Increasing lithium mining could threaten endemic species in biodiversity hotspots

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Abstract

Electric vehicles (EVs) are being rapidly deployed as a technological solution to the climate crisis. However, mineral extraction to supply EV battery production can cause serious environmental damage, threatening ecosystems and biodiversity from local to global scales. Lithium, a key EV battery component, is experiencing an enormous mining boom, which could drive species population declines and eventual extinctions. Using the IUCN Red List, we developed and tested a new metric for assessing the potential threats posed by 400 operational and prospective lithium mines, located across 41 countries, to surrounding species. Our results indicate that Australian lithium mines pose the greatest overall threat and Chilean lithium mines pose the greatest threat on a per species impacted basis. We attribute both countries' mines high potential threat to many of them being located within biodiversity hotspots, where many local species are endemic and already under threat of extinction. A multi-pronged approach may be best to ensure global decarbonization can be achieved without widespread biodiversity loss as a consequence of increasing lithium mining. This approach could involve first reducing lithium demand alongside carbon emissions through behavioural and policy changes. For the remaining lithium demand, restricting lithium mining to areas with low richness of endemic and threatened species, and where the rights of local people have been respected, may produce fewer negative impacts.

Introduction

Electric vehicles (EVs) are being rapidly deployed as a technological solution to the climate crisis because they produce fewer lifecycle carbon emissions than gasoline vehicles[1]. With increasing renewable energy adoption, EV carbon footprints are being further reduced[1]. However, viewing EVs through a carbon-centric lens omits other important aspects of their overall sustainability. Notably, the mineral extraction feeding EV battery production can cause serious ecological harm, a topic often left out of the energy transition discourse[2,3,4]. EV batteries require a wide range of mineral inputs including lithium, nickel, cobalt, manganese, graphite, iron, and phosphorus[5]. Obtaining these minerals, many of which can be toxic to life, requires mining them from the Earth's crust. This process can cause acute harm to both local people and ecosystems[6,7]. With EVs expected to account for over 70 % of new car sales in 2040, many new mines are likely to be built, alongside expansion of existing projects, to fuel this rapidly growing industry[8,9,10]. Lithium mining in particular is experiencing an enormous boom to meet demand, which could grow at least five-fold by 2040[11]. At present, hundreds of new lithium extraction projects are being prospected globally[11].

Lithium is primarily mined via two methods: open pit mining and brine extraction. Open pit lithium mining involves digging pits to access minerals located below the surface and is typically used to extract hard rock and clay lithium deposits. In general, open pit mining's ecological impacts can range from being highly localised, in the form of vegetation and habitat loss, to extending over potentially hundreds of kilometres, through air, water, and soil pollution[6,7]. In the case of brine extraction, lithium-rich brine contained in underground aquifers is pumped into large pans on the surface where the water is evaporated off, leaving lithium salts behind. Like open pit mining, lithium brine extraction can cause significant negative impacts through habitat loss and mine waste pollution[20,64,88]. It notably also has raised serious concerns about groundwater depletion, as many brine mines are located in sensitive arid or wetland environments[7,12]. While the mode of ecological impact may vary by mining method, lithium extraction nevertheless could significantly harm the species living near mine sites, potentially driving population declines and heightening extinction risk for those that are already threatened and/or endemic[13,14,15].

Species population declines, local extinctions, and, ultimately, global biodiversity loss can have serious ramifications[16,17]. Species and ecosystems provide critical contributions to human well-being including food production, carbon sequestration, natural hazard regulation, and nutrient cycling (among many others)[18]. In addition to the material benefits they provide, many species and ecosystems also have intrinsic, cultural, and spiritual value to people around the world[19]. It is therefore urgent and imperative that the ecological consequences of lithium mining are fully understood before, rather than after, more mines are built. A limited number of studies have been conducted on this topic, though primarily focused on particular species and/or regions (namely the Lithium Triangle in South America and the

U.S.A.)[20,21,22,23]. To the best of our knowledge, no study to date has attempted to audit how increasing lithium mining could threaten species from local to global scales.

Using the IUCN Red List of Threatened Species (commonly referred to as the “Red List”) as our foundation, we developed a metric to quantify the potential threats posed by 400 operational and prospective lithium mines to their surrounding species, with the aim of highlighting regions where extractive activities could disproportionately impact already threatened species[24,25]. Additionally, we built a global list of species that could be most severely threatened with extinction from lithium mining, considering various scenarios for future mine construction. Using the Red List’s categorization criteria, we also identified endemic species that are in danger of being driven to more severe threat levels than they are currently classified in, further illuminating the highest risk lithium mining locations. Ideally, this study’s novel findings and methodology will be used to better understand and communicate the potential negative ecological impacts of lithium mining, along with other energy transition minerals more broadly.

Methods

Mine data collection and preparation

A leading battery supply chain market intelligence provider supplied us with a comprehensive list of current and future lithium mines. Totalling 400, these mines encompass the provider’s projections of the likely global lithium sources for the next one to two decades. As the provider is a third-party specialist entity without direct investment in the battery supply chain, we are confident this list reflects an accurate, unbiased outlook for global lithium mining. The provider’s data collection methodology can be found in the **Supporting Information (Extended Methods)**.

Using this list, we obtained the mines’ coordinates through company websites, annual reports, feasibility studies, academic publications, and news articles. An exhaustive list of references is provided in the **Supporting Databook***.* This was straightforward for operational mines, as we could use satellite imagery to confirm visible pits or evaporation ponds at the sites. For mines that have yet to be built, we relied on a combination of maps and project location descriptions published by the operator companies to triangulate each one’s probable future location. Where available, we also extracted the mines’ mineral resource estimates (MREs), reflected in terms of their measured, indicated, and/or inferred resources (in tonnes of lithium). All mine MRE information is provided in the **Supporting Databook**.

We then grouped the mines into three categories, according to their likelihood of becoming operational (referred to as "Active", "Under Development", and "Exploratory"). For the "Active" category, we included all operational and near operational mines. For the "Under Development" and "Exploratory" categories, we relied on whether the mines have MREs published to gauge how far they have progressed. Typically, mine operators only publish MREs once they have conducted significant geological analysis and feasibility studies[65]. Therefore, we assumed that future mines with MREs available are more likely to be constructed than those without. Accordingly, we classified all future mines with MREs into the "Under Development" category and those without into the "Exploratory" category. It is worth noting that, while mines with MREs typically are further along in their lifecycle, other factors including global supply chain trends, government policies, and commodity prices influence a mine's likelihood of becoming operational. Future studies should incorporate a wider range of criteria to better estimate the number of new lithium mines that could be built.

Using QGIS and R, we created point vectors for each mine, with the points located in the approximate centre of the mines' existing sites ("Active" mines) or their likely future sites ("Under Development" and "Exploratory" mines)[77,78]. For the operational mines, we also measured the total direct mining areas of each (in km^2) by drawing polygon shapefiles around the sites and using the st_area() function ("sf" package)[79]. For the operational hard rock / clay mines, we assumed direct mining areas include all mining pits, tailings ponds, and processing units on site. For the operational brine mines, we assumed that all evaporation ponds and visible pumping / piping infrastructure constituted the mining area, although the latter was significantly more challenging to discern from satellite imagery.

For all mines, both operational and prospective, we applied a 50 km radius buffer zone around each centre point to represent the total area within which direct (e.g. deforestation, habitat loss, freshwater consumption, pollution) and indirect (e.g. ancillary infrastructure, roads, etc.) mining impacts could threaten surrounding species. First developed by Sonter *et al.*, 50 km buffers allow for rapid, global assessment of the potential biodiversity impacts of mining projects and have been used in other related studies[30,31,32,33]. This buffer distance is also recommended by the Integrated Biodiversity Assessment Tool (IBAT) Alliance and was used by Rio Tinto, one of the biggest mining companies in the world, in their 2024 sustainability report to record threatened species prevalence near their assets[66,67].

For the operational mines, applying buffers around a singular point does not capture variance in the mines' land use footprints. However, since a point-based method is the only feasible option for assessing "Under Development" and "Exploratory" mines (i.e. it is unclear exactly what these mines will look like), we applied the same approach for the "Active" mines to maintain consistency. We also conducted an analysis of how using the "Active" mines' physical geometries to generate 50 km buffers that extend from each mine's actual footprint rather than a generalized 50 km buffer from each mine's centre would impact the "Active" mines' threat scores. Additionally, we have included a list of the trade-offs to using a generalized 50 km radius in the **Supporting Information**.

IUCN Red List data preparation

We used the Red List to assess how each mine could threaten its surrounding species. The Red List is a globally harmonised database containing detailed information on the extinction risk of over 170,000 species across animals, plants, and fungi[24]. Extant Red List species are classified as Least Concern (LC), Near Threatened (NT), Vulnerable (VU), Endangered (EN), and Critically Endangered (CR), increasing in severity of extinction risk. Vulnerable, Endangered, and Critically Endangered species are considered "threatened" due to their exceptionally high extinction risk. Species that have insufficient population distribution data to be placed in one of these categories are classified as Data-Deficient (DD). The Red List uses five criteria with quantitative thresholds to classify species as Vulnerable, Endangered, or Critically Endangered (named Criteria A – E)[35]. A species only must qualify under one to be designated as Vulnerable, Endangered, or Critically Endangered. In this work, we focused on Criteria B (geographic range area) and E (extinction probability) based on data availability and relevance to the study.

We first obtained all available species range map polygons (i.e. where species are geographically known to occur) from the Red List database for the following taxonomic / species groups: mammals, amphibians, reptiles, plants, freshwater fish, and other freshwater species (crabs, crayfishes, molluscs, odonata, and shrimps)[24,68]. We obtained bird range maps from BirdLife International, the Red List's authority for birds[90].We excluded marine species, as all the mines studied are in terrestrial environments. However, as mine pollution can travel downstream through rivers and eventually reach the ocean, future work should incorporate impacts to marine ecosystems. After filtering, the species selected for analysis totalled 67,050 (5,872 mammals, 7,730 amphibians, 9,999 reptiles, 10,097 birds, 10,593 plants, 13,711 freshwater fish, 9,048 other freshwater species).

While it is the most comprehensive global species database, the Red List also has limitations that should be acknowledged. For the sake of brevity, we have included these in the **Supporting Information (Extended Methods).**

Species threat score computation

Our methodology builds on the concepts underpinning the IUCN's Species Threat Abatement and Restoration (STAR) score, which aims to identify regions that contain disproportionately high percentages of threatened species' habitat[27,28]. Initially proposed for setting species conservation targets, the STAR framework can also be adapted to quantify the species-level threats posed by extractive projects, including mining[29].

