The potential influences of mining on insect communities in northern Sweden

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Bachelor thesis • 15 credits
Swedish University of Agricultural Sciences, SLU
Faculty of Forestry Sciences
Department of Wildlife, Fish and Environmental Studies
Skogsvetarprogrammet (Bachelor program of Forestry Sciences)
Bachelor’s thesis in Forest Sciences • 2024:02
Umeå 2024

The potential influence of mining on insect communities in northern Sweden.

The impact of dust deposition and loss of canopy cover on insect diversity and abundance.

Potentiell inverkan av gruvdrift på insektssamhällen i norra Sverige. Påverkan av gruvdamm och förlust av krontäckning på insektsdiversitet och abundans.

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Examiner:	Therese Löfroth, SLU, Department of Fish, Wildlife and Environmental Studies
Credits:	15 credits
Level:	Grundnivå, G2E
Course title:	Självständigt arbete i Biologi (Bachelor thesis in biology)
Course code:	EX1014
Program/education:	Skogsvetarprogrammet (Bachelor program of Forestry Sciences)
Course coordinating dept:	Forest Ecology and Management
Place of publication:	Umeå
Year of publication:	2024
Cover picture:	Nolan J. Rappa
Copyright:	All featured images are used with permission from the copyright owner.
Title of series:	Bachelor’s thesis in Forestry Sciences
Part number:	2024:02
Keywords:	*biodiversity, insect communities, applied entomology, landscape ecology*

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Abstract

Insect communities are a vital part of ecosystems and are today threatened by species extinction and loss of biodiversity. While several drivers of biodiversity loss have been identified, industrial land-use (e.g mining) causing alterations in habitats is one potential driver. In the present study, we examine the effects of mining operations on insect communities in northern Sweden. Using 120 samples from pan traps located close to two major open pit mines (Aitik and Svappavaara) we studied the effects of dust deposition, proximity to mines tailing dams as well as loss of canopy cover on insect biodiversity metrics. We found that insect abundance was higher with proximity to mines tailing dams, potentially due to generalist taxa thriving in degraded habitats. Both dust deposition originating from mines and loss of canopy cover might be factors affecting insect communities and continued research could potentially reveal more complex effects. While the influence of environmental variables for community composition could not be detected, our data show trends of distinctions among sites, potentially due to parasitoid-host relationships.

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Abbreviations

GLM	Generalized linear model
IDH	Intermediate disturbance hypothesis
LKAB	Luossavaara-Kiirunavaara Corporation
NILU	Norwegian Institute for Air Research
SLU	Swedish University of Agricultural Sciences

1. Introduction

1.1 Background

Insects are crucial parts of ecosystems and humanity heavily depend on the ecosystem services that insects provide. Conservation of insect biodiversity is now more important than ever in the face of mass extinction where insect abundance and diversity are rapidly lost (Hallmann et al. 2017; Sánchez-Bayo & Wyckhuys 2019; Cowie et al. 2022). Climate change and the expansion of anthropogenic activities, such as industrial land use, are contributing factors for this large-scale threat to insect diversity on Earth (Cardoso et al. 2020).

The mining industry is a major contributor to emissions of particulate matter that forms as dust. Dust originates from mining operations such as mineral exploration and the large-scale excavation that often follows (Vanderstock et al. 2019; Ukaogo et al. 2020). Furthermore, mining is also a major contributor to deforestation and forest degradation (Kumar et al. 2022). Large areas of forest are cleared for extraction sites as well as for infrastructural development (Ahmed & Aliyu 2019), such as roads and tailing dams built for storage of mining byproducts. Reduced canopy cover can lead to loss of habitat for certain forest associated species (Betts et al. 2022) while others may potentially thrive in disturbed forest areas (Eckerter et al. 2022; Rappa et al. 2023).

1.2 Insect ecosystem functions and services

Insects play a vital role contributing to key ecosystem functions such as pollination, regulating pests and disease, and nutrient cycling (Noriega et al. 2018; Skaldina & Sorvari 2019; Singh et al. 2022). In turn, these functions also provide humans with a plethora of ecosystem services, from medicinal and pharmaceutical sources, food, water quality and materials such as fiber, to protecting agricultural plants and recycling the soil we grow them in, influencing the agro-economy (Noriega et al. 2018; Skaldina & Sorvari 2019; Singh et al. 2022). The magnitude of their role is reflected in the sheer abundance and dominance of life on Earth, being the largest and most diverse group in the animal kingdom (Skaldina & Sorvari 2019; Singh et al. 2022), found on every continent (Chown & Convey 2016). The importance of insect pollinators for plant communities cannot be overstated, with estimations indicating that around 90 % of all Angiosperms depend on pollination from animals in some measure (Ollerton et al. 2011). This becomes especially apparent when focusing on arctic and sub-arctic ecosystems, as insects become the sole animal group of pollinators present (Totland et al. 2013).

