.
- The CREED guidelines (Di Paolo et al., 2024) for semi-quantitative assessment of data reliability and relevance.

Literature review was conducted using Covidence (Veritas Health Innovation, 2025). We also assessed Norwegian monitoring, sales and emissions data.

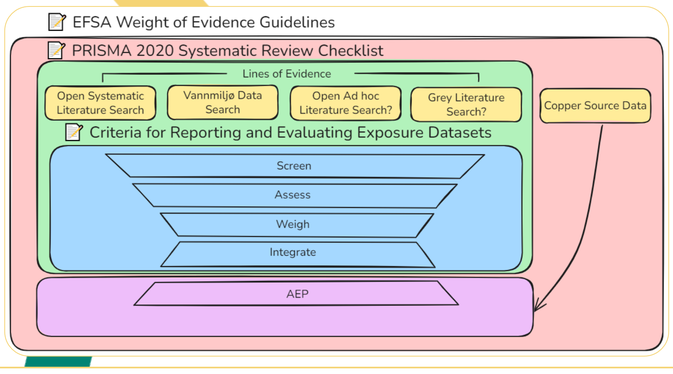

Figure 2: Methodological framework used in literature review, built on EFSA Weight of Evidence guidelines, PRISMA 2020 systematic literature review protocol, and Criteria for Reporting and Evaluating Exposure Datasets.

Search string:

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(copper OR Cu OR cuprous OR cupric OR kobber OR coper OR 7440-50-8)
AND (Barents OR Norwegian OR Arctic OR Svalbard OR North Atlantic OR Greenland*)
AND (wildlife OR ecotox* OR biota OR environment* OR animal OR ecosystem*)
AND (emission OR exposure OR fate OR behaviour OR concentration OR dose OR chem* OR bioaccumul* OR trophic)
AND (aqua* OR water* OR marine OR river OR lake OR fjord OR estuary OR sea OR ocean OR sediment* OR soil)
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Screening Process

- 478 Web of Science hits and 438 PubMed hits (Fig. 3) were obtained for the search string.
- 116 manuscripts were removed as duplicated using a combination of automatic and manual screening, while 717 titles and abstracts were screened by two independent reviewers.
- Disagreements between these two reviewers were resolved by an arbitrator, resulting in a shortlist of 229 manuscripts.
- Full texts for included abstracts were then obtained and reviewed by a single reviewer, resulting in a final tally of 195 included. It is anticipated that this will rise to around 270 manuscripts once screening is completed.

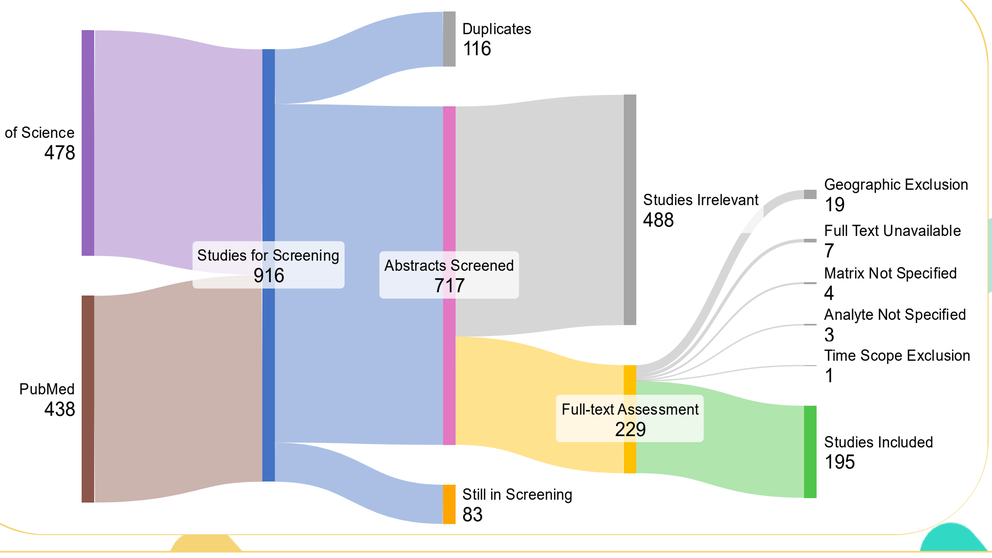

Figure 3: Sankey diagram of screening of abstracts and manuscripts from PubMed and Web of Science, deduplication, and paper exclusion. Screening is currently ongoing, so 83 manuscripts (bottom centre) have not yet been fully processed. *Diagram rendered by SankeyMATIC.com.*

Results

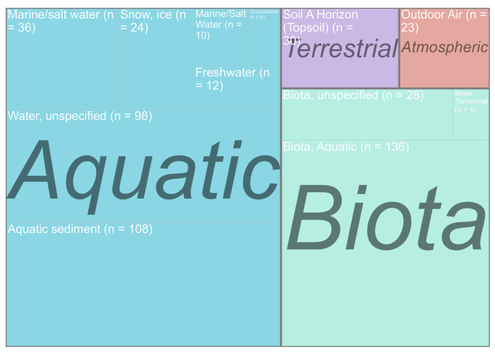

Figure 4: Abstract hits for environmental compartments analysed for copper concentrations across 195 selected papers, organised by compartment and sub-compartment.