Using the STAR philosophy, we developed a threat metric that considers both the amount of species' ranges overlapping with mining impact areas and the species' extinction probabilities. First, we identified which Red List species could occur within each 50-km-buffered mining area and quantified the fraction of the species' ranges coinciding with the site (from 0 to 1). Next, we translated each species' Red List threat category into an extinction probability. The Red List categories inherently incorporate extinction risk (Criterion E), with the IUCN stating that extinction probabilities are ≥ 50% in 10 years for Critically Endangered species, ≥ 20% in 20 years for Endangered species, and ≥ 10% in 100 years for Vulnerable species. However, as these time windows vary significantly, it is difficult to compare species' extinction risks across categories. Additionally, the Red List does not provide extinction probabilities for Near Threatened and Least Concern species.

We therefore utilized extinction probabilities developed by Gumbs *et. al* for the EDGE2 protocol, which has been widely used to support real-world species conservation efforts[34]. Assessed for a uniform 50-year time window, the Gumbs *et. al* identified Critically Endangered species as having an extinction probability of 0.97, with probabilities then halving as categories descend (Endangered = 0.485; Vulnerable = 0.243; Near Threatened = 0.121; Least Concern = 0.0606). While extinction risk time windows can be subjective, Gumbs *et. al* chose 50 years as a suitable time frame to drive conservation action, being neither too far nor too near into the future. This is also well-aligned with the expected lifetimes of lithium mines, which can be decades[69,70,71]. For Data-Deficient species, we assumed their possible weightings could range from 0.0606 (LC) to 0.97 (CR), with a median weighting of 0.243 (VU).

We then multiplied each species' mine-range overlap fraction by its extinction probability to compute a species threat score, normalising to the maximum possible score (0.97) and yielding values between 0 and 1. Finally, we summed each mine's individual species' threat scores to get the mine's overall threat score.

Our overall mine threat score metric is summarised with the following formula:

$$S_i = \sum_{j}^{n} \frac{O_{i,j} * E_j}{1.0 * 0.97}$$

where $O_{i,j}$ is the overlap fraction of a mine *i* with a species *j*'s range (from 0 to 1), E_j is the extinction probability of species *j* based on its Red List category (from 0.0606 for Least Concern to 0.97 for Critically Endangered), and *n* is the total number of species overlapping with the mine. The methodology is visualized in **Fig. 1** and a sample calculation is provided in the **Supporting Information (Extended Methods)**.

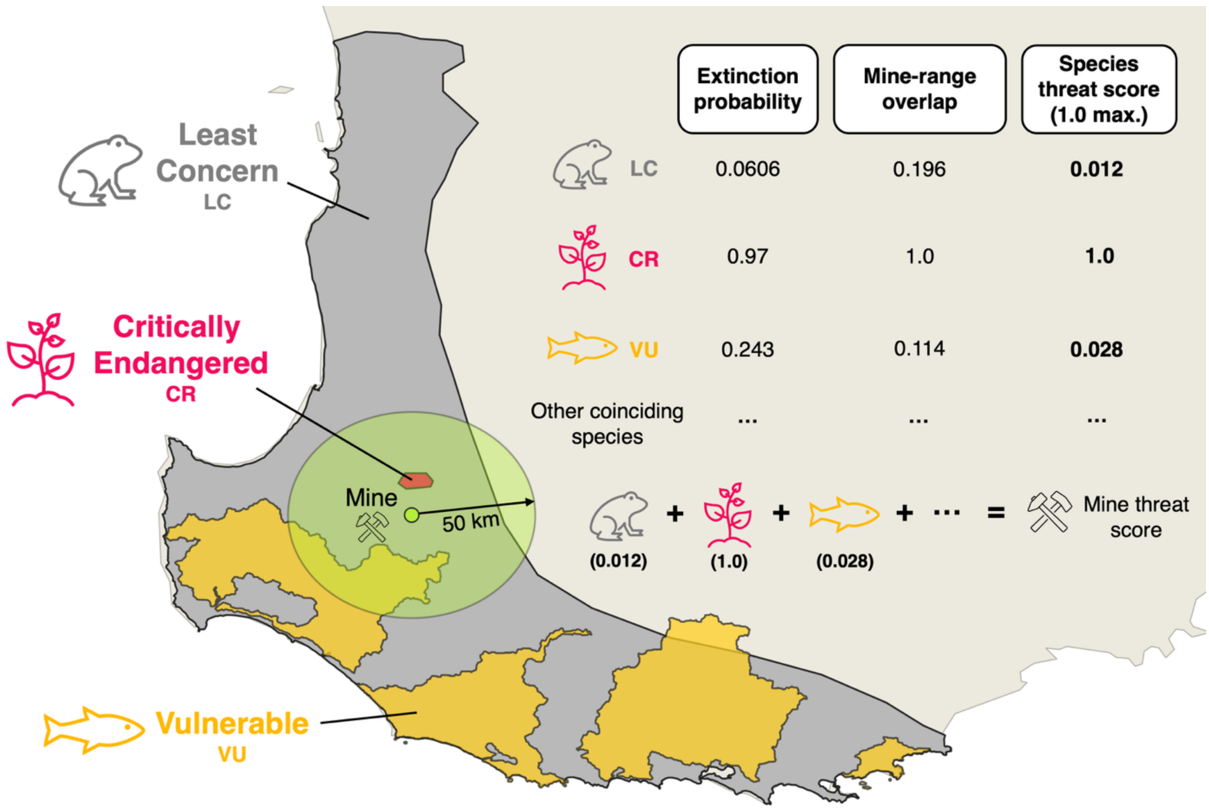


Figure 1 I Species threat metric methodology. Our methodology for computing species-level and mine-level threat scores is depicted for a hypothetical active lithium mine (indicated in green with a 50 km buffer) in Western Australia. The grey, yellow, and red regions indicate each corresponding species' range. Species threat scores are normalised to the maximum score of a Critically Endangered species (0.97) to yield values between 0 and 1. "Other coinciding species" refers to all possible Red List species that could be in proximity to the mine, other than the three explicitly shown.

In addition to mine threat scores, we developed a global list of species that could face the greatest extinction risk because of lithium mining. For this analysis, we considered not just the impact of individual mines on a species, but the combined impact of multiple mines distributed across the species' range (i.e. a cumulative threat score).

For this cumulative impact analysis, we developed three scenarios, accounting for the varying likelihood of prospective lithium projects being constructed. The first scenario ("Scenario 1") assumes that only mines in the "Active" category are / become operational. The second scenario ("Scenario 2") assumes that both "Active" and "Under Development" mines are / become operational. The third scenario ("Scenario 3") assumes that all 400 mines across the "Active", "Under Development", and "Exploratory" categories are / become operational. We then obtained cumulative threat scores for each species per scenario. As many Red List species have little to no occurrence in mining areas and thus very low threat scores, we introduced a cut-off score threshold over which species were deemed to be facing sufficient risk to warrant inclusion in the main analysis (referred to as "at risk" species). We selected a cumulative threat score of 0.125 as our threshold, corresponding with the maximum score a Near Threatened species would receive if 100 % of its range were affected by lithium mining. This ensured that all species scoring above the threshold were Vulnerable, Endangered, or Critically Endangered species with considerable portions of their range impacted.

Future category shift assessment

Many of the species we assessed are currently categorized as Least Concern or Near Threatened but have significant fractions of their ranges within the 50 km impact area of lithium mines. Severe mining impacts, such as pollution or habitat fragmentation, could cause these species' ranges to become uninhabitable and their populations to decline, dramatically shifting them from being of minimal concern to facing serious risk of local and/or global extinction. With this in mind, we conducted a future projection of species that could shift to more severe threat categories, using Red List Criterion B to re-designate species as the appropriate level of endangerment if they become impacted by mining activities.

For a species to qualify for a "threatened" category under Criterion B, it should 1) have an area of occupancy (AOO) less than 10 km^2 (Vulnerable), 500 km^2 (Endangered), or 2,000 km^2 (Critically Endangered) and/or an extent of occurrence (EOO) less than 100 km^2 (Vulnerable), 5,000 km^2 (Endangered), or 20,000 km^2 (Critically Endangered) and 2) be experiencing significant fragmentation, fluctuation, and/or continuing decline in its AOO, EOO, and/or population size. We assumed that negative mining impacts would cause the second condition to be met for all species. We also assumed that if a species' range coincides with mine impact areas, the entirety of the overlapping area would become uninhabitable. Since Criterion B only has thresholds for EOO and AOO rather than range (i.e. our only available species distribution data), we chose to apply the AOO thresholds to the species' range areas (after assumed reduction) to identify if they could qualify for categorization as "threatened". The difference between AOO, EOO, and range and the implications of selecting AOO thresholds for the analysis are explained in the **Supporting Information (Extended Methods)**. We have also included results using EOO thresholds in the **Supporting Databook** to show a different perspective.

For the analysis, we first calculated the species' current range polygon area (in km^2). We then subtracted the total mine overlap area from each species' range and re-assessed what category the species would be in based on the Criterion B AOO thresholds. We did not include Data-Deficient species in this analysis, as we already assumed their categorizations could range from Least Concern to Critically Endangered. In addition to identifying Least Concern or Near Threatened species that could shift to "threatened" categories, we used the same approach to identify species that are already classed as Vulnerable or Endangered but could still qualify for more severe categories. Finally, we quantified how mine threat scores could increase in the future because of species shifting categories.

We acknowledge that assuming a species range is entirely removed because of mining impacts could be too extreme in some cases. Therefore, we considered an additional scenario, which assumes mine impacts would not be severe enough to cause species' ranges to be entirely lost but would nevertheless cause their populations to go into decline, potentially still qualifying them for a "threatened" Red List designation (**Fig. S8-S9**).

Results

Mine overview

The 400 mines are dispersed across 41 countries, with Australia (74), USA (68), Canada (62), Argentina (52), China (40), and Chile (17) containing nearly 80 % (**Fig. 2a**). Approximately 65 % of the mines are hard rock or clay (258), with the remainder primarily brine (129). The hard rock mines include spodumene, petalite, and lepidolite ores, and the brine mines include both evaporative and direct lithium extraction projects[26]. Fifty-six of the mines are operational and 7 are likely to become operational in the next two years – we categorized these 63 mines as “Active”. We classed 124 as “Under Development” because we were able to find mineral resource estimates (MREs) for them, indicating the mines may be operational within a decade. We designated the remaining 213 mines as “Exploratory” because no MREs have been published for them, suggesting they are likely over a decade away from becoming operational.

