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Original Research

Soil-Dwelling Insect Diversity Along a Post-Mining Recovery Gradient: Associations with Soil Chemical Properties and Mercury Contamination

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ABSTRACT

Gold mining removes vegetation and topsoil, often leaving mercury (Hg) in the soil. However, the recovery of soil insects on mined land is poorly documented because soil macrofauna are usually analyzed as a single group. This study examined soil-dwelling insects along a time-since-mining gradient in an artisanal gold mining landscape in Dharmasraya Regency, West Sumatra, Indonesia, and related them to soil chemical properties. Four land-use conditions on Ultisols were compared from January to March 2026: active mining, 5-year and 10-year ex-mining land, and secondary forest. Insects were hand-sorted from three 30 cm × 30 cm × 20 cm monoliths per condition and identified to family level, and soil pH, organic carbon, total nitrogen, C/N ratio, and Hg were analyzed. In total, 51 insects from 11 families and five orders were found, none of them on active mining land. The number of families rose from 4 to 8 and 11, and the Shannon-Wiener index from 1.27 to 1.81 and 2.24, at 5 years, 10 years, and in the forest. Ants dominated recovering sites, but their share fell from 44.4% to 25.9%. Diversity correlated positively with organic carbon ($r = 0.98$) and negatively with Hg ($r = -0.97$), although these exploratory results rest on four land uses. Family-level insect indicators may support monitoring of rehabilitation on gold-mined land.

Keywords: bioindicators; formicidae; gold mining; mercury; soil insects.

INTRODUCTION

Gold mining is a major driver of land-use change in the humid tropics. Where ore lies close to the surface, extraction strips away vegetation and topsoil, the layers that hold most of the organic matter and soil life, and leaves exposed, acidic, nutrient-poor substrates behind (Timsina et al., 2022). In Indonesia, much of this disturbance comes from artisanal and small-scale gold mining (ASGM), which is often informal and relies on mercury (Hg) amalgamation to separate gold from ore (Meutia et al., 2022). Indonesia is consequently among the largest emitters of Hg from ASGM, and Hg released onto land can remain in soils long after mining stops (Ansari et al., 2026). Abandoned mining land, therefore, faces two overlapping problems: the loss of the organic,

nutrient-rich surface layer and chemical stress from acidity and toxic metals.

Recovery of such land is usually assessed by vegetation cover or soil nutrient levels. However, recovery also depends on the animals living in the soil, because they fragment litter, mix soil layers, and recycle nutrients (Wu et al., 2025). Insects are the most diverse of these animals. Ants, beetles, crickets, cockroaches, and true bugs feed on litter, roots, fungi, and other invertebrates, thereby contributing to decomposition, nutrient cycling, and the regulation of other organisms (Noriega et al., 2018). Soil insects also help improve soil physical properties and add organic matter, and they are used as bioindicators of environmental conditions (Wulandari et al., 2018). Ants alone are estimated at 20 quadrillion individuals worldwide (Schultheiss et al., 2022). Because many insects have short life cycles and respond strongly to temperature, moisture, food supply, and soil chemistry (Ikhsan, 2022), their communities are widely proposed as bioindicators, that is, organisms whose diversity or abundance reflects the condition of their habitat. Such indicators can capture aspects of habitat quality that vegetation surveys alone may miss (Cross et al., 2019).

Existing evidence supports this idea but remains uneven. A global review found only 101 peer-reviewed studies over 49 years that assessed fauna responses to mine restoration, most of them from Australia, and many focused on invertebrates (Cross et al., 2019). In Indonesian post-mining landscapes, soil fauna have been linked to reclamation age, organic carbon, pH, temperature, and humidity, but the direction of these links is not always consistent. For example, macrofauna abundance in revegetated limestone land correlated positively with organic carbon and pH (Wasis et al., 2025), and ground-dwelling insect diversity in reclaimed limestone and clay sites rose with soil temperature and humidity (Nuraeni et al., 2026). In contrast, soil-insect diversity in reclaimed limestone quarries showed a moderate negative correlation with soil organic carbon (Oktafitria et al., 2019). Studies on Hg-contaminated land are scarcer still. Ant communities (19 species) persisted on Hg-contaminated gold-mining soil in Colombia, where more even distributions were attributed to greater vegetation complexity (Perez-Garcia et al., 2026). On Obi Island, Indonesia, ASGM altered soil properties and Hg levels, and the composition of ground-dwelling invertebrates differed among sites, with ants dominating the catch (Ansari et al., 2026).