1.3 The insect communities of northern Sweden's boreal forests

The overall species richness of macro-organisms in Sweden is highest among insects, with Coleoptera (beetles), Diptera (flies), Hymenoptera (bees, ants and wasps), and Lepidoptera (moths, butterflies) being the Orders with highest richness (Nilsson et al. 2001; Korotyaev et al. 2017). Of these, 63% of Lepidoptera species are flower seeking, followed by 50% within the Order Hymenoptera, and 10% of Coleoptera. It is worth noting that these estimates are skewed since there still exists a considerable knowledge gap in pollinating behavior within Orders such as Diptera and Hymenoptera (Ahrné et al. 2022), with bias in existing species knowledge in the Coleoptera Order (Forbes et al. 2018). The distribution of insect richness varies between the different vegetation zones in Sweden, these being the boreal, hemiboreal and the nemoral zones. The pattern over the country seems to be according to the species-energy theory (Wright 1983) that ties increase in species richness to the available energy present, with highest richness being in the southeast of Sweden and lowest in the northwest (Väisänen & Heliövaara 1994). This also ties into the idea that specialization for different food sources among Orders goes a long way in creating species richness in more northern regions, where the climate is harsher and resources become scarcer (Korotyaev et al. 2017). In the arctic region of Sweden (Västerbotten County, Norrbotten County), Muscidae (Diptera) is the dominant insect group and are also responsible for pollinating most flowering plants present, since other typical pollinators such as Apidae (Hymenoptera), Lepidoptera, and Coleoptera become less prevalent (Pont 1993; Totland et al. 2013; Ahrné et al. 2022). Similarly, Diptera flower-visitors accounted for almost 55-59% of total observations made (with the families Muscidae and Syrphidae being most prominent) in a study by Zoller et al (2020), where pollinator activity was observed during peak summers in the Finnish Lapland from 2018 to 2019.

In northern Sweden, more diverse insect communities can generally be found in forest ecosystems, where more niches exist for specialists. Here, many species of Coleoptera can be found under the bark of standing trees, deadwood, and in the forest floor litter alongside families of Diptera, parasitic Hymenoptera, and other Orders (Korotyaev et al. 2017). Broadly, specialist insects are more susceptible to extinction than generalists and more affected by habitat fragmentation (Tscharntke et al. 2002). By contrast, some insects prefer open areas created through forest disturbance (e.g clear-cuts in forest stands), even among certain forest specialized species such as cavity- nesting bees and wasps (Rappa et al. 2023). This was also observed by Eckerter et al. (2022), where abundance and richness of Hymenoptera species and their parasitoids were found to be higher in small clear-cut areas than in unmanaged forest, indicating the importance of open, disturbed areas. However, Eckerter et al. (2022) also found that the network of host-parasitoids interactions was larger and less specialized in clear-cut spots. Similarly, a study by Kyerematen, R., et al. (2020) found that generalist species of Orthoptera and Hymenoptera benefitted and thrived in high impact, degraded areas in proximity to a mining operation, therefore highly influencing the biodiversity in the area.

1.4 Mining operations in northern Sweden and mining pollution

The mining industry has expanded in northern Sweden over the past several years with the green initiatives that Sweden and EU are implementing. With the rapidly rising demand for heavy metals in the green energy sector, mines provide an important economic resource. The Aitik mine in Norrbotten county is one of Europe's largest open pit copper mines (Boliden Minerals AB n.d.). The iron mine in Svappavaara, also an open pit mine, is one of the oldest in Sweden, were mining operations started in the 1600s (LKAB n.d.). However, mining, as many other anthropogenic land use changes, takes its toll on ecosystems. The extraction of natural resources over several decades disrupts ecological processes and has cumulative impacts, including long lasting contamination from industrial byproducts (Wells et al. 2020), loss of biodiversity, water pollution as well as degradation of nutrients and soil structure (Kyerematen et al. 2020).

Tailing dams are used for the depositing of waste rock and byproducts (tailings) from mining operations. In Aitik, the main tailing dam treatment facility covers approximately 16 km^2 of the area west of the open mine and processing plant (Boliden 2023). Heavy vehicles, mainly used to transport ore and rock, grind down the gravel on the road to smaller fractions, creating fine dust that spreads in the air. Measurements of controlling dust pollution consists of watering/salting roads and dust beaches, as well as releasing tailings slurry through spigots to keep the main area moist (Boliden 2023).

The mining industry is a major contributor to emissions of particulate matter. This pollution can form as airborne dust from operations such as mineral exploration and large-scale excavation (Vanderstock et al. 2019; Ukaogo et al. 2020). Numerous well-documented studies highlight the negative effects of dust pollution on human health (Dominici et al. 2014; Kim et al. 2015; Mukherjee & Agrawal 2017) and plants (Naidoo & Chirkoot 2004; Chandawat et al. 2011; Rai 2016). In contrast, research on the effects on insects is less abundant (Skaldina & Sorvari 2019), especially regarding particulates originating from mining in terrestrial habitats.

Dust pollution as particulate matter consists of heterogeneous pollutants that vary in size, composition, and origin. However, it is typically defined and measured by the size fraction of the particles (Grantz et al. 2003; Vanderstock et al. 2019; Skaldina et al. 2023). This dust includes fine and coarse size fractions, with trace elements and heavy metals present in the coarser particles (Grantz et al. 2003). Heavy metals such as iron, copper, and zinc, are released into terrestrial and aquatic ecosystems through erosion, volcanic activity, and forest fires. Anthropogenic activities also contribute to particulate matter spreading through water contamination and atmospheric deposition (Singh et al. 2022). While some metals are crucial for biochemical processes in plants and animals, others, such as lead, cadmium, and mercury, are innately toxic. Overexposure to heavy metals, even beneficial ones, can lead to severe health issues, including organ system collapse and behavioral changes in insects (Jensen & Trumble 2003; Karadjova & Markova 2009; Skaldina & Sorvari 2019; Feldhaar & Otti 2020; Singh et al. 2022; Monchanin et al. 2023).

Both particulate matter and heavy metals from mining operations negatively impact insect fitness, yet particulate matter is disproportionately understudied (Vanderstock et al. 2019; Feldhaar & Otti 2020; Skaldina et al. 2023). When examining the effects of particulate matter on insects, the majority of the limited studies focus solely on Hymenoptera due to their crucial role as pollinators (Feldhaar & Otti 2020). Vanderstock et al. (2019) conducted one of the earliest non-Hymenoptera studies examining the effects of particulate matter emissions from open-pit coal mines on herbivorous taxa. Their study found that *Helicoverpa armigera* (Lepidoptera) had higher mortality rates in late-instar larvae when consuming dust-ridden foliage and avoided establishing feeding sites on leaves covered in fine coal dust when given a choice. As this suggests, insects are likely to ingest particulate matter via nectar or plant material that is covered in fine dust. Additionally, insects and other animals higher up the trophic hierarchy are exposed to particulate matter through predation (Karadjova & Markova 2009; Vanderstock et al. 2019; Feldhaar & Otti 2020; Singh et al. 2022). Despite these findings, a substantial knowledge gap remains regarding the ecological consequences of dust expulsion from mining operations. For instance, little is known about the influences of dust deposition on understudied insect communities in terrestrial ecosystems, particularly forests.