Mine size varies significantly between the operational hard rock / clay and brine lithium mines. The median active mining area (i.e. pits, tailings, processing equipment, evaporation ponds, pumping equipment) of the hard rock / clay mines is ~2 km^2 whereas it is ~120 km^2 for the brine mines (60-fold greater). This difference in scale is clearly visible in two representative mines' satellite images shown in **Fig. 2b**. Regardless of mine type, the active mining area represents a small share of the broader inferred impact area (50 km buffer) throughout which the mines could harm surrounding species. For a median hard rock / clay mine, the active mining area represents ~0.03 % of the mine's total potential impact area. For the larger brine mines, this value increased to only ~1.5 %.

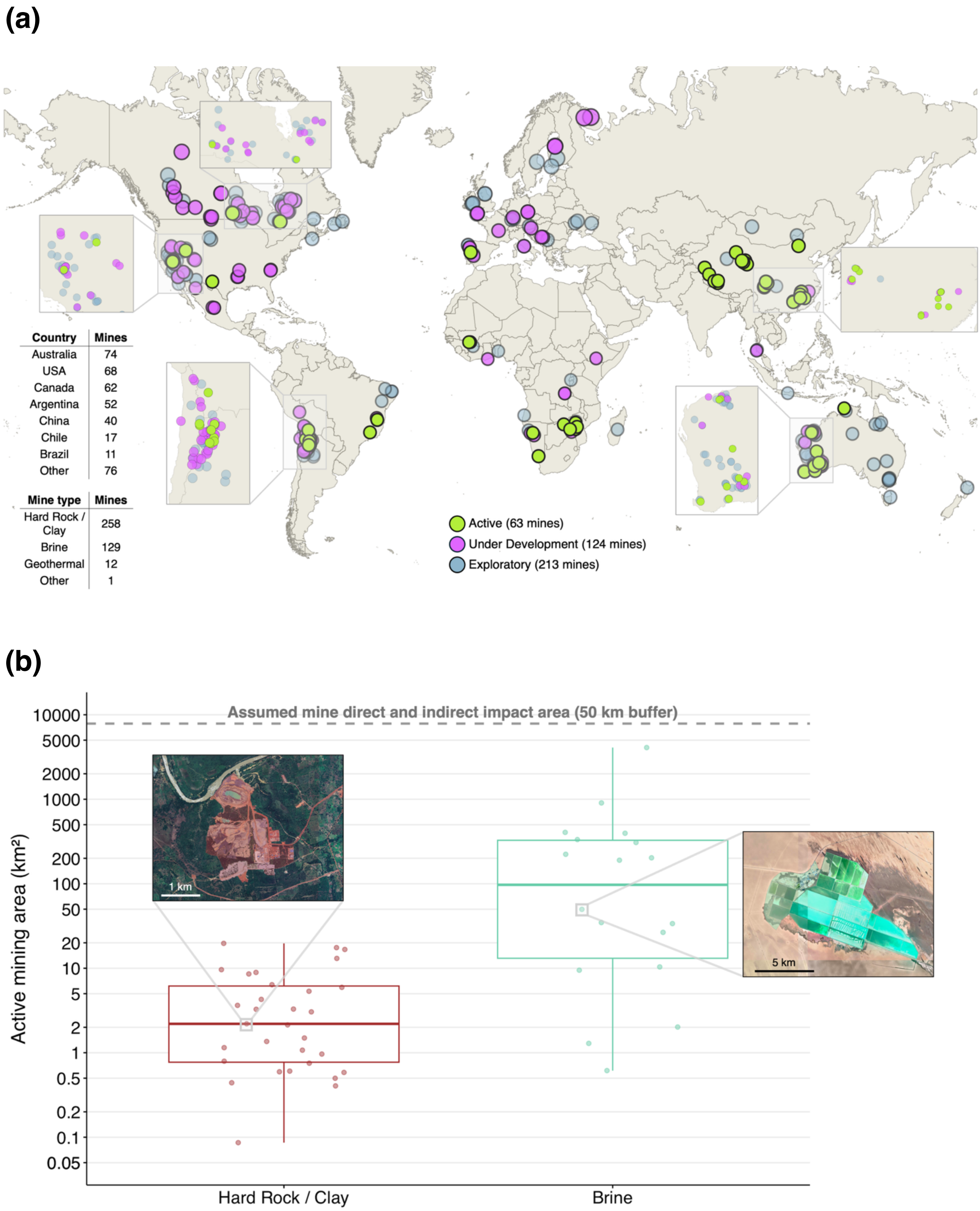


Figure 2 I A summary of the lithium mines assessed in this study. (a) A map of the 400 lithium mines considered in this study is depicted along with their respective categories. **(b)** The active mining areas of all operational lithium mines for which mining areas could be located (33 hard rock/clay, 18 brine) is shown, along with satellite images of two representative mines of close to median size for each mine type. The total impact area assumed for all the mines based on a 50 km buffer is shown as a dashed grey line.

Threat scores

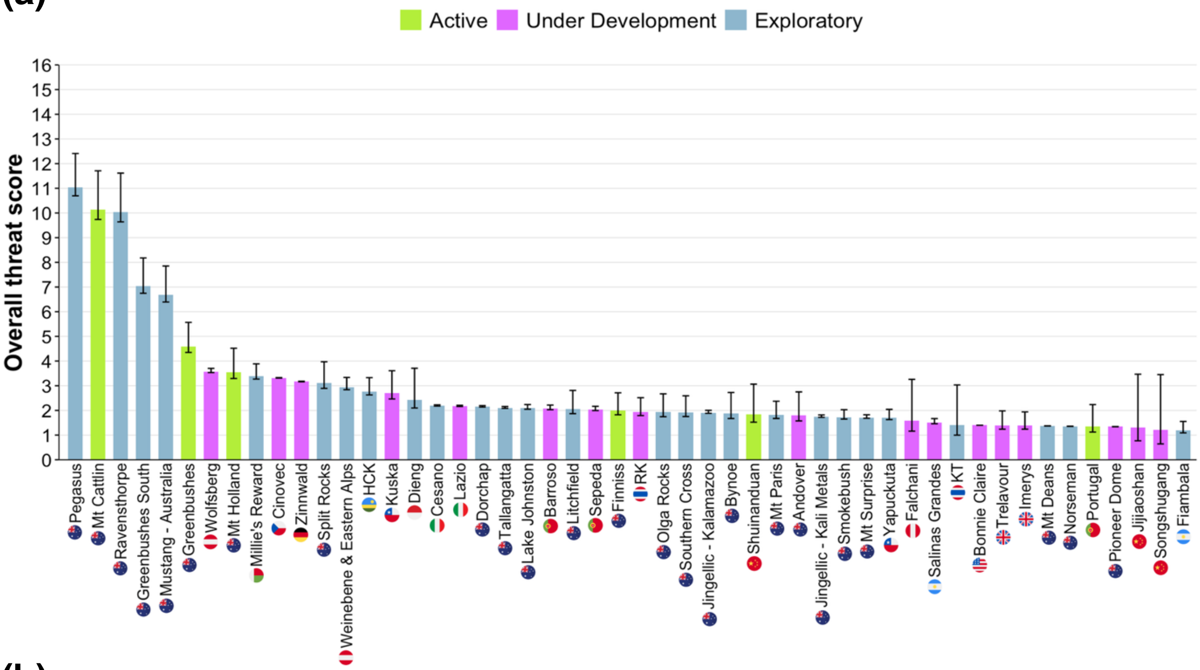
Across all 400 mines, the mean and median overall mine threat scores were 0.575 and 0.219, respectively. The Pegasus hard rock mine in Australia had the highest overall threat score (11.04), its potential impact area strongly coinciding with numerous Vulnerable (6), Endangered (9), and Critically Endangered (3) species' ranges (**Fig. 3a**). The Galinee hard rock mine in Canada had the lowest overall threat score (0.0056; ~ 2000-fold less than Pegasus), minimally impacting any Red List species. Seventy-two mines have at least one Vulnerable, Endangered, or Critically Endangered species with 50% or more of its range within a 50 km radius.

The highest overall scoring mines tend to be concentrated in Australia, including seven of the top 10 and 25 of the top 50. Most of these mines are located in the state of Western Australia. This trend is also clearly reflected when considering country-level scores, with Australia having a total overall threat score of 50.2, over five times greater than the next highest scoring country, China (9.41) (**Fig. 3c**). In general, we found that countries with more mines have higher overall scores. However, this is not always the case. Canada, for example, ranks 3rd for total number of mines (62) but only 18th for overall threat score (1.63). Its threat score is between those of Spain and the UK, which only have four and five lithium mines each, respectively.

Alongside overall mine threat scores, we also considered the mines' relative species threat scores (i.e. average threat score per species potentially occurring in the mine impact area) (**Fig. 3b and 3d**). Across all the mines, the mean and median relative species threat scores were 0.00139 and 6.29×10^{-4}, respectively. The seven highest overall scoring Australian mines remained in the top 10 mines by relative species threat score. Two Chilean mines (Kuska and Yapuckuta) also entered the top 10 after scoring 16th and 38th overall, respectively. At the country-level, Chile ranked 1st for relative species threat score (0.021), followed by Australia (0.017).

We also found that the "Active" mines' overall threat scores did not meaningfully change when using 50 km buffers that incorporate each mine's geometry rather than generalized 50 km buffers around the mines' approximate centres. We've provided this threat score comparison for the top 25 scoring "Active" mines in the **Supporting Information (Fig. S4)**. Additionally, we conducted a sensitivity analysis on the mine buffer radius using 10 km as a more conservative impact distance and found that, though the magnitude of mine threat scores understandably decreased, Australia and Chile both still had the highest overall and relative threat scores, respectively (**Fig. S6-S7)**.