Three gaps remain. First, relatively few studies address gold-mining landscapes, where Hg adds a toxic filter atop nutrient loss. Soil macrofauna and soil chemistry have also been examined mostly in plantation and agricultural systems, such as Arabica coffee under different shade plants (Hasibuan et al., 2026) and oil palm established on former paddy fields in Dharmasraya Regency, where Hymenoptera (ants) dominated (Rosana et al., 2023), rather than on mined land. Second, soil macrofauna are commonly analyzed as a single group that includes insects, earthworms, mollusks, and spiders. These groups differ in mobility, feeding habits, and tolerance to acidity and metals, so pooled indices may mask or distort insect responses, which are the group most often proposed for monitoring restoration. Third, to our knowledge, few studies relate insect diversity indices simultaneously to several soil chemical properties and to soil Hg along a time-since-mining gradient, even though this combination is needed to identify which soil constraints matter most as land recovers. Without such evidence, insect-based monitoring and rehabilitation planning in ASGM-affected land rest on assumptions borrowed from other mine types.

This study addresses these gaps by focusing exclusively on soil-dwelling insects collected from the topsoil (0-20 cm) at four land-use conditions within a single ASGM landscape in Dharmasraya Regency, West Sumatra, Indonesia: land under active mining, land abandoned for 5 years, land abandoned for 10 years, and secondary forest as a reference. Using this space-for-time (chronosequence) design, we ask whether insect diversity recovers with time since mining, and whether recovery tracks soil chemistry and Hg

contamination. The novelty of the work is threefold: (i) an insect-specific analysis of data that are usually pooled as soil macrofauna, (ii) the joint evaluation of soil fertility indicators and Hg in the same recovery gradient, and (iii) a family-level assessment in an ASGM setting that has received little attention in Sumatra.

The aims of this study were therefore to (1) describe the composition, diversity, richness, and evenness of soil-dwelling insect families across the four land-use conditions; (2) characterize soil chemical properties (pH, organic carbon, total nitrogen, C/N ratio, and Hg) in each condition; and (3) determine how insect diversity indices relate to these soil properties. We hypothesized that insect diversity would increase with time since mining, and would correlate positively with organic carbon and negatively with Hg. The findings are expected to support insect-based monitoring and evidence-based rehabilitation of land affected by gold mining.

METHODS

Study site and period

The study was conducted from January to March 2026 in a gold mining area in Nagari Koto Nan IV Dibawuh, IX Koto District, Dharmasraya Regency, West Sumatra, Indonesia. The soils of the area are Ultisols. Soil chemical analyses were carried out at the Soil Laboratory and the Environmental Engineering Laboratory, Universitas Andalas, Padang. Insects were identified at the Integrated Pest Management Laboratory, Universitas Andalas, Dharmasraya.

Experimental design

A survey method with purposive site selection was used, and the study was conducted from January to March 2026. Sites were selected on Ultisols with similar topography so that differences among sites could be attributed mainly to mining history. Four land-use conditions representing a time-since-mining gradient (space-for-time approach) were compared (Table 1). Each condition covered approximately 1–2 ha and contained three observation points, giving a total of 12 observation points.

Table 1. Land-use conditions and locations of the study

Land-use condition	Coordinates	Vegetation cover
Active mining	1.02364501° S, 101.35474818° E	None; open land with excavation pits and standing water
5-year ex-mining	1.02089523° S, 101.35503524° E	Grasses and shrubs
10-year ex-mining	1.02148996° S, 101.35429375° E	Denser shrubs
Secondary forest	1.01868577° S, 101.35015908° E	Trees, shrubs, and litter

Environmental measurements

At each observation point, soil temperature and a soil moisture index were measured at a depth of about 10 cm using a digital soil thermometer and an analog 3-in-1 soil tester, respectively. The moisture index ranges from 1 to 10 (1-3: dry, 4-7: moist, 8-10: wet). Air temperature and relative humidity were recorded with a thermohygrometer placed on the soil surface. Light intensity was measured with a lux meter, with the sensor about 50 cm above the ground. All variables were recorded in the morning, at noon, and in the afternoon, and the three readings were averaged for each point. These variables were included because microclimate strongly influences ground-dwelling insects in post-mining land (Nuraeni et al., 2026). Rainfall data for February 2026 were obtained from the UPTD SDA-BK Southern Region office and assumed to be uniform across sites because all sites lie within a single landscape.

