Evidence of the impacts of metal mining and the effectiveness of mining mitigation measures on social–ecological systems in Arctic and boreal regions: a systematic map protocol

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Abstract

Background: Mining activities, including prospecting, exploration, construction, operation, maintenance, expansion, abandonment, decommissioning and repurposing of a mine can impact social and environmental systems in a range of positive and negative, and direct and indirect ways. Mining can yield a range of benefits to societies, but it may also cause conflict, not least in relation to above-ground and sub-surface land use. Similarly, mining can alter environments, but remediation and mitigation can restore systems. Boreal and Arctic regions are sensitive to impacts from development, both on social and environmental systems. Native ecosystems and aboriginal human communities are typically affected by multiple stressors, including climate change and pollution, for example.

Methods: We will search a suite of bibliographic databases, online search engines and organisational websites for relevant research literature using a tested search strategy. We will also make a call for evidence to stakeholders that have been identified in the wider 3MK project (https://osf.io/cvh3u/). We will screen identified and retrieved articles at two distinct stages (title and abstract, and full text) according to a predetermined set of inclusion criteria, with consistency checks at each level to ensure criteria can be made operational. We will then extract detailed information relating to causal linkages between actions or impacts and measured outcomes, along with descriptive information about the articles and studies and enter data into an interactive systematic map database. We will visualise this database on an Evidence Atlas (an interactive, cartographic map) and identify knowledge gaps and clusters using Heat Maps (cross-tabulations of important variables, such as mineral type and studied impacts). We will identify good research practices that may support researchers in selecting the best study designs where these are clear in the evidence base.

Keywords: Evidence synthesis, Extractive industries, Knowledges, Knowledge systems, Local knowledge, Resource extraction, Metal mines

Background

On the impacts of mining

Mining activities, including prospecting, exploration, construction, operation, maintenance, expansion, abandonment, decommissioning and repurposing of a mine can impact social and environmental systems in a range of positive and negative, and direct and indirect ways. Mine exploration, construction, operation, and maintenance may result in land-use change, and may have associated negative impacts on environments, including deforestation, erosion, contamination and alteration of soil profiles, contamination of local streams and wetlands, and an increase in noise level, dust and emissions (e.g. [1–5]). Mine abandonment, decommissioning and repurposing may also result in similar significant environmental impacts, such as soil and water contamination

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[6–8]. Beyond the mines themselves, infrastructure built to support mining activities, such as roads, ports, railway tracks, and power lines, can affect migratory routes of animals and increase habitat fragmentation [9, 10].

Mining can also have positive and negative impacts on humans and societies. Negative impacts include those on human health (e.g. [11]) and living standards [12], for example. Mining is also known to affect traditional practices of Indigenous peoples living in nearby communities [13], and conflicts in land use are also often present, as are other social impacts including those related to public health and human wellbeing (e.g. [14–17]. In terms of positive impacts, mining is often a source of local employment and may contribute to local and regional economies [18, 19]. Remediation of the potential environmental impacts, for example through water treatment and ecological restoration, can have positive net effects on environmental systems [20]. Mine abandonment, decommissioning and repurposing can also have both positive and negative social impacts. Examples of negative impacts include loss of jobs and local identities [21], while positive impact can include opportunities for new economic activities [22], e.g. in the repurposing of mines to become tourist attractions.

Mitigation measures

'Mitigation measures' (as described in the impact assessment literature) are implemented to avoid, eliminate, reduce, control or compensate for negative impacts and ameliorate impacted systems [23]. Such measures must be considered and outlined in environmental and social impact assessments (EIAs and SIAs) that are conducted prior to major activities such as resource extraction [24, 25]. Mitigation of negative environmental impacts in one system (e.g. water or soil) can influence other systems such as wellbeing of local communities and biodiversity in a positive or negative manner [23]. A wide range of technological engineering solutions have been implemented to treat contaminated waters (e.g. constructed wetlands [26], reactive barriers treating groundwater [27], conventional wastewater treatment plants). Phytoremediation of contaminated land is also an area of active research [28].