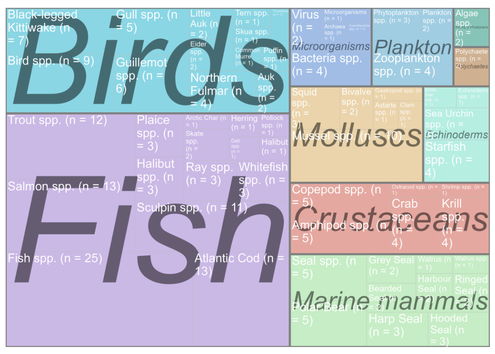

Figure 5: Abstract hits for species (common and scientific names) analysed for copper concentration reported in 195 selected papers, by taxonomic/ecological group.

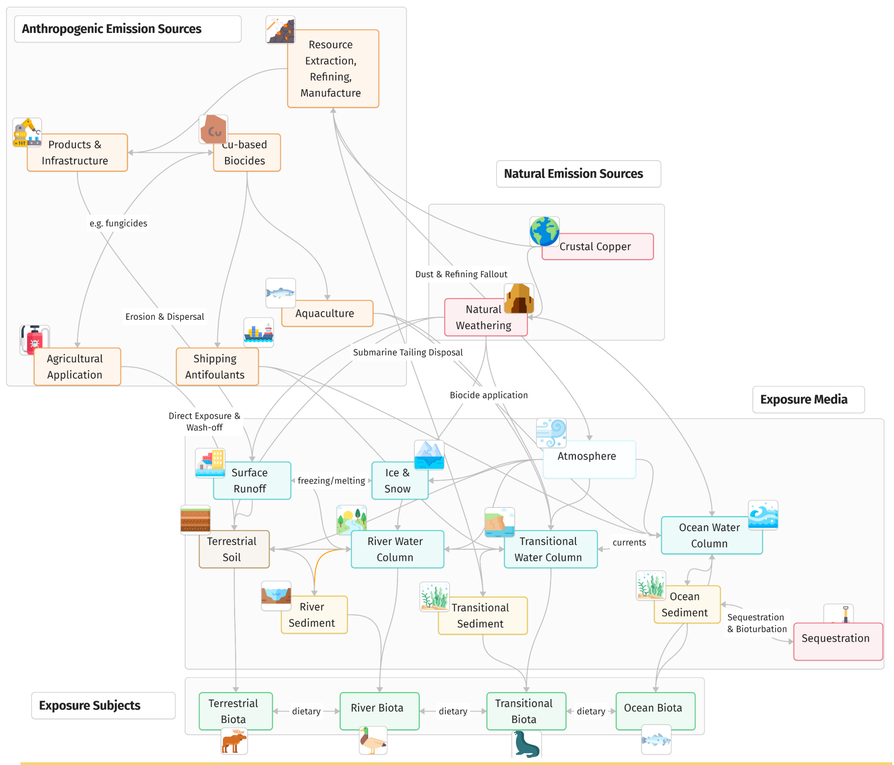

Figure 6: Basic AEP network diagram, based on relevant sources, media and subjects reported in reviewed manuscripts. *Icons: Freepik, Flaticons, Wanicon, Iconic Panda*

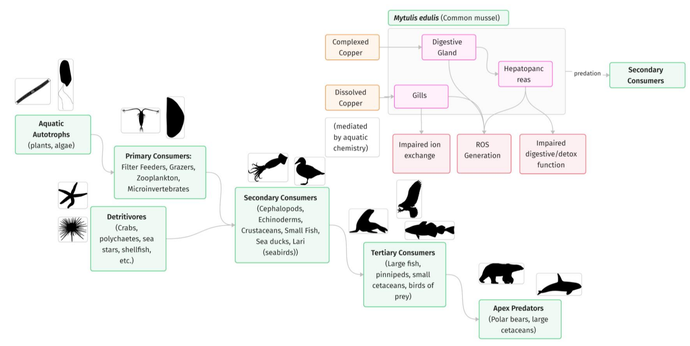

Figure 7: Expanded food chain/network diagram of biota dietary transfers; and relevant exposure routes and exposure surfaces for *Mytilus edulis*, linked to mechanisms of toxicity.
Silhouette images are by Alexandra Hahn (Gadus morhua), An Ignorant Atheist (Phocidae), Becky Barnes and Kurtis Wothe (Illex illecebrosus), Chris huh (Orcinus orca), Katie S. Collins (Mytilus platensis), Margot Michaud (Ursus maritimus), Mario Quevedo (Asteriidae), Matt Crook (Nitzschia sigmoidea), Steven Traver (Pandion haliaetus), and others (Calanus finmarchicus, Chilomonas, Prionocidaris baculosa).

- Marine sediments (especially Svalbard fjords; Fig. 4) and larger species (birds, marine mammals; Fig. 5) were well-represented, but micro-invertebrates and primary producers were reported less.
- Taxonomic gaps may limit understanding of copper trophic dynamics, though focused searches in other Arctic regions could fill these gaps.
- A putative AEP has been constructed based on keyword analysis of abstracts (Figs 6, 7), that will be expanded with addition detail and qualified Weight of Evidence as data are extracted from manuscripts.

Conclusions

- Although **no clear methodological framework exists for Aggregate Exposure Pathway development**, **existing protocols** and guidelines from allied fields **can be adapted**.
- Existing **literature** on Arctic region copper pollution is **biased towards marine ecosystems** and **higher trophic organisms** but generally covers a wide range of compartments and biota.
- We have constructed a **putative Aggregate Exposure Pathway** that will be expanded and detailed, as well as having **Weight of Evidence and importance of different components**, etc. qualified.

Find out more!

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Citations

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Partnership for the Assessment of Risks from Chemicals

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