Insect sampling and identification

Sampling was conducted once per observation point in the morning after environmental measurements to minimize disturbance to the habitat. A wooden monolith (30 cm × 30 cm) was placed at each point, the soil was dug to a

depth of 20 cm, and it was spread on a white tarpaulin for hand sorting, following the approach used for post-mining soil macrofauna by Wasis et al. (2025) and for soil macrofauna surveys in Dharmasraya Regency by Rosana et al. (2023). All specimens longer than 2 mm were removed with forceps and preserved in labeled vials containing 70% ethanol. Non-insect macrofauna (earthworms, spiders, and snails) were recorded but excluded from the analysis. Insects were examined under a stereo microscope and identified to family level using insect identification keys (Borror et al., 1996).

Soil sampling and chemical analysis

One soil sample was taken at each observation point from a 0-20 cm depth using an auger, a depth that contains most organic matter and soil biota. Samples were air-dried, crushed, and passed through a 2 mm sieve. The following were determined: (1) soil pH in water and in KCl, by potentiometry (soil to solution ratio 1:2.5; 1 M KCl); (2) organic carbon by Walkley-Black wet oxidation with potassium dichromate and sulfuric acid followed by titration (Oktafitria et al., 2019), with organic matter calculated as organic carbon × 1.724; (3) total nitrogen by the Kjeldahl method ; (4) the C/N ratio as organic carbon divided by total nitrogen; and (5) total mercury (Hg) by atomic absorption spectrometry, expressed in mg/kg, an approach comparable to that applied to composite 20 cm soil samples from artisanal gold mining land by Ansari et al. (2026). Soil chemical values were classified according to national criteria (Eviati et al., 2023).

Data analysis

Insect diversity at each land-use condition was calculated at family level from the insect data only, using three indices: the Shannon-Wiener index ($H' = -\Sigma\ pi \ln pi$, where pi is the proportion of individuals in family i), the Margalef richness index ($DMg = (S - 1)/\ln N$, where S is the number of families and N is the number of individuals), and Pielou's evenness index ($E = H'/\ln S$). Diversity was classed as low (H' below 1), moderate (1–3), or high (above 3); richness as low (DMg below 2.5), moderate (2.5–4), or high (above 4); and evenness as low (0–0.4), moderate (above 0.4–0.6), or high (above 0.6–1). Indices cannot be calculated where no insects were found and were set to zero for correlation analysis. Relationships between soil and environmental variables and insect diversity indices were tested with Pearson correlation (r) across the four land-use conditions at the 5% and 1% significance levels. All statistical data analyses were performed using IBM SPSS Statistics for Windows, version 29.0.

RESULTS AND DISCUSSION

Environmental and soil conditions along the recovery gradient

Environmental and soil conditions improved consistently from actively mined land to secondary forest (Table 2). Actively mined land was hot (soil temperature 33 °C), dry (soil moisture index 2.0), and fully exposed to light (62,888 lx). Its soil was very acidic (pH 3.83 in water) and contained 0.83% organic carbon, 0.09% total nitrogen, and 9.57 mg/kg Hg. Toward the forest, soil temperature fell to 26 °C, surface light fell about 146-fold to 432 lx, the soil moisture index rose to 6.3, and organic carbon rose 3.7-fold to 3.09%. Rainfall in February 2026 was 109 mm at all sites, so these differences reflect vegetation cover and mining history rather than regional weather.

The Hg pattern deserves particular attention. Hg declined from 9.57 mg/kg on active land to 5.99 mg/kg after 5 years and 3.71 mg/kg after 10 years, yet the 10-year site still held about 124 times the Hg concentration of the forest (0.03 mg/kg). Because artisanal and small-scale gold mining (ASGM) releases Hg during amalgamation (Meutia et al., 2022), and Hg can remain in soil long after mining stops (Ansari et al., 2026), natural attenuation appears slow on this land. Organic carbon followed the opposite trajectory, and its gradual build-up from 0.83% to 2.29% over 10 years is consistent with the long recovery times typical of tropical surface gold mines (Timsina et al., 2022). For soil insects, abandoned sites are therefore transitional habitats: microclimate and food supply improve within years, whereas Hg contamination persists for much longer.