Mitigation measures designed to alleviate the negative impacts of mining on social and environmental systems may not always be effective, particularly in the long-term and across systems, e.g. a mitigation designed to affect an environmental change may have knock on changes in a social system. Indeed, the measures may have unintentional adverse impacts on environments and societies. To date, little research appears to have been conducted into mitigation measure effectiveness, and we were unable to find any synthesis or overview of the systems-level effectiveness of metal mining mitigation measures.

Mining in the Arctic

Boreal and Arctic regions are sensitive to impacts from mining and mining-related activities [29, 30], both on social and environmental systems: these northern latitudes are often considered harsh and thus challenging for human activities and industrial development. However, the Arctic is home to substantial mineral resources [31, 32] and has been in focus for mining activities for several 100 years, with a marked increase in the early 20th century and intensifying interest in exploration and exploitation in recent years to meet a growing global demand for metals (Fig. 1). Given the region's geological features and society's need for metals, resource extraction is likely to dominate discourse on development of northern latitudes in the near future. As of 2015, there were some 373 mineral mines across Alaska, Canada, Greenland, Iceland, The Faroes, Norway (including Svalbard), Sweden, Finland and Russia (see Table 1), with the top five minerals being gold, iron, copper, nickel and zinc [33].

Many topics relating to mining and its impacts on environmental and social systems are underrepresented in the literature as illustrated by the following example. The Sami people are a group of traditional people inhabiting a region spanning northern Norway, Sweden, Finland and Russia. Sami people are affected by a range of external pressures, one of which pertains to resource extraction and land rights, particularly in relation to nomadic reindeer herding. However, there is almost no published research on the topic [34].

Mining is important across the circumpolar north. The map shows mining sites registered as productive in 2011 by the US Geological Survey. Some of these mines have closed and new mines opened in the intervening time.

Hugo Ahlenius, Nordpil, based on data from US Geological Survey Mineral Resources Data System (http://mrdata.usgs.gov/mrds/)

Fig. 1 Map of mines in the Arctic region active as of 2011

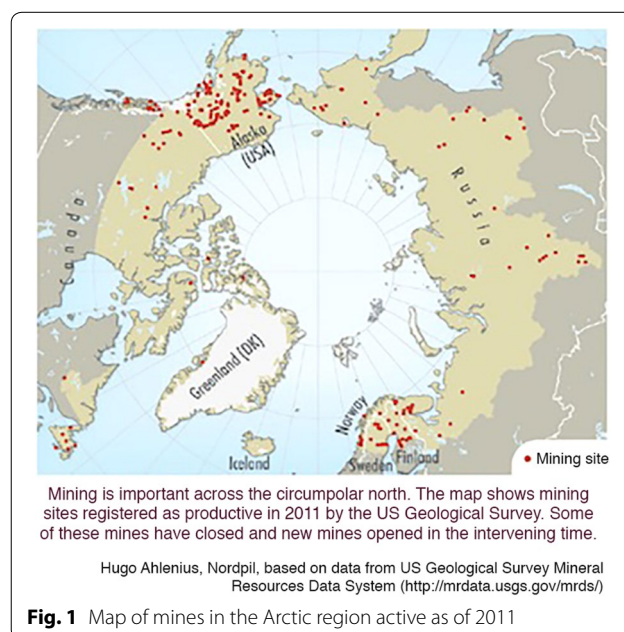Haddaway *et al. Environ Evid*   (2019) 8:9

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Table 1 List of minerals mined across Arctic and boreal countries (Alaska (US), Canada, Greenland, Iceland, The Faroes, Norway (including Svalbard), Sweden, Finland and Russia) and the number of mines according to a 2015 survey [33]