(a)



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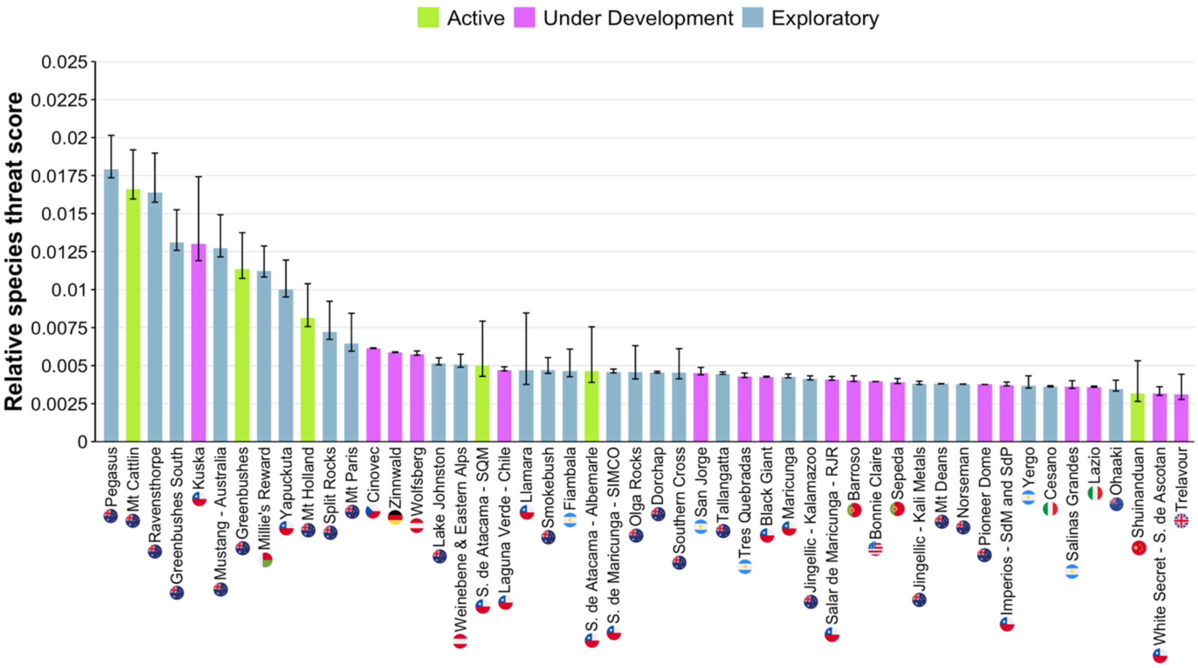

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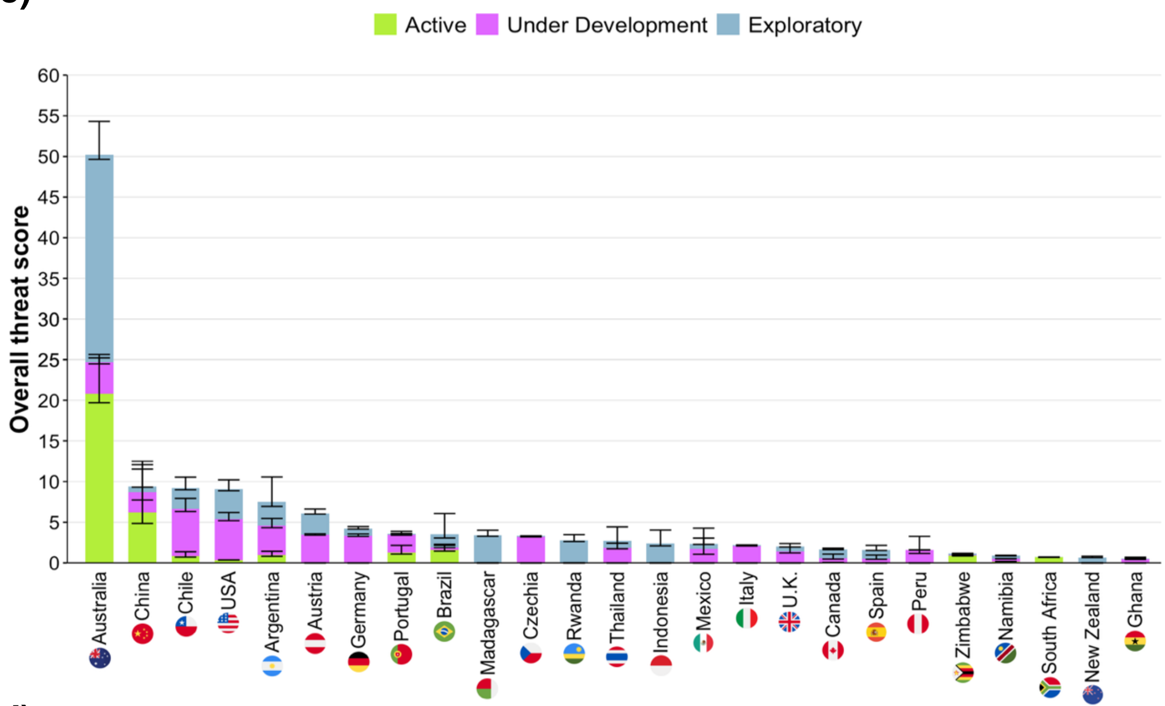


(d)

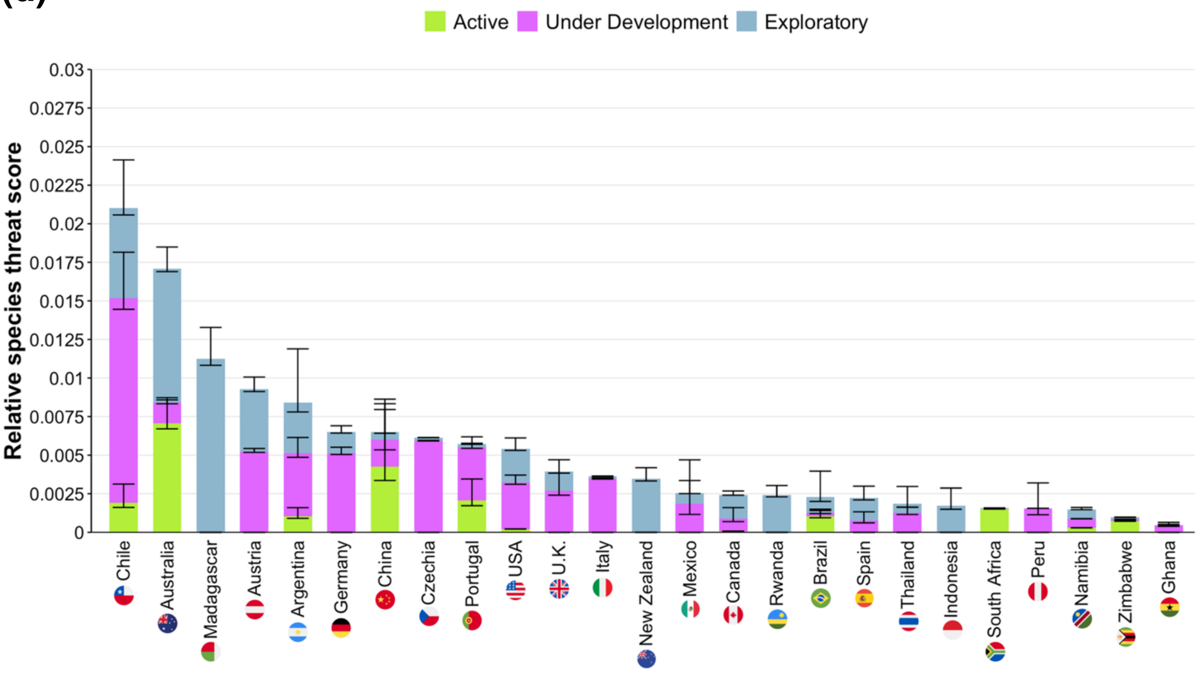


Figure 3 I Mine and country-level threat scores. (a) Top 50 individual mines by overall threat score, (**b)** Top 50 individual mines by relative species threat score, **(c)** Top 25 countries by overall threat score, **(d)** Top 25 countries by relative species threat score. Score bars assume Data-Deficient species are equivalent to Vulnerable species. Error bars show the upper and lower bounds for Data-Deficient species – lower bound assumes all Data-Deficient species are Least Concern, upper bound assumes all are Critically Endangered. Colour coding indicates mine category. Country-level scores account for mine impact areas potentially overlapping with each other to avoid double counting (see **SI – Extended Methods**). Relative species threat scores were calculated by dividing each mine's overall threat score by the number of Red List species potentially occurring within the mine's impact area. Flag icons reprinted with permission from www.flaticon.com.

Species at the greatest risk

At the global level, we identified 46 (Scenario 1) to 193 (Scenario 3) "at risk" species (cumulative threat score ≥ 0.125). Many of these species are located in Australia (30-79) and the majority are plants (28-97). Approximately 35 % of these plant species are from the *Eucalyptus* or *Grevillea* genera. Non-fish freshwater species ("Freshwater other") and reptiles make up the next two taxonomic groups facing the greatest threats (up to 31 and 24 "at-risk" species, respectively). The non-fish freshwater species are distributed across a number of countries, and the reptiles are predominantly concentrated in Australia and the Lithium Triangle (Chile, Argentina, Bolivia). Up to 14 species (Scenario 3) received the maximum threat score of 1.0, indicating they would face the most extreme risk of global extinction. A detailed list of all "at-risk" species is provided in the **Supporting Information (Tables S5-S7).**

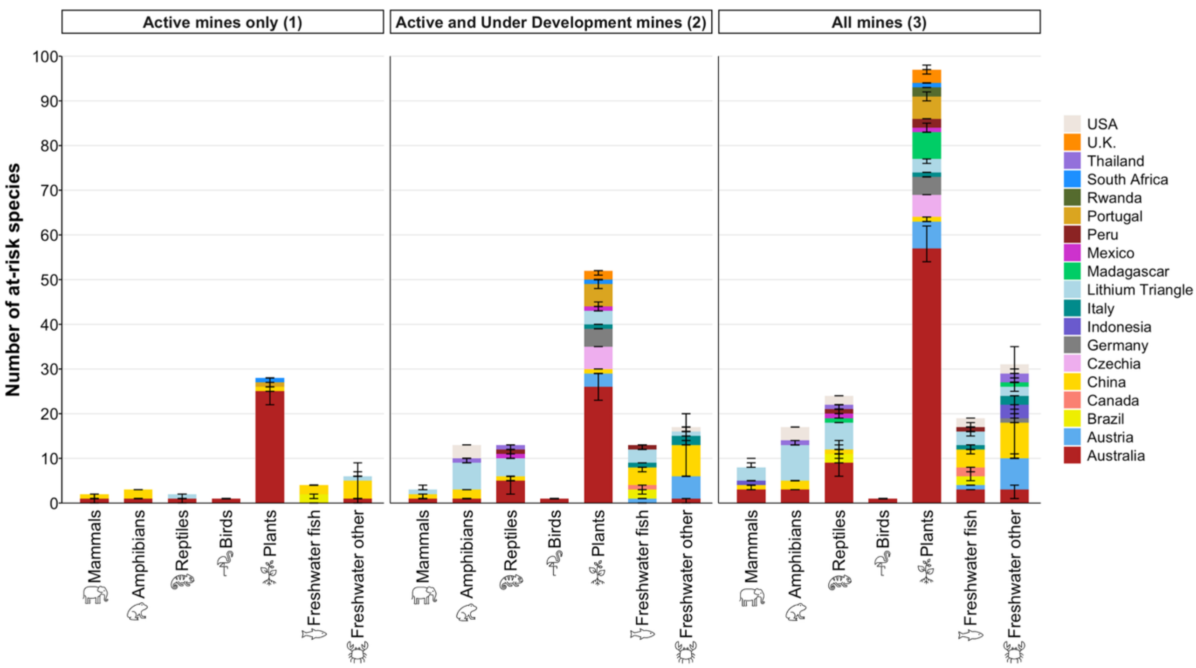


Figure 4 | "At-risk" species by taxonomic group and country. The number of "at-risk" species (cumulative threat score ≥ 0.125) per taxonomic group and broken down by country. Freshwater other includes crabs, crayfishes, molluscs, odonata, and shrimps. Chile, Argentina, Bolivia mines are aggregated into one stack called "Lithium Triangle" to avoid double counting species impacts as many of these mines have overlapping 50 km radii.