1.5 Objectives

The present study aims to examine the effects of mining operations on insect communities in northern Sweden, in terms of insect abundance, community composition as well as diversity and richness of taxonomic Orders (richness and diversity hereafter). Changes in these insect biodiversity metrics may respond to environmental changes driven by mining operations, particularly loss of canopy cover, dust deposition and proximity to tailing dams.

We expect that insect abundance, diversity and richness to be lower closer to mining operations which produce dust and open habitat available for certain insects. We expect composition of insect Orders to be similarly influenced by proximity to tailing dams, reduced canopy cover and dust deposition, with more generalist (and thus tolerant) taxa dominating communities closer to the mines.

Research regarding the influences of dust deposition from mining on insects is a relatively scarce topic. We hope to contribute to closing the knowledge gap by investigating the effects dust deposition has on forest insect communities from data relating to two major mines in northern Sweden: Aitik and Svappavaara. The results of these analyses may provide valuable insights for mitigating potentially harmful effects of mining on insect communities.

2. Method

2.1 Study area and insect sampling

The study sites were located near two mines in Norrbotten county, Sweden; the Aitik mine, Gällivare municipality (lat. 67,05° N, long. 20,9333° E) and Svappavaara mine, Kiruna municipality (lat. 67,65° N, long. 21,05° E) (Fig. 1). The forest composition of Norrbotten county is boreal forest dominated by *Pinus Sylvestris* L. (Scots pine) with a mix of *Picea abies* L. (Norway spruce) and *Betula pubescens* Ehrh. (Birch). The forest floor vegetation is typically dominated by the Ericaceae family such as *Vaccinium vitis-idea* (Cowberry), *Empetrum nigrum* (Crowberry) and *Vaccinium myrtillus* (Bilberry).

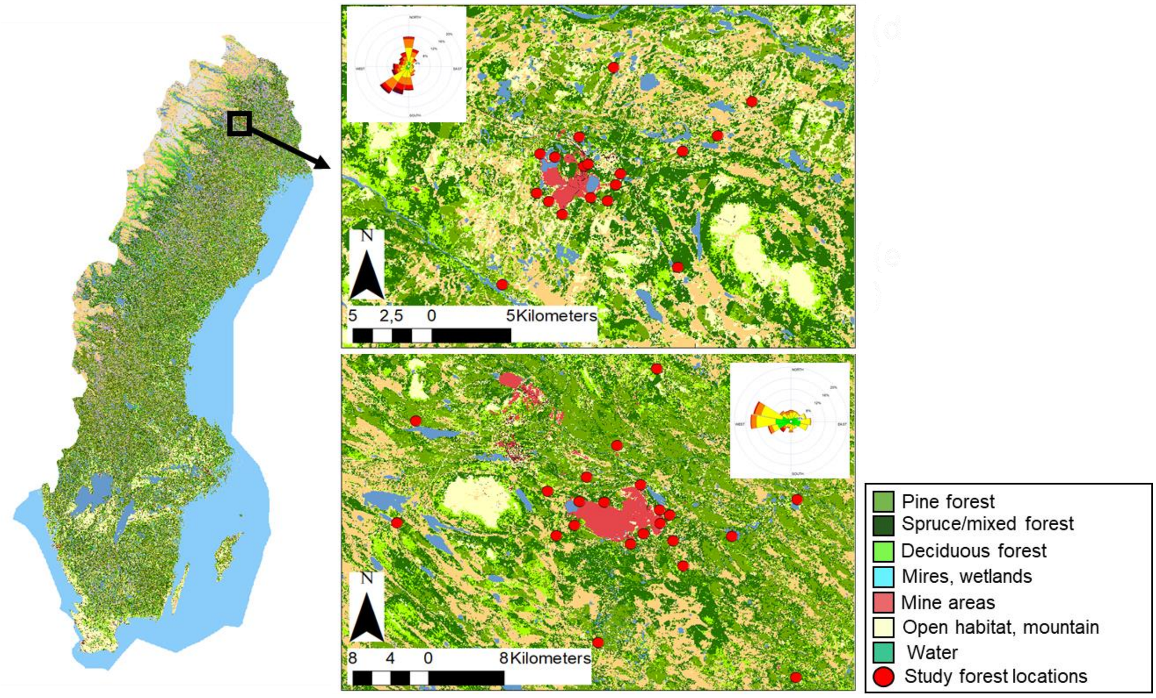

Fig 1. Location of mines (left), Svappavaara mine (top right) and Aitik mine (bottom right), both with forest stand locations (red dots) and fraction of forest plots in each cardinal direction for each mine.

Insect communities were sampled in June and July 2023 using pan traps targeting pollinators. Pan traps are brightly colored containers which attract insect pollinators that visit flowers for gathering pollen and/or nectar. The containers are filled with preservative liquid that holds insects until the sample can be collected. Pan traps were located 10 meters north (N), west (W) and south (S) of center points in a total of 40 circular forest plots (19 plots in Svappavaara and 21 plots in Aitik) with Scots pine aged > 60 years, with the exception of two sites where older stands were not available. Forest plots were located at three rough distance intervals: close to the mine within the highly impacted industrial area (< 100 m), a few hundred meters away from the mine (< 1km), and much further away (‘reference areas’, < 2 km). Forest stands also needed to be relatively accessible for the monthly collection of dust deposition. Pan traps were emptied every 7-10 days, for three sampling cycles between late June and late July. Pan traps were emptied into funnel paper and insects were preserved in propylene glycol until identification.