Table 2. Environmental and soil chemical conditions at the four land-use conditions

Variable	Active mining	5-year ex-mining	10-year ex-mining	Secondary forest
Soil temperature (°C)	33	30	28	26
Soil moisture index (scale 1-10)	2.0	3.8	5.6	6.3
Air temperature (°C)	31.3	29.1	28.2	26.9
Relative humidity (%)	60	72	80	84
Light intensity (lx)	62,888	5,392	3,130	432
pH (H_2O)	3.83	4.12	4.82	5.59
Organic carbon (%)	0.83	1.92	2.29	3.09
Total nitrogen (%)	0.09	0.19	0.23	0.46
C/N ratio	9.22	10.11	9.96	6.72
Mercury, Hg (mg/kg)	9.57	5.99	3.71	0.03

Note: Values are means of three observation points (environmental variables) or single laboratory determinations per land-use condition (soil chemistry), as described in Materials and Methods.

Composition of the soil-dwelling insect assemblage

In total, 51 insects from 11 families and five orders were collected (Table 3). Insects accounted for 90%, 83%, and 77% of all macrofauna at the 5-year, 10-year, and forest sites, respectively; the remainder (earthworms, spiders, and snails) was excluded from this analysis. Insects also dominated arthropod communities in West Sumatran maize fields, at 97.1% of individuals (Sari et al., 2022). No insect was found on actively mined land. Hymenoptera (Formicidae) was the most abundant order (33.3% of individuals), followed by Coleoptera (23.5%, five families), Orthoptera (19.6%), Hemiptera (13.7%), and Blattodea (9.8%).

Family composition changed in a clear sequence. Four families (Acrididae, Formicidae, Chrysomelidae, and Blaberidae) occurred at all three recovering sites and formed a tolerant core, the only insect assemblage 5 years after mining. Four more families (Cicadidae, Rhyparochromidae, Carabidae, and Gryllidae) appeared at 10 years, and three beetle families (Lycidae, Nitidulidae, and Scarabaeidae) were recorded only in the forest, each with one or two individuals. Because counts are small, absence from a site should be read as "not detected" rather than "absent".

Ants dominated the assemblage at every recovering site, but their share fell as recovery progressed, from 44.4% of insects at 5 years to 40.0% at 10 years and 25.9% in the forest. Ant dominance on disturbed or contaminated land agrees with the gold-mined land of Obi Island, where ants dominated the ground-dwelling invertebrate catch (Ansari et al., 2026), and with Colombia, where ant communities persisted on Hg-contaminated soil (Perez-Garcia et al., 2026). Ants (Hymenoptera) also dominated soil macrofauna on oil palm land converted from paddy fields in Sitiung District, Dharmasraya, where their abundance was attributed to tolerance of direct sunlight and generalist feeding (Rosana et al., 2023). Tolerance of sunlight cannot explain our results on its own, because ants were absent from our fully exposed active mining site, which points to soil conditions such as acidity, low organic matter, and Hg as additional limits. Ants are among the most abundant and widespread insects on Earth (Schultheiss et al., 2022) and are frequently used as indicator groups in mine restoration studies (Cross et al., 2019). According to Andersen (2019), the effects of

disturbance on ants act mainly indirectly, through habitat structure, microclimate, resource availability, and competition, with habitat openness as a key driver. This framework fits the decline in the ant share as our sites became shaded and more humid, although the complete absence of ants from the open mining site shows that severe soil stress can override the openness effect. Our result adds a nuance: the mere presence of ants says little about recovery, but their relative share declined as other families joined the community. The proportion of ants may therefore serve as a simple recovery indicator, although this interpretation is tentative because it rests on three small samples.

Table 3. Number of soil-dwelling insects by order and family at the four land-use conditions

Order	Family	Active mining	5-year	10-year	Forest	Total
Hymenoptera	Formicidae	0	4	6	7	17
Coleoptera	Chrysomelidae	0	1	1	3	5
Coleoptera	Carabidae	0	0	1	2	3
Coleoptera	Scarabaeidae	0	0	0	2	2
Coleoptera	Lycidae	0	0	0	1	1
Coleoptera	Nitidulidae	0	0	0	1	1
Orthoptera	Acrididae	0	2	2	3	7
Orthoptera	Gryllidae	0	0	1	2	3
Hemiptera	Cicadidae	0	0	2	2	4
Hemiptera	Rhyparochromidae	0	0	1	2	3
Blattodea	Blaberidae	0	2	1	2	5
Total individuals		**0**	**9**	**15**	**27**	**51**
Number of families		**0**	**4**	**8**	**11**	**11**

Note: Counts are from three 30 cm × 30 cm × 20 cm monoliths per land-use condition.