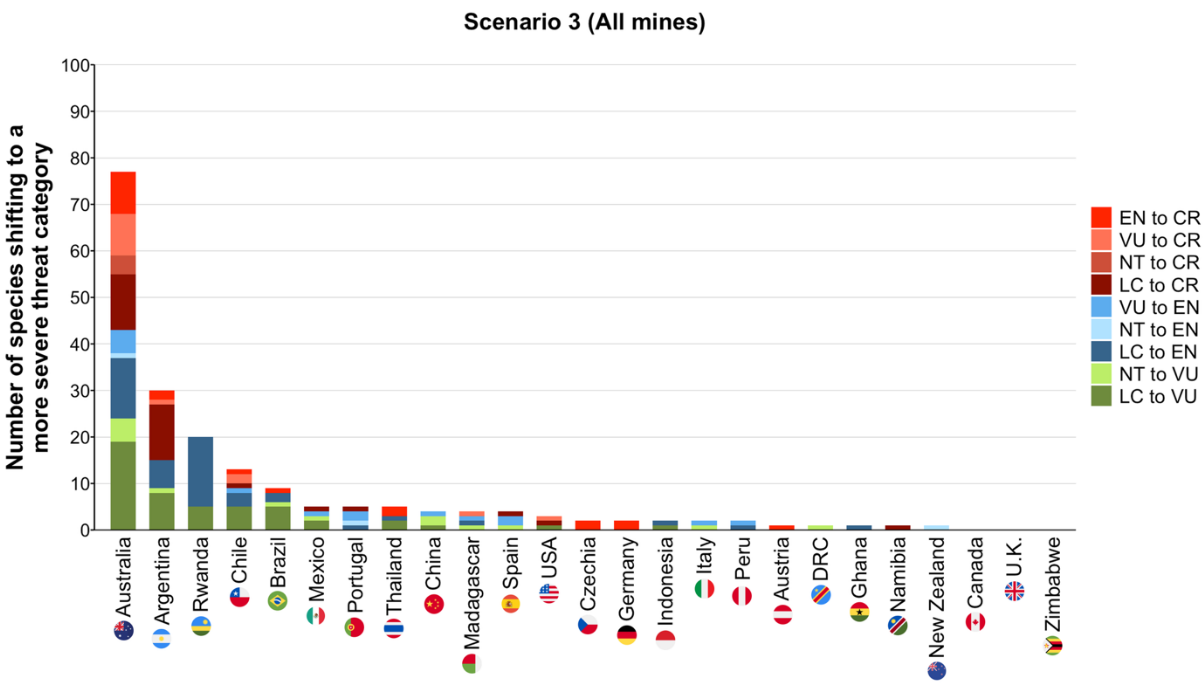
Future species category shift

Across all three mine construction scenarios, at least 184 endemic species could be at risk of being pushed to more severe threat categories if negatively impacted by lithium mining, the majority being plants (~ 60-75 %) and reptiles (~ 8-25 %) (**Fig. S12**). A considerable

number of these species could dramatically shift from Least Concern to Endangered (10-44 species) or even Critically Endangered (5-29 species).
~ 34-40 % of the plant species that could shift to more severe categories are from the *Eucalyptus* genus alone. The majority of the reptiles are lizard species from the *Liolaemus* genus (~ 53-75 %). By country, Australia has the greatest number of species that could shift categories (77 in Scenario 3), with 34 species (44 %) that could become Critically Endangered. Argentina follows behind Australia, with 30 species in danger of shifting to more severe categories. Accounting for variation in the total number of Red List species affected in each country, we found Argentina to have the highest fraction of impacted species that could shift categories (~ 0.033), the majority of these from Least Concern to Critically Endangered. Chile and Australia follow close behind, with species category shift fractions of ~ 0.03 and ~ 0.026, respectively.

We found Australian lithium mines to exhibit the largest potential threat score increase in the future, their combined overall threat score rising from ~ 50 at present to potentially ~ 83 (over 1.5-fold greater). The threats posed by Argentinian and Chilean lithium mines could also become significantly greater in the future, with their overall threat scores increasing from ~ 7 to ~ 22 and ~ 9 to ~ 14, respectively. On a per species impacted basis, similar trends are observed, although with Chile having the greatest future relative species threat score (~ 0.031) and Australia and Argentina following closely behind (~ 0.028 and ~ 0.025, respectively).

(a)



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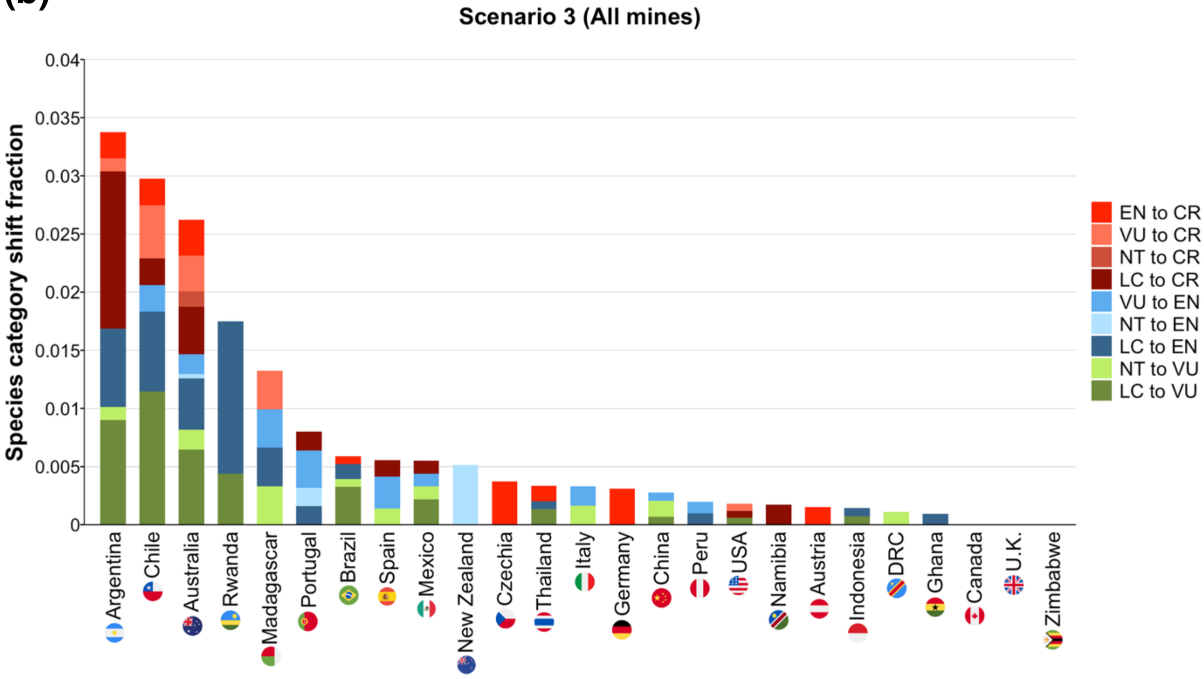

Scenario 3 (All mines)
Species category shift fraction
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
EN to CR
VU to CR
NT to CR
LC to CR
VU to EN
NT to EN
LC to EN
NT to VU
LC to VU
Argentina
Chile
Australia
Rwanda
Madagascar
Portugal
Brazil
Spain
Mexico
New Zealand
Czechia
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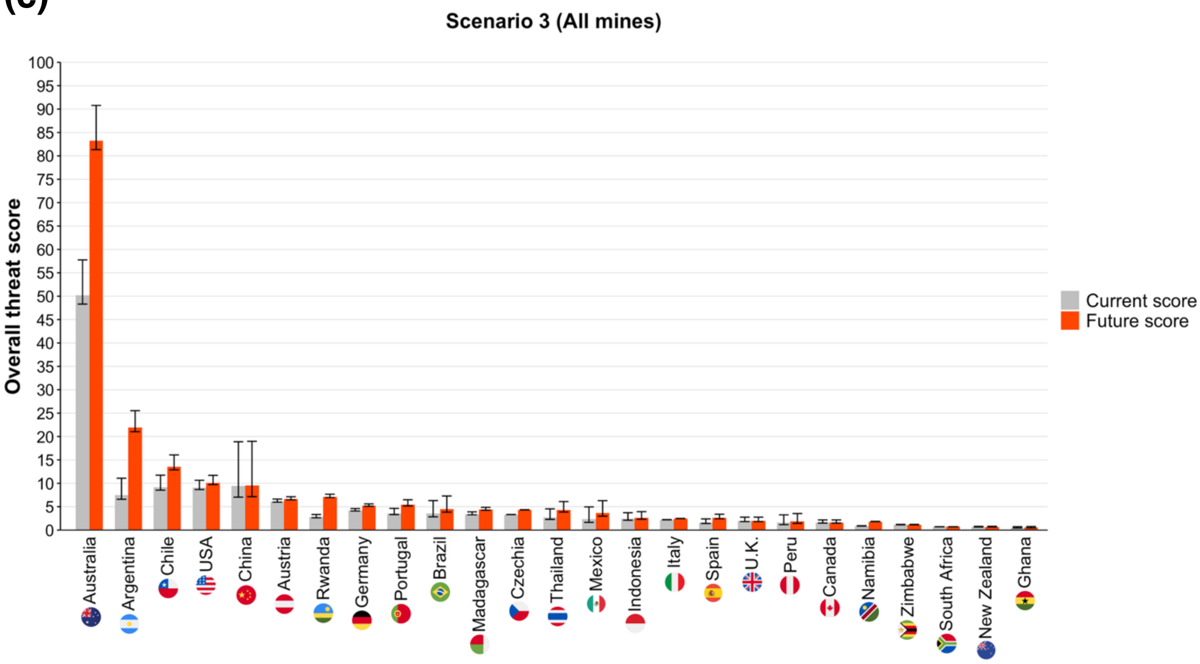
Canada
U.K.
Zimbabwe