2.2 Environmental variables

An environmental variable is defined as a factor or condition in a study setting that can influence the result of research analysis (McKee 2023). In the case of this study, the environmental variables consist of physical factors in the environment that is altered by mining operations.

Environmental variables include atmospheric dust pollution originating from the mines, distance to mine/tailing dams and canopy cover in terms of cleared forest areas for mining operations. Distance from mine edge was recorded as well as distance to the mines tailing dams. Dust deposition was collected monthly throughout January- August 2022 in aluminum containers that act as atmospheric particulate fallout collectors. These containers were developed by NILU (Norwegian Institute for Air Research). Structural forest data on tree canopy cover were measured using hemispherical photos, one for each cardinal direction (except east) circa 10 meters from center of plot. All environmental variables can be found in Table 1.

Table 1. Definition, units measured, range mean, and standard deviation of environmental variables

Environmental variable	Unit	Definition	Range	Mean	Standard deviation (±)
Canopy cover	%	Mean tree canopy cover from fisheye hemisphere photos (4 per plot)	27.41 - 72.29	54.34	10.39
Distance to mine edge	km	Distance to the edge of the mine	0.05 - 22.40	4.67	6.19
Distance to tailing dams	km	Distance to the mines tailing dams	1.06 - 26.85	8.12	6.64
Dust deposition	g/ 100m² /30days	Mean dust deposited during the period Jan-Aug 2023	3.18 - 3149.13	299.51	604.24

2.3 Insect sorting and identification

Due to time constraints only samples of the latest sampling cycle, ending on July 24th, were sorted. This sample cycle corresponds to peak insect activity in northern Sweden, and therefore can be considered representative of biodiversity trends. Individuals within samples were identified to Order level and counted prior to entry into a data matrix. A total of 120 insect samples were sorted from this sample cycle. The insects were then put in separate vials and preserved in 70% ethanol, with a project ID label (e.g. MD146) on the front and the field collection ID (e.g. A4W) on the backside. The project ID acts as a failsafe in case of mix ups and to more easily find and reexamine specific samples if necessary.

A few exceptions to the insect Order level division were made with Formicidae (ants) in the Order Hymenoptera. These were sorted accordingly but were counted separately, to not skew the result of the analyses since some samples had a disproportionately large number of ants compared to other taxonomic groups of Hymenoptera. In addition, the eusocial nature of ants may yield false conclusions when not filtered from ecological data. Due to numerous individuals and the potential to skew analyses, Thysanoptera (thrips) were approximately counted and excluded from analyses.

Data were then compiled in a scientific table which summarizes identified insect Orders, using total count and proportion of each Order in the entire dataset (Table 2) In addition, key morphological identification characters are listed for each Order. Other non-Order-level findings identified and collected that could prove useful for future studies included gastropods, larvae and unidentifiable insects (labelled "Unknown"), which were all retained and preserved. These findings also include arthropod Orders not belonging to the Class Insecta, being Acari (mites), Araneae (spiders) and Opiliones (harvestmen). While preserved and stored for further studies, these exceptions were excluded prior to analyses in the present study. For details regarding Orders excluded from analyses, refer to Appendix A. All insect and non-insect findings were identified using field guidebooks (Chinery 1973; Douwes et al. 1997; Gibb & Oseto 2006).

Table 2. Count (number of individuals), proportion in analyzed dataset and identification characteristics of taxa (insect Orders) identified from pan trap samples. The total insect Order count used in analysis amounted to 42,968 individuals.

Taxon	**Count**	**Proportion of analyzed samples (%)**	**Identification characteristics**
Coleoptera (beetles)	861	2.00	Elytra (modified forewings) present
Collembola (springtails)	45	0.10	Springlike tail
Diptera (flies)	40,443	94.12	Halteres (modified hindwings) present
Ephemeroptera (mayflies)	1	< 0.10	Triangular wings present, 2-3 long cerci
Hemiptera (true bugs)	137	0.30	Plant sucking beak present
Hymenoptera (bees, wasps, sawflies)	1366	3.17	Presence of 2 pairs of flying wings, petiole and/or sting (when present)
Lepidoptera (moths)	92	0.20	Coiled proboscis present, scaly wings

Neuroptera (lacewings)	1	< 0.10	Net-like wings present
Plecoptera (stoneflies)	1	< 0.10	Presence of 2 pairs long flattened wings with tail-like cerci extending from abdomen
Psocoptera (booklice)	21	< 0.10	Hump-shaped pronotum with bulging head and round soft abdomen

2.4 Data analyses

Prior to analyses, all environmental variables were tested for potential collinearity using Spearman’s correlation coefficient (R package stats (Dormann et al. 2013). Distance to mine edge correlated with both distances to tailing dams (rho > 0.70) and dust deposited (rho > 0.70), as shown in Appendix A and was therefore excluded prior to analyses.

Modeling of insect abundances, insect diversity (Shannon of Orders) and Order level composition, was done using R Statistical Software (version 4.4.0; R Core Team 2024). Insect abundances were pooled across taxa per sample for a total of 120 data points (R package MASS (Venables et al. 2002)). Abundance was modelled using a GLM (generalized linear model) with a negative binomial distribution to account for overdispersion. Shannon of Orders was calculated per sample for a total of 120 data points and modelled using a linear model (R package car (Fox & Weisberg 2011)). Composition of Orders was analyzed using PCA (principal component analysis) with the ‘rda’ function, including environmental fitting of variables with the ‘envfit’ function (R package vegan (Oksanen et al. 2018); R package lme4 (Bates et al. 2015). All figures were made with R Statistical Software (R package ggplot 2, Wickham, 2016; R package ggpubr (Kassambara 2023).