The absence of insects on actively mined land is consistent with the extreme combination of heat, dryness, acidity, low organic carbon, and Hg at that site (Table 2). Lower macrofauna abundance on open post-mining land than on revegetated land was also reported by Wasis et al. (2025). Hand sorting of topsoil cannot detect highly mobile or winged insects, so our result describes only soil-dwelling insects, and no single factor can be identified as the cause. The later arrival of Cicadidae, Gryllidae, and ground beetles may reflect a need for more developed vegetation and litter, and for stable moisture. However, vegetation and litter were not measured, so this remains a hypothesis. Hemiptera were also the order of soil macrofauna most affected by herbicide application in smallholder rubber in Dharmasraya (Chaniago et al., 2023), suggesting that this order is sensitive to habitat disturbance.

Insect diversity, richness, and evenness

Insect richness and diversity increased with time since mining (Table 4). The number of families rose from 4 at 5 years to 8 at 10 years and 11 in the forest, and the number of individuals rose from 9 to 15 and then to 27. The Shannon-Wiener index (H′) increased from 1.27 to 1.81 and 2.24 (all in the moderate category), and the Margalef index (D_{Mg}) from 1.37 (low) to 2.58 and 3.03 (moderate). Evenness was high and similar at the three sites (0.87-0.93). Indices could not be calculated for actively mined land, where no insects were found, and were set to zero for the correlation analysis.

Table 4. Insect community indices at the four land-use conditions, with pooled macrofauna indices for comparison

Index	Active mining	5-year	10-year	Forest
Number of families (S)	0	4	8	11
Number of individuals (N)	0	9	15	27
Shannon-Wiener index (H′)	-	1.27	1.81	2.24
Margalef index (D_{Mg})	-	1.37	2.58	3.03
Pielou evenness (E)	-	0.92	0.87	0.93
Ants (% of insects)	-	44.4	40.0	25.9
Pooled macrofauna H′	-	1.47	2.14	2.57
Pooled macrofauna D_{Mg}	-	1.74	3.46	3.94

Note: Insect indices were recalculated from Table 3. Pooled macrofauna values include earthworms, spiders, and snails. A dash indicates that the index cannot be calculated because no individuals were found.

Restricting the analysis to insects altered the picture derived from pooled macrofauna data for the same samples. Pooled indices exceeded insect-only indices by 0.20-0.33 for H′ and by 0.37-0.91 for D_{Mg}, because non-insect families added 1, 3, and 4 families at the 5-year, 10-year, and forest sites, and most of these appeared only at 10 years or later. Pooling therefore overstated insect richness, most strongly at the older sites. This supports analyzing insects separately, as insects are the group most often proposed for monitoring restoration (Cross et al., 2019).

The increase in insect diversity over time since mining aligns with the general pattern in Indonesian post-mining land, where macrofauna abundance was greater on revegetated than on open land (Wasis et al., 2025) and where ground-dwelling insects were associated with microclimate and reclamation conditions (Nuraeni et al., 2026). Recovery was, however, incomplete: after 10 years, insects had regained about 73% of the family richness (8 of 11 families) and about 56% of the abundance (15 of 27 individuals) found in the forest, and the Margalef index remained below the forest value. High evenness should not be read as a balanced community, because with only 9-27 individuals per site, each family is represented by one to seven individuals.

Relationships between insect diversity and soil properties

Pearson correlations across the four land-use conditions (n = 4) showed that insect diversity and richness were positively related to organic carbon, soil moisture, and air humidity, and negatively related to Hg and soil temperature (Table 5). Correlations with pH, total nitrogen, C/N ratio, and surface light were not significant at the 5% level. These results agree in direction with our hypothesis that diversity increases with organic carbon and decreases with Hg.

Organic carbon had one of the strongest relationships with insect diversity (r = 0.98 with H′). Organic matter provides food and shelter for litter- and soil-associated insects, and positive associations between organic carbon and soil macrofauna have been reported in revegetated limestone post-mining land (Wasis et al., 2025). By contrast, Oktafitria et al. (2019) found a moderate negative correlation between soil organic carbon and soil arthropod diversity in reclaimed limestone quarries. The disagreement may reflect the range of conditions sampled: our gradient starts from a bare, hot, Hg-contaminated site with almost no organic carbon and no insects, which produces a steep positive relationship, whereas reclaimed quarries lack such an end member.

Our correlation, therefore, describes recovery from a severely degraded state rather than a general effect of organic carbon within vegetated soils.