Main metal mined	Number of mines
Gold	144
Iron	58
Copper	45
Nickel	39
Zinc	27
Diamonds	15
Uranium	8
Potash	7
Silver	6
Molybdenum	4
Lead	4
Chromium	3
Titanium	2
Tin	2
Tungsten	1
Palladium	1
Nobelium	1
Platinum	1
Lithium	1
Rare earth oxides	1
Antimony	1
Manganese	1
Aluminium	1

The literature on the environmental and social impacts of mining has grown in recent years, but despite its clear importance, there has been little synthesis of research knowledge pertaining to the social and environmental impacts of metal mining in Arctic and boreal regions. The absence of a consolidated knowledge base on the impacts of mining and the effectiveness of mitigation measures in Arctic and boreal regions is a significant knowledge gap in the face of the continued promotion of extractive industries. There is thus an urgent need for approaches that can transparently and legitimately gather research evidence on the potential environmental and social impacts of mining and the impacts of associated mitigation measures in a rigorous manner.

Stakeholder engagement

This systematic map forms a key task within a broader knowledge synthesis project called 3MK (Mapping the impacts of Mining using Multiple Knowledges, https ://osf.io/cvh3u/). The stakeholder group for this map includes representatives of organisations affected by the broader 3MK project knowledge mapping project or who have special interests in the project outcome. We define stakeholders here as all individuals or organisations that might be affected by the systematic map work or its findings [35, 36], and thus broadly includes researchers and the Working and Advisory Group for this project.

Invitations to be included in this group were based on an initial stakeholder mapping process and soliciting expressions of interest (see Stakeholder Engagement Methodology Document, https://osf.io/cvh3u/). This group included government ministries and agencies such as the Ministry of Enterprise and Innovation, the Mineral Inspectorate (Bergstaten) and County Administrative Boards, the mining industries' branch organisation (Svemin) and individual companies such as LKAB Minerals and Boliden AB, Sami organisations, including the Sami Parliament, related research projects, and representatives of international assessment processes, such as activities within the Arctic Council. Stakeholders were invited to a specific meeting (held at Stockholm Environment Institute in September 2018) to help refine the scope, define the key elements of the review question, finalise a search strategy, and suggest sources of evidence, and also to subsequently provide comments on the structure of the protocol .

Objective of the review

The broader 3MK project aims to develop a multiple evidence base methodology [37] combining systematic review approaches with documentation of Indigenous and local knowledge and to apply this approach in a study of the impacts of metal mining and impacts of mitigation measures. This systematic map aims to answer the question:

What research evidence exists on the impacts of metal mining and its mitigation measures on social and environmental systems in Arctic and boreal regions?

The review question has the following key elements:

Population: Social, technological (i.e. industrial contexts, heavily altered environments, etc.) and environmental systems in circumpolar Arctic and boreal regions.

Intervention/exposure: Impacts (direct and indirect, positive and negative) associated with metal mining (for gold, iron, copper, nickel, zinc,

silver, molybdenum and lead) or its mitigation measures. We focus on these metals as they represent approximately 88% of Arctic and boreal mines (according to relevant country operating mine data from 2015, [33]), and contains the top 5 minerals extracted in the region (gold, iron, copper, nickel and zinc). Furthermore, these minerals include all metals mined within Sweden, the scope of a related workstream within the broader 3MK project (https://osf.io/cvh3u/).

Comparator: For quantitative research; the absence of metal mining or metal mining mitigation measures—either prior to an activity or in an independent, controlled location lacking such impacts. Additionally, alternative mining systems is a suitable comparator. For qualitative research; comparators are typically implicit, if present and will thus not be required.

Outcome: Any and all outcomes observed in social and environmental systems described in the literature will be iteratively identified and catalogued.

Data type: Both quantitative and qualitative research will be included.

Methods

The review will follow the Collaboration for Environmental Evidence Guidelines and Standards for Evidence Synthesis in Environmental Management [38] and it conforms to ROSES reporting standards [39] (see Additional file 1).

Searching for articles
Bibliographic database searches
We will search bibliographic databases using a tested search string adapted to each database according to the necessary input syntax of each resource. The Boolean version of the search string that will be used in Web of Science Core Collections can be found in Additional file 2.