A PCA is a multivariate statistical approach of compressing and simplify large datasets and still maintain significant trends or patterns. It is a useful technique for ecological field data (Janžekovič & Novak 2012). In this study, PCA was used to analyze insect composition between sample sites. With the envfit function, environmental variables were fitted to the PCA model to show trends in composition. Here, the environmental variables act as vectors for that trend.

3. Results

In total, 42,968 insect specimens were collected and identified for the analyzed sampling cycle, comprising of a total of 10 Orders (Table 2). The dominant Order in terms of abundance was Diptera (94%), followed by Hymenoptera (3%) and Coleoptera (2%). The remaining 7 Orders comprised less than 1% of all individuals collected. Richness of insect Orders could not be analyzed as values ranged between 2 and 6 (number of Orders found in samples) and therefore fell into a range too narrow to analyze and detect any spatial relationships.

Insect abundance increased with increasing proximity to tailing dam (z= -2,577, p = 0.009) (Fig. 2) (Table 3). Shannon of Orders was not significantly related to any environmental variable tested, as shown in Appendix A. While not statistically significant, insect diversity revealed trends with both mean canopy cover (t=1.892, p= 0.061) (Fig. 3) and mean dust deposition (t=-1.713, p=0.089) (Fig. 4).

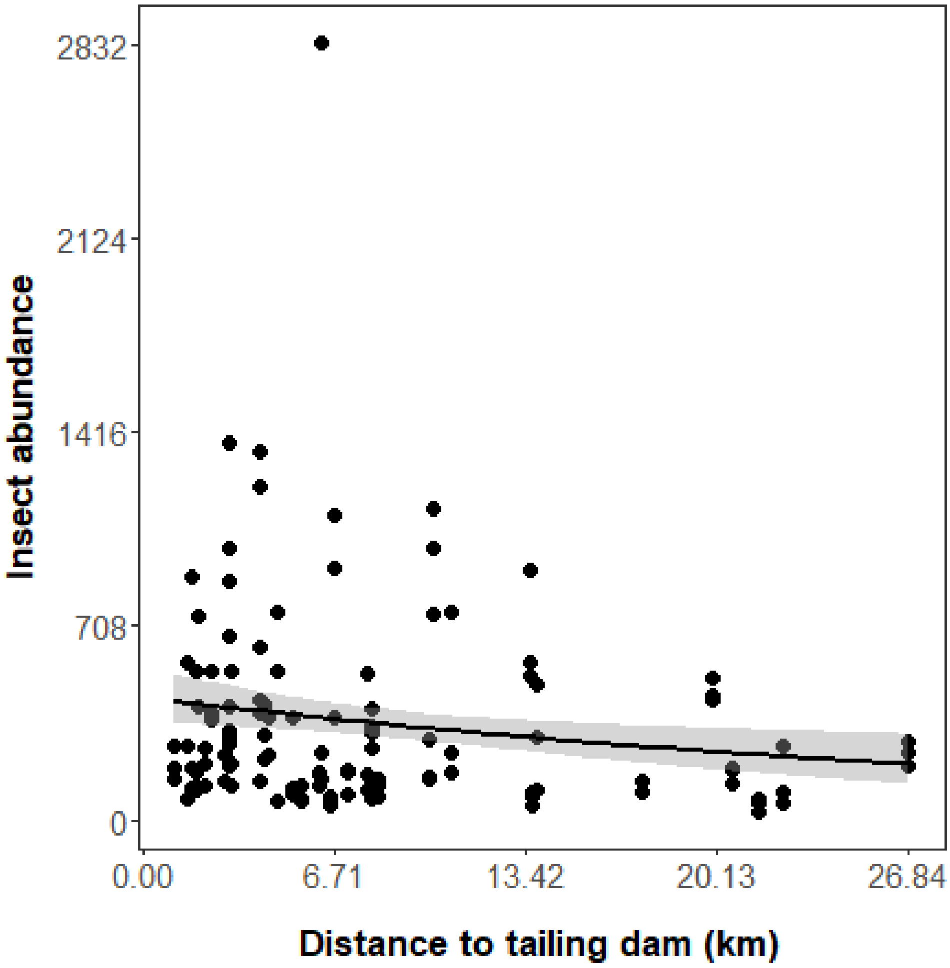

Fig 2. Insect abundance and distance to tailing dams (i,e sand magazine) (km). Solid lines represent a significant relationship between variables, with 95% confidence intervals shaded in gray.

