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

Sam A. Welch[1], Pierre Blévin[2], Richard Handy[3] & Knut Erik Tollefsen[1]

1. Norwegian Institute for Water Research (NIVA), Økernveien 94, N-0579 OSLO, Norway; 2. Akvaplan NIVA, Framsenteret, Postboks 6606, Stakkevollan, 9296 Tromsø, Norway; 3. University of Plymouth, Plymouth, Devon, PL4 8AA, United Kingdom

Norsk institutt for vannforskning

saw@niva.no

Placeholder for piece of actual physical copper I will stick up here

- **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 classic 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.

Methods

We drew on four methodological frameworks (Fig. 2):

- The Aggregate Exposure Pathway (Teeguarden *et al.*, 2016) conceptualises an Adverse Outcome Pathway-like network model of key exposure states and key transitional relationships for understanding total ecotoxicological exposure to a given tissue or organ (target site exposure).
- To accommodate diverse lines of evidence on copper's environmental occurrence and flow, we adopted EFSA's guidelines on Weight of Evidence assessment (EFSA, 2017).
- Our primary evidence source is a systematic review of literature from the databases Web of Science and PubMed (see search string below), which we conducted largely in line with the PRISMA 2020 guidelines (Page *et al.*, 2021). We excluded some aspects that were less relevant for ecotoxicology; for example, we include no risk of bias assessment in our study.
- We adapted the Criteria for Reporting and Evaluating Exposure Datasets (CREED) guidelines (Di Paolo *et al.*, 2024), which we are using to assess the reliability and relevance of given data in a semi-quantitative framework.

Review infrastructure was provided by Covidence (Veritas Health Innovation, 2025), a paid online systematic literature review service based on the PRISMA 2020 model. In addition to open scientific literature, we will also be assessing monitoring, sales and emissions data for Norway as lines of evidence.

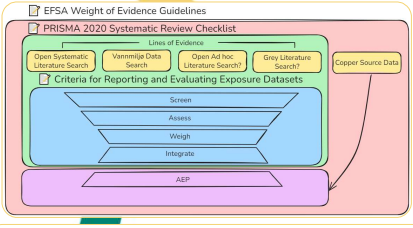

Figure 2: Methodological framework used in literature review, built on EFSA Weight of Evidence guidelines, PRISMA 2020 systematic literature review protocol, and Criteria for Reporting and Evaluating Exposure Datasets.

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.

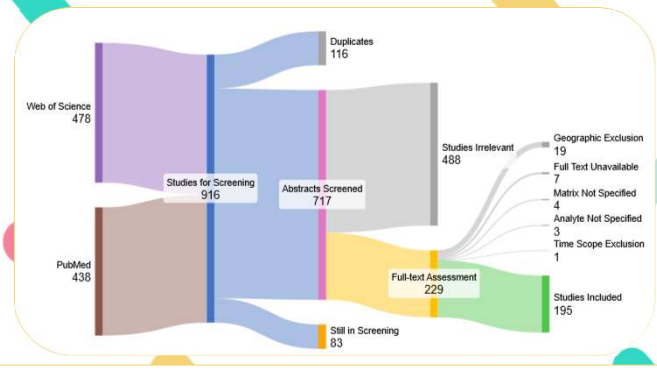

Figure 3: Sankey diagram of screening of abstracts and manuscripts from PubMed and Web of Science, deduplication, and paper exclusion. Screening is currently ongoing, so 83 manuscripts (bottom centre) have not yet been fully processed. *Diagram rendered by SankeyMATIC.com.*

Results

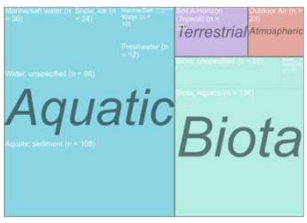

Figure 4: Abstract hits for environmental compartments analysed for copper concentrations across 195 selected papers, organised by compartment and sub-compartment.

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

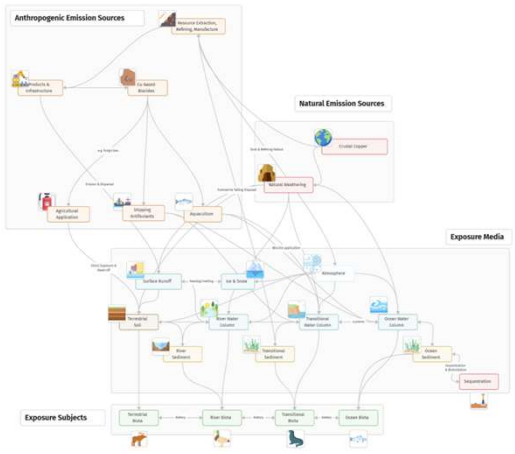

Figure 6: Basic AEP network diagram, based on relevant sources, media and subjects reported in reviewed manuscripts. Icons: Freepik, Flaticons, Wanicon, Iconic Panda

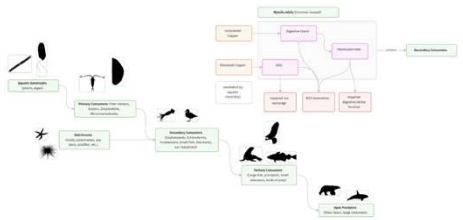

Figure 7: Expanded food chain/network diagram of biota dietary transfers; and relevant exposure routes and exposure surfaces for *Mytilus edulis*, linked to mechanisms of toxicity.

- 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 under-sampled.
- 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.

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Citations

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PARC Partnership for the Assessment of Risks from Chemicals

EXPECT