We will search across 17 bibliographic databases as show in Table 2. Bibliographic database searches will be performed in English only, since these databases catalogue research using English titles and abstracts.

Web-based search engines
Searches for academic (i.e. file-drawer) and organisational grey literature (as defined by [40]) will be performed in Google Scholar, which has been shown to be effective in retrieving these types of grey literature [41]. The search strings used to search for literature in Google Scholar are described in detail in Additional file 3.

Search results will be exported from Google Scholar using *Publish or Perish* [42], which allows the first 1000 results to be exported. These records will be added to the bibliographic database search results prior to duplicate removal.

Organisational websites
In order to identify organisational grey literature, we will search for relevant evidence across the suite of organisational websites listed in Table 3. For each website, we will save the first 100 search results from each search string as PDF/HTML files and screening the results in situ, recording all relevant full texts for inclusion in the systematic map database. The search terms used will be based on the same terms used in the Google Scholar searches described above but will be adapted iteratively for each website depending on the relevance of the results obtained. In addition, we will hand search each website to locate and screen any articles found in publications or bibliography sections of the sites. All search activities will be recorded and described in the systematic map report.

Bibliographic searches
Relevant reviews that are identified during screening will be reserved for assessment of potentially missed records. Once screening is complete (see below), we will screen the reference lists of these reviews and include relevant full texts in the systematic map database. We will also retain these relevant reviews in an additional systematic map database of review articles.

Estimating the comprehensiveness of the search
A set of 41 studies known to be relevant have been provided by the Advisory Team and Working Group (review team); the benchmark list (see Additional file 4). During scoping and development of the search string, the bibliographic database search results will be checked to ascertain whether any of these studies were not found. For any cases where articles on the benchmark list are missed by

Table 2 List of bibliographic databases to be searched for evidence along with the platform and subscription through which they will be accessed

Database	Portal	Comments
1. Academic Search Premier	EBSCO Host	Stockholm University subscription
2. Agricola	National Agricultural Library	Open Access
3. AGRIS	Food and Agriculture Organisation	Open Access
4. Aquatic Sciences and Fisheries Abstracts	ProQuest	Stockholm University subscription
5. CAB Abstract	CAB Direct	Stockholm University subscription
6. DART-Europe E-theses Portal	DART-Europe E-theses Portal	Open Access
7. DOAJ	DOAJ	Open Access
8. EconLit	EbscoHost	Stockholm University subscription
9. EThOS	British Library	Open Access
10. GreenFILE	EbscoHost	Stockholm University subscription
11. International Bibliography of the Social Sciences (IBSS), Sociological Abstracts, and Worldwide Political Science Abstracts	Social Science Premium Collection (via ProQuest)	Stockholm University subscription
12. JSTOR	JSTOR	Stockholm University subscription
13. MEDLINE	Web of Science	Stockholm University subscription
14. ProQuest Dissertations and Theses	ProQuest	Stockholm University subscription
15. Russian Science Citation Index	Web of Science	Stockholm University subscription
16. Scopus	Scopus	Stockholm University subscription
17. Web of Science Core Collections	Web of Science	Stockholm University subscription

the draft search string, we will examine why these studies may have been missed and adapt the search string accordingly.

Search update

We will perform a search update immediately prior to completion of the systematic map database (i.e. once coding and meta-data is completed). The search strategy for bibliographic databases will be repeated using the same search string, restricting searches to the time period after the original searches were performed. New search results will be processed in the same way as original search results.

Assembling a library of search results

Following searching, we will combine results in a review management platform (e.g. EPPI-Reviewer) and duplicates will be removed using a combination of automated removal and manual screening.

Article screening and study eligibility criteria
Screening process

We will screen records at three levels: title, abstract and full text. Screening will be performed using a review management platform (e.g. Rayyan, EPPI Reviewer, Colandr).