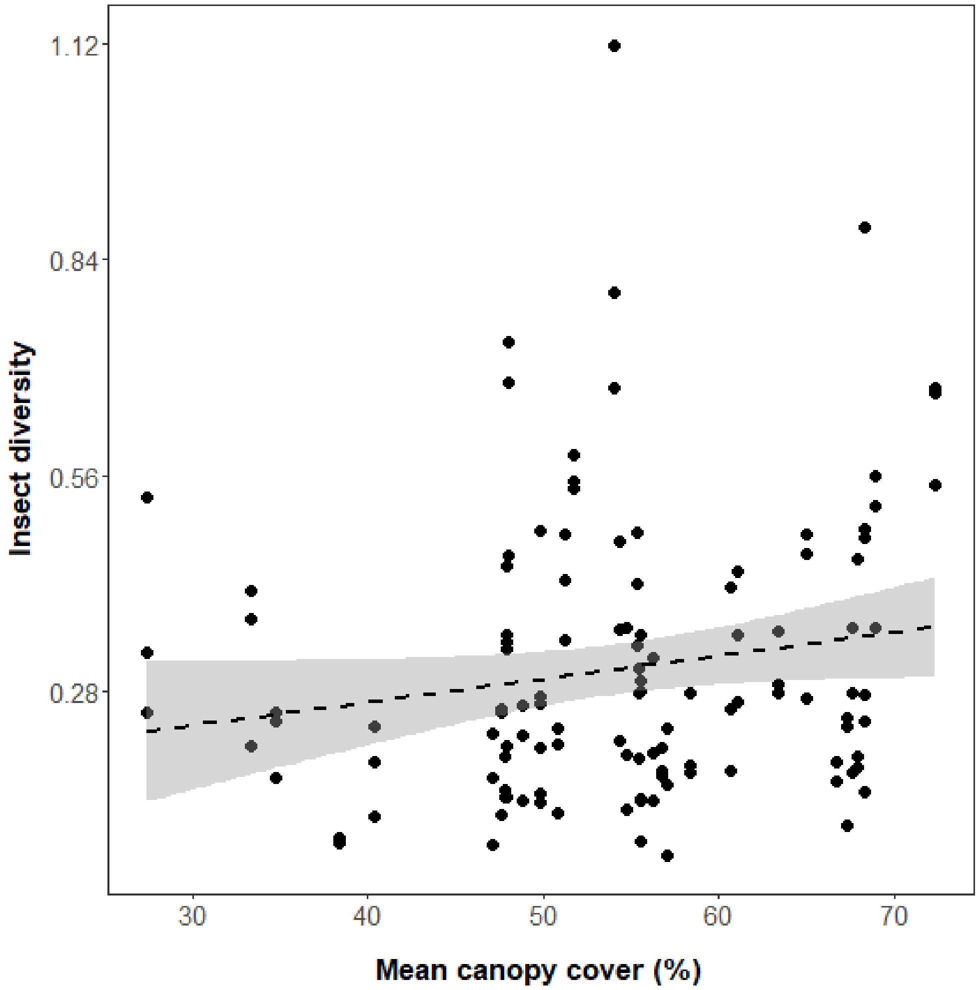

Fig 3. Insect diversity with mean canopy coverage (%). Dashed lines represent relationships determined not to be significant, with 95% confidence intervals shaded in gray.

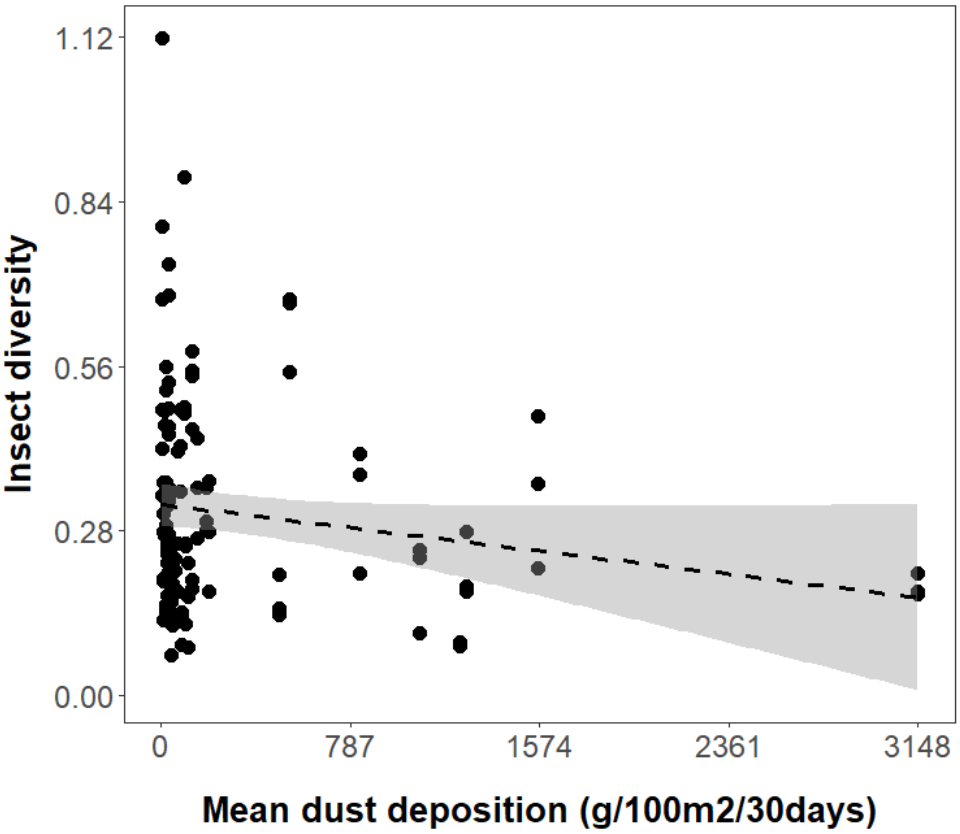

Fig 4. Insect diversity and mean dust deposition (g/100m2/30 days). Dashed lines represent relationships determined not to be significant, with 95% confidence intervals shaded in gray

Table 3. Regression coefficients of generalized linear models of insect abundance and environmental variables. All fixed effects were scaled in each model. Significant effects are displayed in bold.

Environmental variable	Estimate	Standard error (±)	z- value	p- value
Canopy cover (mean)	0.114	0.074	1.540	0.124
Distance to tailing dams	-0.203	0.079	-2.577	**0.010**
Dust deposition (mean)	0.0085	0.078	0.108	0.914

Principal component analysis revealed no relationship between any of the environmental variables and insect community composition. The first two principal components (Diptera and Hymenoptera) accounted for 43.60% of the variation among sites (Fig. 5) (Table 4). In the environmental fitting of variables to the PCA model, none of the environmental variables was significant and therefore no vectors were added in the model (Fig.5). For more information, see Appendix A.