(c)



Scenario 3 (All mines)
Overall threat score
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
Current score
Future score
Australia
Argentina
Chile
USA
China
Austria
Rwanda
Germany
Portugal
Brazil
Madagascar
Czechia
Thailand
Mexico
Indonesia
Italy
Spain
U.K.
Peru
Canada
Namibia
Zimbabwe
South Africa
New Zealand
Ghana

(d)

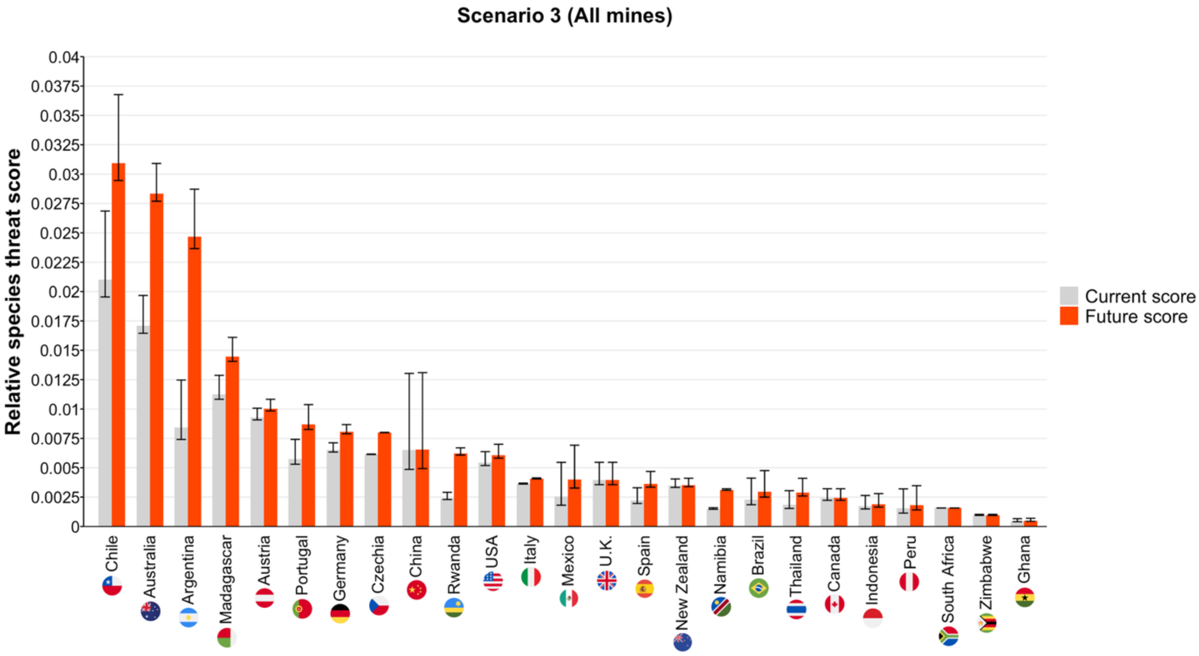


Figure 5 I Future species Red List category shift and threat scores. (a) Number of species at risk of shifting to a more severe threat category per country, **(b)** Fraction of Red List species potentially coinciding with each country's mines that could shift to a more severe threat category, **(c)** Top 25 future country overall threat scores, assuming all species that could shift to a more severe threat category do, **(4)** Top 25 future country relative species threat scores, determined by dividing country overall future threat score by number of Red List species potentially impacted by the country's mines. Flag icons reprinted with permission from www.flaticon.com.

Discussion

This work aimed to conduct a global assessment of how the rapid, widespread increase in lithium mining could harm threatened and/or endemic species and where impacts could be most severe. Using the Red List, we developed a method to quantify lithium mining areas' relative risk of contributing to species extinctions, allowing for insights to be drawn and compared from the individual mine level up to the country and global level. Our findings indicate that Australian lithium mines pose the greatest overall threat, based on both current species threat categorizations and potential future shifts. When considering the average threat per species impacted, however, we found Chilean mines to have the greatest relative species threat under both current and future species categorization scenarios, with Australia ranking 2nd.

We attribute Australian lithium mines' high overall threat and Chilean lithium mines' high relative species threat to the same phenomenon – both countries' mines are heavily co-located with biodiversity hotspots. Biodiversity hotspots are regions containing exceptionally high numbers of endemic species that are also heavily threatened by habitat loss[81]. At present, there are 36 such regions around the world[39].

In the case of Australia, all seven of the Australian lithium mines that rank in the top 10 highest overall scoring mines exist within the Southwest Australia biodiversity hotspot, where over 50 % of local plant species are found nowhere else[40]. Taking the Mt Cattlin mine as an example, 92 % of the mine's overall threat score is from plant species, largely those from the *Eucalyptus* genus (41 %). Approximately a quarter of *Eucalyptus* species*,* which are flowering trees native to Australia, are estimated to be facing extinction risk because of anthropogenic land use change[36,37]. *E. purpurata* (Critically Endangered; threat score = 1.0), *E. desmondensis* (Endangered; threat score = 0.5), and *E. stoatei* (Endangered; threat score = 0.44) are the genus' most threatened species near the Mt Cattlin mine, all restricted to a limited number of locations in southwestern Western Australia. *E. purpurata* is the most severely confined of the three species, having only one known locality and a very narrow range (~70 km^2) that is entirely covered by the mine's potential impact area[38]. Mining-induced population decline could further increase these species' risk of both local and global extinction.

Numerous mines' occurrence in the Southwest Australia hotspot also helps explain Australia's high number of species potentially shifting to more severe threat categories and high future overall threat score. As many species in the region are highly endemic, even those that are not currently listed in high severity Red List categories could still face dramatically elevated extinction risk from adverse mining impacts. This is evident for the Mt Cattlin mine, which coincides with up to 14 endemic *Eucalyptus* species currently categorized as Least Concern or Near Threatened that could be pushed to Endangered or Critically Endangered if they begin to experience population or habitat instability. These 14 species' category shift alone would be responsible for over 50 % of Mt Cattlin's potential future score increase.

To the best of our knowledge, this result is also the first time the potentially severe ecological threats posed by Australian lithium mining have been articulated. Cabernard *et al.* identified the potential for bauxite, gold, and coal mining in southwest Australia to cause biodiversity loss, however their results do not include the impacts of lithium mining in the region[82]. Yu *et al.* acknowledged that demand for clean energy technologies and concurrent lithium mining in Australia could increase biodiversity loss risks, though their analysis similarly focuses on other metal mines in southwest Australia, such as coal and copper[83].

The high threat posed by Chilean lithium mines is not immediately clear when solely considering overall country-level threats scores, in which Australia scores over five times higher than Chile. However, Australia also has a much greater number of published Red List species than Chile (~ 14,000 vs. ~ 2,500), a product of both Australia's higher inherent species richness and potential biases in the Red List data collection process itself[48,84]. Additionally, Australia has more lithium mines than Chile (74 vs. 17), meaning the total area over which its species could be impacted is significantly larger. In this study, we found Australian lithium mines could cumulatively overlap with 2,937 Red List species' ranges, compared to 437 for Chile. Chile's higher relative species threat score therefore indicates that, while Chilean lithium mines may impact fewer total Red List species than Australian lithium mines, the relative average threat to each of these species is greater in Chile than it is in Australia (or any other country for that matter). It is crucial to include this more nuanced perspective to avoid solely focusing attention on regions with many mines or large numbers of species, which risks glossing over serious impacts to rare and/or endangered species in other geographies.

All 17 operational and prospective Chilean lithium mines are located within the Tropical Andes and/or Chilean Winter Rainfall-Valdivian biodiversity hotspots. Similar to Southwest Australia, both of these hotspots are known for their abundance of endemic plant species. The Tropical Andes hotspot in particular is thought to hold the world's highest percentage of endemic plants[85]. However, plant species ultimately contribute only ~ 10 % of Chile's threat score, with reptiles and amphibians contributing much larger shares (~ 70 % combined). This is because, although biodiversity hotspots are often defined based on their local plant species, the endemic richness observed in plants in these regions is also generally thought to be similar for other taxonomic groups[41,42,43]. It is therefore important to consider that lithium mines in biodiversity hotspots such as those in Chile could threaten non-plant endemics in addition to plant species.

Telmatobius, a genus of aquatic frogs found in high-altitude Andean locales, and *Liolaemus,* a genus of lizards accounting for three-quarters of the reptiles in the Chilean Winter Rainfall-Valdivian hotspot, are two such examples[44,45,86,87]. Three *Telmatobius* species (*T. vilamensis, T. philippi, and T. fronteriensis)* received the maximum possible species threat score (1.0), with all classified as Critically Endangered and having their entire ranges potentially impacted by Chilean mines. Salica *et al.* have documented the threats lithium extraction in the region pose to *Telmatobius* species, highlighting that water pollution and groundwater consumption associated with lithium mining could adversely impact the frogs' habitat and food availability[21]. We also identified a total of six “at-risk” *Liolaemus* species that could be significantly threatened by Chilean mines and up to seven that could potentially be pushed to more severe Red List categories. Including Argentinian mines as well, which also coincide with numerous *Liolaemus* species, this could increase to 23 species at risk of shifting categories (~ 10 % of the genus’ known species)[45]. As observed with *Eucalyptus* in Australia, many of the *Liolaemus* species that could shift categories are currently listed as Least Concern but could qualify as Endangered or Critically Endangered if impacted by mining activities. This also helps explain Argentina having the highest fraction of observed species at risk of shifting categories and the 2nd highest overall future threat score. ~ 70 % of Argentina’s future threat score increase can be attributed to potential category shift from range-restricted *Liolaemus* species. Like Chile, nearly all the Argentinian lithium mines are also located within a biodiversity hotspot (Tropical Andes).

To further explain the relationship between mine occurrence in biodiversity hotspots and threat scores, we can consider Canada as a counter example. As stated in the **Results**, Canada has a disproportionally low overall threat score relative to its abundance of lithium mines. All Canadian mines also have identical current and future threat scores, indicating none have Red List species in their vicinities at risk of shifting to more severe categories. Starkly different from the Australian and South American lithium mining regions, Canada contains no biodiversity hotspots and has relatively low endemic and threatened species richness[42,46]. This provides additional evidence that degree of local species endemism is a key determinant of a mine’s threat score. Lamb *et al.* raised a similar point, concluding that regions with high endemism face heightened vulnerability to biodiversity loss from mineral extraction[73]. It is also important to mention that mine occurrence in biodiversity hotspots not only indicates potential threats to known endemic species, such as those in the Red List, but also to undescribed species that may be present in these regions[47]. As many of these species are likely to be similarly endemic with narrow ranges, the true magnitude of the threats posed by lithium mines in biodiversity hotspots cannot be captured by the Red List alone[47,80].