Consistency checking

A subset of 10% of all titles and abstracts will be screened by two reviewers, with all disagreements discussed in detail. Refinements of the inclusion criteria will be made in liaison with the entire review team where necessary. A kappa test will be performed on the outputs of screening of this subset and where agreement is below $k = 0.6$, a further 10% of records will be screened and tested. Only when a kappa score of greater than 0.6 is obtained will a single reviewer screen the remaining records. Consistency checking on a subset of 10% will be undertaken at full text screening in a similar manner, followed by discussion of all disagreements. A kappa test will be performed and consistency checking repeated on a second subset of 10% where agreements is below $k = 0.6$. Consistency checking will be repeated until a score of greater than 0.6 is obtained.

Eligibility criteria

The following inclusion criteria will be used to assess relevance of studies identified through searching. All inclusion criteria will be used at full text screening, but we believe that *data type* and *comparator* are unlikely to be useful at title and abstract screening, since this information is often not well-reported in titles or abstracts.

Eligible population: We will include social, technological   and

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Table 3 List of organisational websites that will be searched for organisational grey literature

Organisation	URL
1. Swedish Environmental Protection Agency (SEPA)	http://www.swedishepa.se/
2. Finnish Environment Institute	http://www.environment.fi/
3. United States Environmental Protection Agency	http://www3.epa.gov/
4. European Commission	http://ec.europa.eu/
5. Resource Extraction and Sustainable Arctic Communities project (REXSAC)	https://www.rexsac.org/
6. Health Canada	http://www.hc-sc.gc.ca
7. European Environment Agency	http://www.eea.europa.eu/
8. Alaska Department of Natural Resources	http://dnr.alaska.gov
9. Arctic Centre (University of Lapland)	http://www.arcticcentre.org
10. Arctic Council	http://www.arctic-council.org
11. Bioforsk	http://www.bioforsk.no
12. Bureau of Land Management, US Dept. of the Interior	http://www.blm.gov
13. Conservation of Arctic Flora and Fauna (CAFF)	http://www.caff.is
14. Environment and Climate Change Canada	http://www.ec.gc.ca
15. Finnish Game and Fisheries Research Institute	http://www.rktl.fi
16. Greenland Institute of Natural Resources	http://www.natur.gl
17. GRID Arendal	http://www.grida.no
18. International Union for Conservation of Nature	http://www.iucn.org
19. Ministry of Natural Resources of the Russian Federation	http://www.mnr.gov.ru
20. Natural Resources Canada	http://www.nrcan.gc.ca
21. Nordic Council of Ministers	http://www.norden.org
22. Northern Research Institute (NORUT)	http://www.norut.no
23. Norwegian Directorate for Nature Management	http://www.dirnat.no
24. Norwegian Institute for Nature Research (NINA)	http://www.nina.no
25. Norwegian Polar Institute	http://www.npolar.no
26. Russian Guild of Ecologists	http://www.ecoguild.ru
27. Russian Regional Environmental Centre	http://www.rusrec.ru
28. Sámediggi (Finnish Sami Parliament)	http://www.samediggi.fi
29. Sámediggi (Norwegian Sami Parliament)	http://www.sametinget.no
30. Sápmi (Sami Parliament in Sweden)	http://www.eng.samer.se
31. Swedish University of Agricultural Sciences (SLU)	http://www.slu.se
32. United Nations Environment Programme	http://www.unep.org
33. United States Environmental Protection Agency	http://www.epa.gov
34. United States Fish and Wildlife Service	http://www.fws.gov
35. University of Alaska Anchorage	http://www.uaa.alaska.edu
36. Arctic Monitoring and Assessment Programme (AMAP)	https://www.amap.no/
37. Norwegian Environment Agency	http://www.miljodirektoratet.no/en/
38. Canadian Northern Contaminants Program	http://www.science.gc.ca/eic/site/063.nsf/eng/h_7A463DBA.html
39. Norwegian Institute for Water Research (NIVA)	http://www.niva.no
40. Swedish Agency for Marine and Water Management	http://www.havochvatten.se
41. United Nations Environment Programme	http://www.unep.org
42. United States Environmental Protection Agency	http://www.epa.gov
43. Business and Biodiversity Offset Program (BBOP)	http://bbop.forest-trends.org/
44. International Zinc Association	https://www.zinc.org/about/
45. International Lead Association	https://www.ila-lead.org/home
46. International Lead and Zinc Study Group	http://www.ilzsg.org/static/home.aspx
47. Copper Alliance - The International Copper Association	http://copperalliance.org/
48. International Copper Study Group	https://www.icsg.org/
49. International Iron Metallics Association	https://www.metallics.org/