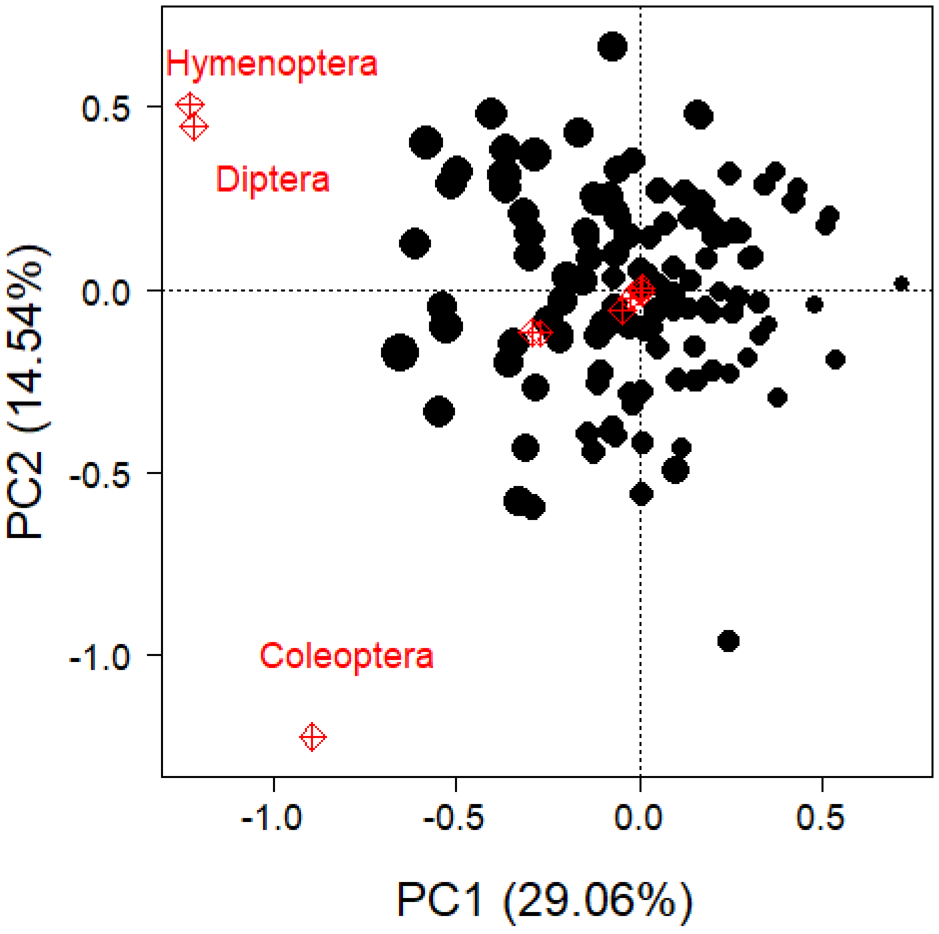

Fig 5. Principal component analysis (PCA) of insect community composition by abundance. Axis represents the two most influential principal components and their respective species score (%). Species scores are plotted and labeled in red, while point size corresponds to insect abundance.

Table 4. Species' scores of principal components derived from principal component analysis (PCA) using insect abundance. The most influential variables for each principal component (>0.5) are displayed in bold.

Insect Order	PC1	PC2
Coleoptera	**-0.8939**	**-1.2237**
Collembola	-0.0473	-0.0555
Diptera	**-1.2196**	-0.4466
Ephemeroptera	0.0052	-0.0087
Hemiptera	-0.2962	-0.1158
Hymenoptera	**-1.2293**	**0.5040**
Lepidoptera	-0.2743	-0.1201
Neuroptera	0.0019	0.0004
Psocoptera	-0.0231	-0.0224
Plecoptera	0.0048	0.0009

4. Discussion

4.1 Insect abundance and tailing dams

Contrary to our expectations, analysis revealed that insect abundance increased with increasing proximity to the tailing dams, which is both a source and a site that has high concentrations of dust deposition originating from mining. Perhaps this can be tied to generalist insects of the Order Diptera showing greater tolerance to disturbances of mining in contrast to more sensitive specialists. In turn, Diptera could be followed by parasitoid Hymenoptera that utilize Diptera as hosts and therefore also contribute to our results regarding insect abundance. This conclusion is in line with the studies of Eckerter et al. 2022, Tscharntke et al. 2002 and Kyerematen 2020. However, fewer datapoints further away from the tailing dams means uncertainty in the current predictions. With more extensive data, the trend might continue and further investigations to explain the relationship between abundance and tailing dam are needed.

Further sorting of the samples at family level and conducting a new analysis would likely reveal the abundance of families Muscidae and Syrphidae within the composition of Diptera as in line with previous studies on arctic insect communities (Pont 1993; Zoller et al. 2020), and potentially indicate a dominance in generalist flower visiting Diptera in samples closest to the tailing dams. Additionally, Coleoptera, Hymenoptera and Lepidoptera could be further sorted to identify specific pollinator families and species. Given this, specialist groups within these Orders may be more vulnerable to mining disturbances, and research needs to be extended to find the distinctions.

4.2 Insect diversity and canopy cover

Although not significant with current data for this study, a trend seems to be emerging, where diversity increases with tree canopy cover. However, canopy cover values are slightly clustered between 50-60%, indicating that sampling a wider gradient may be needed. The presence of several high values of diversity around median values of canopy cover may indicate that medium forest disturbances creates heterogenic structures valuable for non-forest species (Rappa et al. 2023). Potentially, this could signify support for the intermediate disturbance hypothesis (IDH).