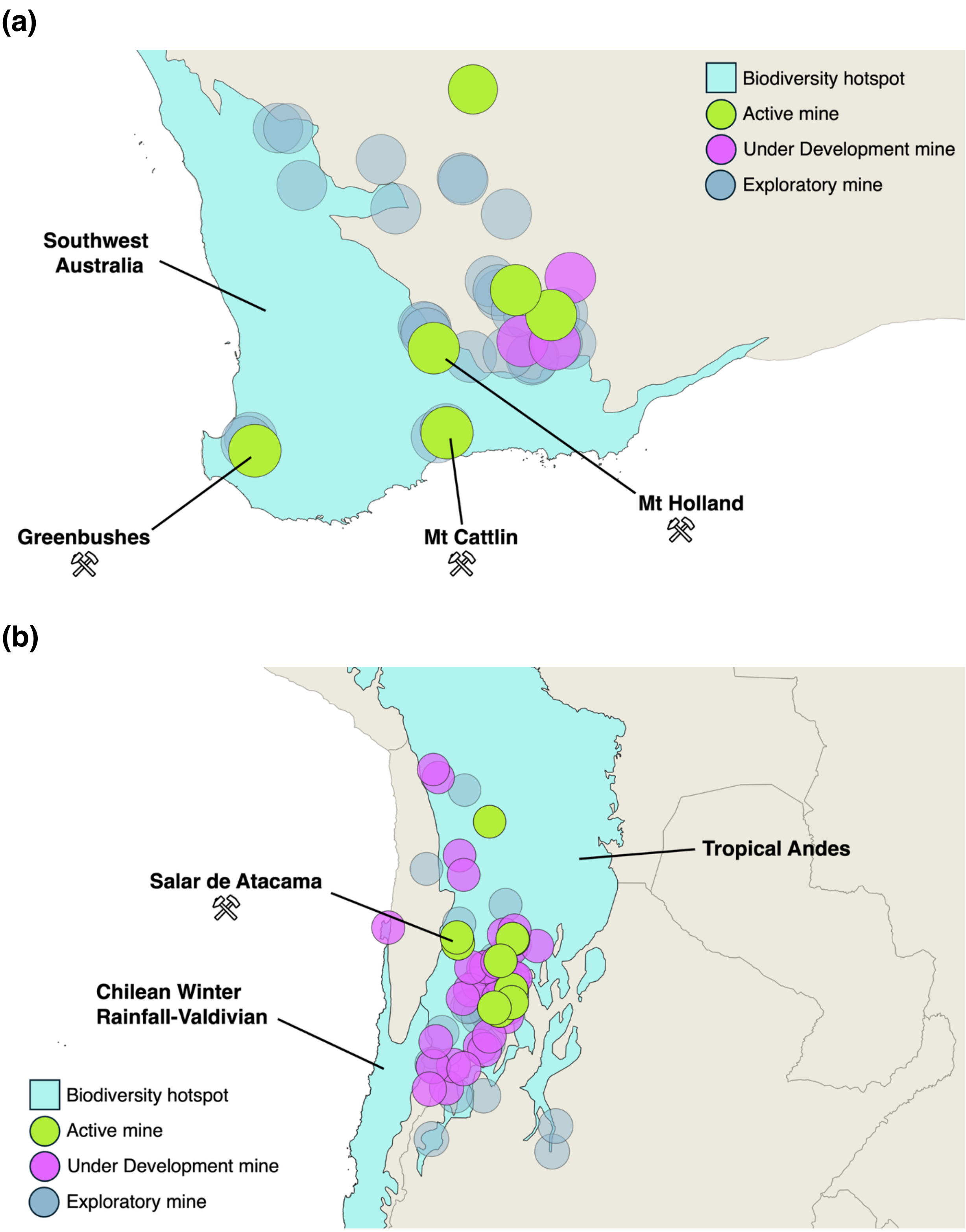


Figure 6 | The co-location of Australian and Chilean lithium mines with biodiversity hotspots. (a) The Southwest Australia biodiversity hotspot overlapping with Australian lithium mines across the three mine categories. The operational Mt Cattlin, Greenbushes, and Mt Holland mines are also labelled, **(b)** The Tropical Andes and Chilean Winter-Rainfall Valdivian biodiversity hotspots overlapping with Chilean and Argentinian lithium mines across the three mine categories. The operational Salar de Atacama mine is also labelled.

Furthermore, whilst the Red List is undoubtedly the most comprehensive global database currently available, it only covers 8 % of the world's described species, and an even smaller fraction of the species thought to exist on Earth[48]. Therefore, our threat scores could be underestimates for mines with endemic or threatened species in their vicinities that aren't on the Red List. The Rhyolite Ridge mine in Nevada (USA) exemplifies this point. Despite notable opposition to Nevadan lithium mines from local environmental and community groups, rooted in concerns about their ecological impact, Rhyolite Ridge received a relatively low overall threat score with our method, ranking 260 of 400[49,50,51]. However, we identified an endemic species, *Eriogonum tiehmii* (Tiehm's buckwheat), that is not on the Red List but has been cited locally as facing significant risk of extinction because of the mine[52,53,54]. *E. tiehmii* is a rare, wild buckwheat that is located directly on the planned Rhyolite Ridge site and has an extremely narrow range – its sole known population is restricted to approximately 10 acres (0.04 km^2) across a three-square mile area (7.8 km^2)[52]. If the buckwheat were considered analogous to a Critically Endangered Red List species and included in the mine's threat score, the mine's ranking would rise dramatically to 51 of 400. This example underscores the necessity of integrating local species knowledge, obtained through consultation with communities, NGOs, and government agencies, with global datasets like the Red List to build a more comprehensive understanding of the species-specific threats posed by lithium mines.

Indigenous peoples in particular are critical local stakeholders with an expansive knowledge of ecosystems and whose land intersects with several of this study's mines, namely those in Australia, Argentina, Chile, and the U.S.A[57]. Under international law, indigenous peoples must be consulted (and provide consent) before, during, and after any extractive projects take place on their ancestral lands[55,56]. Where requirements for consultation are met, and indigenous peoples consent to lithium mining in their territories, they should also be involved in identifying, documenting, and developing protection plans for local species that are at risk. The IPBES' approach for recognizing and working with indigenous knowledge systems offers a useful framework for facilitating such community engagement[58].

This study's focus on the species that could be most severely threatened with extinction from lithium mines, while indeed crucial, should not be considered in isolation. Species exist within deeply complex ecosystems, and their survival often requires a vast collection of other species to be present (for food, habitat, pollination, etc.). Solely focusing on a small number of rare species can be problematic when aiming to prevent wider ecological degradation, unless the species also act as important "umbrella" species (those whose conservation could, in turn, protect other local species) and/or “flagship” species (well-known, charismatic animals that generate public interest) that sustain broader ecosystem integrity[75,76]. The Red List species underpinning our analysis should effectively be thought of as “canaries in the coal mine” to indicate mining areas that pose outsized risks of contributing to species extinctions and spur further investigation into these locations. This further investigation would ideally involve use of a more robust framework for capturing the totality of mining impacts on both Red List species and those that are dependent upon them. This framework should include a deeper mechanistic understanding of the effects of habitat loss and metal pollution on species population declines as a precursor to local, regional and ultimately global biodiversity loss.

Future threat evaluation methodologies should also be designed to help better inform the Red List’s species assessments along with national and regional species conservation lists. While we found reasonable alignment between our results and the species the Red List have classified as facing ongoing threats from mining, there were still several potentially threatened species we identified whose threats are not represented in the database, including some with ranges coinciding with direct mining areas (**Fig. S4**). Comprehensive identification and reporting of lithium mining threats to species is even more critical for those not currently considered threatened but have restricted ranges. Given these species’ sensitivity to facing unexpectedly elevated risks of extinction if adversely impacted by lithium mines, it is imperative that any future frameworks enable more detailed, proactive identification of potential threats to such species before, rather than after, they start being negatively affected.

Increasing lithium mining ultimately presents a sustainability paradox. Decarbonized transportation is urgently needed for combatting the climate crisis (itself a major driver of species extinctions), and EVs are a viable option for helping accomplish that[59]. However, if mineral extraction to supply EV battery production leads to wide-scale ecological damage and biodiversity loss, we must question whether the scale of expected growth in lithium (and other battery mineral) mining is justifiable. At the same time, fossil fuel extraction causes much of the same ecological harm as mining at a larger scale, while also fuelling the climate crisis[60,74]. Therefore, a future that preserves the status quo is not acceptable either. A multi-pronged approach that simultaneously ensures global decarbonization can be achieved while minimizing both lithium consumption and adverse mining impacts on ecosystems may be the best path forward. This could involve first reducing lithium demand alongside carbon emissions through behavioural and policy changes, including decreased personal vehicle use, smaller vehicle sizes, increased public transportation, and mandated metal recycling[61,62]. The establishment of “no-go” zones where mining is off-limits must also be considered for high-risk areas within biodiversity hotspots and other locations with exceptional species endemism[89]. For the lithium demand that remains, restricting lithium mining to sites with low endemic and threatened species richness, and where local people have consented to mining activities, may produce fewer negative impacts. It cannot be overstated, however, that the ecological threats lithium mining poses are complex, multifaceted, and require careful, thorough examination on a site-by-site basis.

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Data Availability

The list of 400 lithium mines was provided by a leading battery supply chain market intelligence provider (name withheld at their request). A summary of the mines’ names, types of lithium resources, coordinate locations, and mineral resource estimates (if available), along with the references for each, can be found in the **Supporting Databook**. IUCN Red List species range polygons (with the exception of birds) can be downloaded from https://www.iucnredlist.org/resources/spatial-data-download. Bird range polygons can be downloaded from https://datazone.birdlife.org/. Biodiversity hotspot polygons can be downloaded from https://www.cepf.net/our-work/biodiversity-hotspots/hotspots-defined.

References

1. *Global EV Outlook 2024.* (International Energy Agency, 2024).
2. Sharma, S.S. & Manthiram, A. Towards more environmentally and socially responsible batteries. *Energy & Environmental Science* **11**, (2020).
3. Lo, M.G.Y et al. Nickel mining reduced forest cover in Indonesia but had mixed outcomes for well-being. *One Earth* ***7**,* 2019-2033 (2024).
4. Chaudry, M.S.A. Lithium dreams, local struggles: Navigating the geopolitics and socio-ecological costs of a low-carbon future. *Energy Research & Social Science* **121**, (2025).
5. *The Role of Critical Minerals in Clean Energy Transitions*. (International Energy Agency, 2021).