Table 5. Pearson correlation coefficients (r) between insect diversity indices and soil and environmental variables (n = 4 land-use conditions)

Variable	r with H′	p	r with D_{Mg}	p
Organic carbon (%)	0.98*	0.016	0.97*	0.029
Hg (mg/kg)	−0.97*	0.034	−0.97*	0.031
pH (H_2O)	0.90	0.101	0.93	0.069
Total nitrogen (%)	0.87	0.127	0.87	0.130
C/N ratio	−0.52	0.484	−0.53	0.472
Soil temperature (°C)	−0.99*	0.013	−0.99*	0.010
Soil moisture index	0.98*	0.016	1.00*	0.001
Relative humidity (%)	1.00*	0.004	1.00*	0.002
Light intensity (lx)	−0.94	0.061	−0.89	0.113

Note: * indicates $p < 0.05$ (two-tailed, 2 degrees of freedom). Indices for active mining were set to zero.

Soil temperature, moisture, and humidity were as strongly related to insect diversity as soil chemistry. Nuraeni et al. (2026) also found microclimate to be associated with ground-dwelling insect diversity on reclaimed land, but with soil temperature positively associated, which differs from our negative relationship. Humidity was also the microclimate variable most strongly associated with the abundance of parasitic Hymenoptera in tidal swamp rice (Ikhsan, 2022), which is consistent with the strong relationship between air humidity and insect diversity in our data. However, the habitat and insect group differ. The difference may arise because our hottest site (33 °C soil temperature) was also bare and contaminated, so temperature here serves as a marker of exposure rather than a direct driver; within a cooler or shaded range, warmer soil may favor insect activity.

Mercury (Hg) showed a strong negative relationship with insect diversity (r = −0.97 with both indices). A direct toxic effect is plausible: Hg taken up from food reduced growth and appeared to trigger food avoidance in a soil-dwelling springtail (Cardoso et al., 2019), and Hg from gold mining is considered to degrade soils and the arthropod fauna living in them (Perez-Garcia et al., 2026). However, our data cannot separate Hg from other variables. Hg, organic carbon, temperature, moisture, and humidity all change together along the gradient; with only four data points, these variables cannot be disentangled. The persistence of four insect families at 5.99 mg/kg Hg and of ants on Hg-contaminated soil in Colombia (Perez-Garcia et al., 2026) suggests that many insects tolerate moderate Hg levels when habitat conditions allow. We therefore interpret Hg primarily as an indicator of mining impact and a plausible contributor to the absence of sensitive families, rather than as the sole cause.

The correlations should also be treated as exploratory. With 18 tests (nine variables and two indices), the Bonferroni threshold is $p = 0.0028$; only the correlations between soil moisture and air humidity, and between D_{Mg} and organic carbon, pass this threshold, whereas those between Hg and organic carbon do not. Microclimate may thus be at least as important as soil chemistry for soil insects on this land, a possibility that deserves direct testing.

Implications for restoration monitoring and study limitations

Three simple family-level signals emerge that could be used for monitoring: no soil insects at all on active mining land; a tolerant core dominated by ants (more than 40% of individuals) in early recovery; and, at later stages, the arrival of crickets, ground beetles, and other beetle families alongside a falling ant share. Because soil Hg remained far above forest levels after 10 years, rehabilitation of ASGM land should combine revegetation, which restores microclimate and organic inputs, with measures to limit Hg exposure, and insect monitoring can then show whether these measures work (Cross et al., 2019; Timsina et al., 2022).

Several limitations apply. First, each land use was represented by one site with three monoliths sampled once, so land-use effects are confounded with site and season. Second, the space-for-time design assumes that all sites started from similar conditions. Third, hand sorting at 0-20 cm misses surface-active, flying, and very small insects, and cicadid specimens are probably nymphs. Fourth, family-level identification obscures species-level responses, particularly among ants. Fifth, the correlations rest on four land-use means. Future work should replicate sites, add pitfall trapping and litter sampling, identify ants to genus or species level, measure vegetation structure and bioavailable Hg, and analyze plot-level data using multivariate or mixed models.

CONCLUSIONS

Soil-dwelling insect diversity was higher at older and forested sites than at recently mined ones. No insects were detected on active mining land, and family richness and the Shannon-Wiener index increased progressively from the 5-year to the 10-year ex-mining site, reaching their highest values in the secondary forest. This pattern coincided with higher soil organic carbon and much lower mercury (Hg) concentrations, which remained clearly above forest levels even after 10 years. These associations are exploratory because a single site represented each land use, and the sample was small, and they were not robust once the active mining site was excluded. Future studies should include replicated sites, litter and pitfall sampling, and measurements of bioavailable Hg. They should track the proportion of ants and the occurrence of beetle families as candidate indicators of ecosystem recovery.

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