The intermediate disturbance hypothesis (Connell 1978) suggests that a community reaches maximum diversity at intermediate levels of disturbance intensity and frequency, while low or extreme levels of disturbance reduce diversity (Moi et al. 2020). This is because a balance is reached between competition and colonization, that allow colonizing and highly competitive species to coexist with each other (Moi et al. 2020). In this case, partial loss of canopy cover provides habitat both for generalist Diptera and specialist insects, because of intermediate disturbance, i.e clear-cutting. Overall, reduction in canopy covers seems to change the insect community dynamics and composition, in the balance between generalists and specialists, colonizers and competitive species, and parasitoids and their hosts. These forest disturbances might be explained by proximity to the mine, with more roads and cleared areas, but could also be explained by conventional forest management. With more data, canopy cover could be an important factor to further investigate and might provide evident support for the IDH.

4.3 Insect diversity and dust deposition

Analysis results revealed that deposition was not significant with insect diversity. However, a trend seems to be emerging with a decrease diversity with increasing dust deposition. What this entails is not completely certain but perhaps increasing dust deposition at sites reduces the presence of insect specialists since they show lower tolerance towards disturbances such as pollution (Tscharntke et al. 2002). The prediction becomes less certain with increasing mean dust deposition, which could be due to the relatively low concentrations of dust sampled even at the higher range (SD ± 0.017). Additionally, the watering/salting in and around the tailing management facility to reduce dust (Boliden 2023) could explain the cause behind the homogeneity at lower mean dust values and in the dataset. Also, the analyzed sample cycle (late June – early July) may also be a factor to how much dust is deposited in terms of water condensing and releasing more dust on sunny and warm days. Data surrounding weather periods and tailing dam management could potentially complement and further explain the relationship with mean dust deposition and diversity. Overall, with more data present covering longer sampling cycles, the trend that is emerging could potentially become significant. Lastly, one thing to consider is that dust deposition might affect more specific taxa (Vanderstock et al. 2019). Further studies that continue sorting and increasing the resolution of insect identification may reveal the intricacies the effect particulate matter has on tolerance and diversity present. In any case, more research regarding particulate matter on insect communities needs to be covered to make any strong claims.

4.4 Principal component analysis

The PCA revealed site tendencies in Order composition that showed greater abundance in Diptera and Hymenoptera ordinating separately from other sites. Diptera and Hymenoptera species scores accounted for the greatest variation among sites as well. The increased proportions of Diptera and Hymenoptera on these sites could be explained with a host-parasitoid relationship (Rappa et al. 2023), as the majority of Hymenoptera observed were parasitoids. Coleoptera abundance was higher in sites where few of the other Orders were represented. The cause of this distinction cannot be explained by the results of the analysis in the present study, and more data and further studies are needed to understand this distinction.

4.5 Conclusion

In conclusion, insect abundance increased with increased proximity to tailing dams, a source of dust deposition. Both dust deposition originating from mines and loss of canopy cover might be possible factors affecting insect community composition and diversity, with continued research potentially providing significant evidence. Diptera and Hymenoptera accounted for most variation among sites and these two Orders, representing large portions of the insect communities, might be the cause of shifts in both abundance and diversity trends. Disturbances and habitat degradation from mining operations might alter community dynamics in terms of parasitoid-host relationships and generalists favored over less competitive specialists.

It is important to understand how industrial activity may affect insect community dynamics, to develop measures to reduce the impact mining has on habitats. Perhaps with more research the management for preventing dust emissions from roads and tailing dams could be improved. Further research on lower taxa can help us further understand how the communities change and why. More knowledge on this topic can enable preventative action and conservation measurements for insect biodiversity. With that, we can counter the worldwide extinction of Earths most diversified group that are crucial to our ecosystems.

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Acknowledgements

We want to thank Nolan Rappa for supervising our work, helping with the sorting process, and supporting us with valuable feedback and comments. We would also like to thank Mari Jönsson, for providing forest data, collected field data and additional information.

Appendix A

Table l: *Count (number of individuals) and identification characteristics of taxon (arthropods, insect exclusions, others) identified from pan trap samples. Taxa listed in table were excluded prior to analyses.*

Taxon	Count	Identification characteristics
Acari (mites)	101	Piercing-sucking mouthparts present, flat/round bodies
Araneae (spiders)	16	Spinning organ and fangs present, body segmented
Formicidae (ants)	147	Petiole present, often wingless.
Larvae	6	Juvenile stage of insect
Opiliones (harvestmen)	1	Body 5-10 mm long, distinct long legs
Thysanoptera (thrips)	2522	Slender bodies, fringed wings present
Unknown	7	Yet to be identified

Table ll. *A summary of Spearman's correlation coefficients among environmental variables. Paired variables with Spearmans´s values (roh) exceeding 0.7 (shown in bold) were considered colinear and therefore one variable was retained for analysis, based on relevance to dust deposition from mine*

Environmental variable	Canopy cover (mean)	Distance to mine edge	Distance to tailing dams	Dust deposition (mean)
Canopy cover (mean)	1.00	-0.04	0.08	0.06

Distance to mine edge	-0.04	1.00	**0.84**	**-0.79**
Distance to tailing dams	0.08	**0.84**	1.00	-0.63
Dust deposition (mean)	0.06	-0.79	-0.63	1.00

Table lll. *Regression coefficients of linear models of insect diversity and environmental variables. All fixed effects were scaled in each model. Significant effects are displayed in bold.*

Environmental variable	Estimate	Standard error (±)	t - value	p - value
Canopy cover (mean)	0.031	0.017	1.892	0.061
Distance to tailing dams	0.001	0.018	0.073	0.942
Dust deposition (mean)	-0.030	0.017	-1.713	0.089

Table lV. *Summary results from permutation tests (10,000 permutations) fitting environmental variables to principal components using insect abundance. Significant fixed effects ($p < 0.05$) are displayed in bold.*

Environmental variable	PC1	PC2	R^2	p- value
Canopy cover (mean)	-0.8491	-0.5282	0.0236	0.2432
Distance to tailing dams	0.6687	-0.7435	0.0350	0.1227
Dust deposition (mean)	-0.8777	-0.4792	0.0141	0.4405

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