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Table 3 (continued)

Organisation	URL
50. World Steel Association	https://www.worldsteel.org/
51. Nickel Institute	https://www.nickelinstitute.org/
52. International Nickel Study Group	http://www.insg.org/
53. Applied Environmental Research Center, University of Alaska Anchorage	https://www.uaa.alaska.edu/academics/business-enterprise-institute/applied-environmental-research-center/index.cshtml
54. Polar Environmental Atmospheric Research Laboratory (PEARL)	https://eu-interact.org/field-sites/polar-environment-atmospheric-research-laboratory-pearl/
55. Aurora Research Institute	http://nwtresearch.com/research-projects/information-technology/arctic-collaborative-environment
56. Arctic Health	https://arctichealth.nlm.nih.gov/publications_and_research/242/research/244/organizations
57. Centre for Aboriginal Health Research	http://umanitoba.ca/centres/cahr/
58. Canadian Institute of Health Research (CIHR)	http://www.cihr-irsc.gc.ca/e/193.html
59. ArcticNet	http://www.arcticnet.ulaval.ca/
60. Centre for Indigenous Peoples' Nutrition and Environment (CINE)	http://www.mcgill.ca/cine/
61. Centre for Inuit Health and Changing Environments	http://www.nasivvik.ca/
62. Nunavut Research Institute	http://www.nri.nu.ca/
63. Polar Knowledge Canada (POLAR)	http://www.canada.ca/en/polar-knowledge/index.html
64. Yukon Research Centre	http://www.yukoncollege.yk.ca/research
65. Arctic Health (Finland)	http://www.oulu.fi/arctichealth/
66. Thule Institute	http://www.oulu.fi/thuleinstitute/
67. Arctic Research Centre	http://arctic.au.dk/
68. Greenland Institute for Circumpolar Health Research	http://www.pi.gl/da
69. Isaaffik	http://www.isaaffik.org/
70. University of Iceland Centre of Public Health Sciences	http://english.hi.is/public_health_sciences/public_health_sciences
71. Centre for Saami Health Research	http://en.uit.no/ansatte/organisasjon/hjem?p_menu=42374&p_dimension_id=88182
72. Institute for Circumpolar Health Studies, University of Alaska	http://www.uaa.alaska.edu/instituteforcircumpolarhealthstudies/
73. Institute of Arctic Biology	http://www.iab.uaf.edu/
74. Arctic Studies Center	http://www.mnh.si.edu/arctic/index.html
75. International Arctic Research Center (IARC)	http://www.iarc.uaf.edu/
76. International Arctic Social Sciences Association (IASSA)	http://www.iassa.org/
77. Polar Research Board	http://dels.nas.edu/prb
78. The Arctic Institute: Center for Circumpolar Security Studies	http://www.thearcticinstitute.org/
79. Greenland Institute of Natural Resources	https://education.uarctic.org/universities/greenland/23857/greenland-institute-of-natural-resources
80. Fridtjof Nansen Institute	https://www.fni.no/
81. Stockholm Environment Institute	http://www.sei.org/
82. RAND Corporation	https://www.rand.org/topics/russia.html
83. Strategic innovation programme for the Swedish mining and metal producing industry	https://www.sipstrim.se/
84. International Resource Panel	http://www.resourcepanel.org/
85. Swedish Geological Survey	https://www.sgu.se/en/
86. Geological Survey of Finland	http://en.gtk.fi/
87. Geological survey of Norway	https://www.ngu.no/en
88. Geological Survey of Denmark and Greenland (GEUS)	http://www.eng.geus.dk/
89. Faroese Geological Survey: Jarðfeingi	http://jf.fo/en/
90. Geological Survey of Canada–Natural Resources Canada	https://www.nrcan.gc.ca/earth-sciences/science/geology/gsc/17100
91. Alaska Division of Geological and Geophysical Surveys	http://dggs.alaska.gov/
92. All-Russian Geological Research Institute. A.P. Karpinsky	http://www.vsegei.ru/
93. The World Bank	https://www.worldbank.org/

Table 3 (continued)

Organisation	URL
94. Uppsala University Department of Earth Sciences	https://www.geo.uu.se/research/geophysics/ongoing-research/mineral-exploration/
95. World Gold Council	https://www.gold.org/
96. International Molybdenum Association (IMOA)	https://www.imoa.info/index.php
97. University of Eastern Finland	http://www.uef.fi/en/etusivu
98. Luleå University of Technology	https://www.ltu.se/?l=en
99. Saami Council	
100. The European Network for Sustainable Quarrying and Mining	https://ensqm.weebly.com/
101. Finnish Network for Sustainable Mining	https://www.min-guide.eu/mineral-policy/network-sustainable-mining-1814
102. NGO Mining Working Group	https://miningwg.com/
103. Cultural Survival	https://www.culturalsurvival.org/
104. Federal Agency for Mineral Resources	http://government.ru/en/department/53/
105. International Council on Mining and Minerals	https://www.icmm.com/

environmental systems in Arctic and boreal regions based on political boundaries as follows (this encompasses various definitions of boreal zones, rather than any one specific definition for comprehensiveness and ease of understanding): Canada, USA (Alaska), Greenland, Iceland, the Faroe Islands, Norway (including Svalbard), Sweden, Finland, and Russia.

Eligible intervention/exposure: We will include all impacts (positive, negative, direct and indirect) associated with any aspect of metal mining and its mitigation measures. We will include research pertaining to all stages of mining, from prospecting onwards as follows: prospecting, exploration, construction, operation, maintenance, expansion, abandonment, decommissioning, reopening and repurposing. Eligible mines will include those of gold, iron, copper, nickel, zinc, silver, molybdenum and lead.

Eligible comparator: For quantitative research; the absence of metal mining or metal mining mitigation measures—either prior to an activity or in an independent, controlled location lacking such impacts. For qualitative research; comparators are typically implicit, if present and will thus not be required.

Eligible outcome: Any and all outcomes (i.e. measured impacts) observed in social, technological and environmental systems will be included.

Eligible data type: We will include both quantitative and qualitative research.

Eligible study type: We will include both primary empirical research and secondary research (reviews will be catalogued in a separate database). Modelling studies and commentaries will not be included.

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For all articles excluded at title and abstract or full text levels, reasons for exclusion will be provided in the form of one or more a priori exclusion criteria as follows:

- Exclude, not Arctic or boreal (population).
- Exclude, no primary data (i.e. commentary, modelling article or similar) (study type).
- Exclude, no comparator [for quantitative studies only].
- Exclude, not mining or mining mitigation measures (intervention/exposure).
- Exclude, not relevant metal mining (intervention/exposure) [this category is related to the above intervention/exposure exclusion criteria but will only be selected where all other criteria are met, facilitating expansion of the map in the future].
- Exclude, not an existing mine (planned or unrealised mining activity).

Full text retrieval
We will attempt to retrieve full texts of relevant abstracts using Stockholm University and Carleton University library subscriptions. Where full texts cannot be readily retrieved this way (or via associated library inter-loan networks), we will make use of institutional access provided to our Advisory Team members, including: University College London, KTH, University of Lapland, and SLU. Where records still cannot be obtained, requests for articles will be sent to corresponding authors where email addresses are provided and/or requests for full texts will be made through ResearchGate.

Study validity assessment
This systematic map will not involve an assessment of study validity (an optional part of systematic maps), although some extracted meta-data and coding will relate to internal validity.

Demonstrating procedural objectivity
None of the review team has authored or worked on research within this field prior to starting this project, but members of the Advisory Team and project Working Group will be prevented from providing advice or comments relating specifically to research papers to which they may have contributed.

Table 4 Variables that will be extracted as meta-data (descriptive information) and codes during systematic mapping

Variable	Description	Meta-data or coding
Study country/region	Country/region in which study was undertaken (region applicable for Canadian province or Russian Districts)	Coding
Study location	Short textual description of study location	Meta-data
Latitude	Study location latitude as quoted in the report (or obtained from nearest named location)	Meta-data
Longitude	Study location longitude as quoted in the report (or obtained from nearest named location)	Meta-data
Köppen-Geiger climate zone	Study location climate zone according to Kottek et al. [43]	Coding
Mine type	Surface mining, underground mining, highwall mining	Coding
Mine description	Short textual description (possibly a quotation, identified as such) of the type of mine investigated	Meta-data
Status of mine	Prospecting, exploration, construction, operation, maintenance, expansion, abandonment, decommissioning, reopening, repurposing	Coding
Status of mine description	Short textual description (possibly a quotation, identified as such) of the status of the mine	Meta-data
Metal	Gold, iron, copper, nickel, zinc, silver, molybdenum and lead	Coding
Intervention/exposure	Mining impacts/mitigation impacts	Coding
Intervention/exposure description	Short textual description (possibly a quotation, identified as such) of the mining or mitigation impact investigated	Meta-data
Timeframe of mining/mitigation impacts	Time since investigated activity began at time study was completed	Meta-data
Outcome	Social or ecological outcomes measured during the study, iterative cataloguing into distinct categories	Meta-data
Outcome description	Short textual description (possibly a quotation, identified as such) of the outcome measured	Meta-data
Outcome measurement method	Short textual description (possibly a quotation, identified as such) of the method of outcome measurement	Meta-data

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Data coding strategy

We will extract and code a range of variables, outlined in Table 4. All meta-data and coding will be included in a detailed systematic map database, with each line representing one study-location (i.e. each independent study conducted in each independent location).

Meta-data extraction and coding will be performed by multiple reviewers following consistency checking on an initial coding of subset of between 10 and 15 full texts, discussing all disagreements. The remaining full texts will then be coded. If resources allow we may contact authors by email with requests for missing information.

Study mapping and presentation

We will display the results of the systematic mapping using a ROSES flow diagram [44]. We will narratively synthesise the relevant evidence base in our systematic map using descriptive plots and tables showing the number of studies identified across the variables described above. For more complex data, we will use heat maps to display the volume of evidence across multiple variables (see "Knowledge gap and cluster identification strategy", below).

We will display the contents of our systematic map database in an Evidence Atlas; an interactive, web-based geographical information system showing all meta-data and coding on a cartographic map.

Knowledge gap and cluster identification strategy

We will use interactive heat maps (pivot charts) to display the volume of evidence across multiple dimensions of meta-data in order to identify knowledge gaps (sub-topics un- or under-represented by evidence) and knowledge clusters (sub-topics with sufficient evidence to allow full synthesis). Examples of meta-data variables that will be used together include (this is an indicative rather than exhaustive list):

- Study location (country or broad region) versus outcome.
- Study location (country or broad region) versus mine type.
- Study location (country or broad region) versus data/study type.
- Outcome versus mine type.
- Outcome versus data/study type.

Additional files

Additional file 1. ROSES form for systematic map protocols.

Additional file 2. Boolean format search string for database searches.

Additional file 3. Google Scholar search strategy.

Additional file 4. Benchmark list of relevant articles for comprehensiveness checking of search strategy.

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