6. Aska, B. et al. Mining, biodiversity and social conflict in the renewable energy transition. *Nature Reviews Biodiversity* **1**, 597-614, (2025).
7. Sonter, L.J., Ali, S.H. & Watson, J.E.M. Mining and biodiversity: key issues and research needs in conservation science. *Proceedings of the Royal Society B: Biological Sciences* **285**, (2018).
8. *Global EV Outlook 2025.* (International Energy Agency, 2025).
9. *Global Critical Minerals Outlook 2025*. (International Energy Agency, 2025).
10. Sharma, S.S., Edge, J.S. & Mumford, J.D. Connecting rising electric vehicle demand to potential land use impacts and threats to biodiversity near key lithium mines. *Sustainability Science and Technology* **2**, (2025).
11. *Global Critical Minerals Outlook 2025*. (International Energy Agency, 2025).
12. Marconi, P., Argeno, F. & Clark, A. The arid Andean plateau waterscapes and the lithium triangle: flamingos as flagships for conservation of high-altitude wetlands under pressure from mining development. *Wetlands Ecology and Management* **30**, 827-852 (2022).
13. Carlos de Castro Pena, J. et al. Impacts of mining activities on the potential geographic distribution of eastern Brazil mountaintop endemic species. *Perspectives in Ecology and Conservation* **15**, 172-178 (2017).
14. Roy, B.A., Zorrilla, M. & Read, M. New Mining Concessions Could Severely Decrease Biodiversity and Ecosystem Services in Ecuador. *Tropical Conservation Science **11***, (2018).
15. Murguia, D.I., Bringezu S. & Schaldach, R. Global direct pressures on biodiversity by large-scale metal mining: Spatial distribution and implications for conservation. *Journal of Environmental Management* **180**, 409-420 (2016).
16. Cardinale, B.J. et al. Biodiversity loss and its impact on humanity. *Nature* **486**, 59-67 (2012).
17. Lee, M. et al. Impacts of the accumulated extinction of endangered species on stream food webs. *Global Ecology and Conservation* **48**, (2023).
18. Mace, G.M., Norris, K. & Fitter, A.H. Biodiversity and ecosystem services: a multilayered relationship. *Trends in Ecology & Evolution* **27**, 19-26 (2012).
19. Chan, K.M.A., Satterfield, T. & Goldstein, J. Rethinking ecosystem services to better address and navigate cultural values. *Ecological Economics* **74**, 8-18 (2012).
20. Gutierrez, J.S. et al. Climate change and lithium mining influence flamingo abundance in the Lithium Triangle. *Proceedings of the Royal Society B: Biological Sciences* **289**, (2022).
21. Salica, M.J. et al. Threatened aquatic Andean frogs and mining activity in the Lithium Triangle of South America: Can both coexist? *Aquatic Conservation: Marine and Freshwater Ecosystems* **34**, (2024).
22. Parker, S.S., Clifford, M.J. & Cohen, B.S. Potential impacts of proposed lithium extraction on biodiversity and conservation in the contiguous United States. *Science of The Total Environment* **911**, (2024).
23. Clifford, M.J. et al. Potential impacts to biodiversity of rare and vulnerable species from proposed lithium extraction. *Global Ecology and Conservation* **64**, (2025).
24. *The IUCN Red List of Threatened Species*. Data downloaded April 2025. https://www.iucnredlist.org/
25. Mace, G.M. et al. Quantification of Extinction Risk: IUCN's System for Classifying Threatened Species. *Conservation Biology* **22**, 1424-1442 (2008).
26. Zheng, M. et al. Classification and mineralization of global lithium deposits and lithium extraction technologies for exogenetic lithium deposits. *China Geology* **6**, 547-566 (2023).
27. Mair, L. et al. A metric for spatially explicit contributions to science-based species targets. *Nature Ecology & Evolution* **5**, (2021).

28. The Species Threat Abatement and Restoration (STAR) Metric. *The IUCN Red List of Threatened Species*. https://www.iucnredlist.org/assessment/star
29. Species Threat Abatement and Restoration (STAR) data layer: Business User Guidance. *IBAT*, (2021). https://app.ibat-alliance.org/pdf/star-business-user-guidance.pdf
30. Sonter, L.J., Dade, M.C., Watson, J.E.M. & Valenta, R.K. Renewable energy production will exacerbate mining threats to biodiversity. *Nature Communications* **11**, (2020).
31. Sonter, L.J. et al. Mining drives extensive deforestation in the Brazilian Amazon. *Nature Communications* **8**, (2017).
32. Junker, J. et al. Threat of mining to African great apes. *Science Advances* **10**, (2024).
33. Morley, J., Buchanan, G., Mitchard, E.T.A. & Keane, A. Quasi-experimental analysis of new mining developments as a driver of deforestation in Zambia. *Scientific Reports* **12**, (2022).
34. Gumbs, R. et al. The EDGE2 protocol: Advancing the prioritisation of Evolutionarily Distinct and Globally Endangered species for practical conservation action. *PLOS Biology*, (2023).
35. *IUCN Red List categories and criteria, version 3.1, second addition*. (IUCN Species Survival Commission, 2012).
36. Vecchio, M.G., Loganes, C. & Minto, C. Beneficial and Healthy Properties of Eucalyptus Plants: A Great Potential Use. *The Open Agriculture Journal*, (2016).
37. Readfearn, G. Almost a quarter of eucalypt trees found to be threatened with extinction. *The Guardian*, (2019). https://www.theguardian.com/environment/2019/dec/11/almost-a-quarter-of-eucalypt-trees-found-to-be-threatened-with-extinction
38. Eucalyptus purpurata. *The IUCN Red List of Threatened Species*, (2019). https://www.iucnredlist.org/species/133374103/133374105
39. Biodiversity hotspots. *Conservation International*. https://www.conservation.org/learning/biodiversity-hotspots
40. Rix, M.G. et al. Biogeography and speciation of terrestrial fauna in the south-western Australia biodiversity hotspot. *Biological Reviews* **90**, 762-793 (2015).
41. Reid, W.V. Biodiversity hotspots. *Trends in Ecology & Evolution* **13**, 275-280 (1998).
42. Orme, C.D.L. et al. Global hotspots of species richness are not congruent with endemism or threat. *Nature* **436**, 1016-1019 (2005).
43. Grenyer, R. et al. Global distribution and conservation of rare and threatened vertebrates. *Nature* **444**, 93-96 (2006).
44. Moya, F., Mella-Romero, J. & Simonetti, J.A. Do we have the necessary insights to classify species according to their conservation status? A case study in the world's southernmost lizard genus. *Journal for Nature Conservation* **83**, (2025).
45. Abdala, C.S. et al. Increasing knowledge of the denizens of saline environments through integrative taxonomy: new Argentinian endemic taxa of Liolaemus (Iguania: Liolaemidae) and their evolutionary relationships. *Systematics and Biodiversity* **19**, (2021).
46. Rarity-Weighted Richness – Red List version 2025-2. (IUCN, 2025). https://www.iucnredlist.org/resources/other-spatial-downloads
47. Joppa, L.N., Roberts D.L., Myers, N. & Pimm, S.L. Biodiversity hotspots house most undescribed plant species. *PNAS* **108**, 13171-13176 (2011).
48. Summary Statistics. *The IUCN Red List of Threatened Species*. https://www.iucnredlist.org/resources/summary-statistics
49. Sainato, M. 'We were not consulted': Native Americans fight lithium mine on site of 1865 massacre. *The Guardian*, (2023). https://www.theguardian.com/us-news/2023/oct/13/native-americans-1865-massacre-lithium-mine-thacker-pass
50. Bernhard, M. Lithium Could Help Save the Earth. But What Happens to Nevada? *The New York Times Magazine*, (2025). https://www.nytimes.com/2025/01/24/magazine/nevada-lithium-mines.html

51. Donnelly, P., Stephens, F. & Hadder, J. Lawsuit Aims to Protect Rare Flower, Cultural Sites From Nevada Lithium Mine. *Center for Biological Diversity*, (2024).
52. Donnelly, P. Tiehm's Buckwheat: Emergency Listing Petition. *Center for Biological Diversity*, (2019).https://www.biologicaldiversity.org/species/plants/pdfs/Tiehms-buckwheat-petition-to-FWS.pdf
53. Carlo, R. U.S. Fish and Wildlife Service lists Tiehm's buckwheat as an endangered species and designates critical habitat in Nevada. *U.S. Fish and Wildlife Service*, (2022). https://www.fws.gov/press-release/2022-12/tiehms-buckwheat-listed-endangered-species-critical-habitat-designated-nevada
54. Associated Press. Nevada lithium mine approved despite possible harm to endangered wildflower. *The Guardian*, (2024). https://www.theguardian.com/us-news/2024/oct/24/nevada-lithium-mine-endangered-wildflower-tiehms-buckwheat
55. MacInnes, A., Colchester, M. & Whitmore, A. Free, prior and informed consent: how to rectify the devastating consequences of harmful mining for indigenous peoples. *Perspectives in Ecology and Conservation* **15**, 152-160 (2017).
56. Chapter 2.2: Free, Prior and Informed Consent. *The Initiative for Responsible Mining Assurance*, (2018). https://responsiblemining.net/wp-content/uploads/2018/08/Chapter_2.2_FPIC.pdf
57. Owen, J.R. et al. Energy transition minerals and their intersection with land-connected peoples. *Nature Sustainability* **6**, (2022).
58. Report of the Plenary of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services on the work of its fifth session. (IPBES, 2017).
59. Urban, M.C. Climate change extinctions. *Science* **386,** 1123-1128 (2024).
60. Butt, N. et al. Biodiversity Risks from Fossil Fuel Extraction. *Science* **342**, (2013).
61. Riofrancos, T. et al. Achieving Zero Emissions with More Mobility and Less Mining. *Climate & Community Institute*, (2023).
62. Dunn, J., Anair, D., Reichmuth, D. & Pinto de Moura, M.C. Reducing battery electric mineral demand through efficiency, range, and new technology. *Transportation Research Part D: Transport and Environment* **149**, (2025).
63. Lumbierres, M. et al. Area of Habitat maps for the world's terrestrial birds and mammals. *Scientific Data* **9**, (2022).
64. Williams, G.D.Z. & Vengosh, A. Quality of Wastewater from Lithium-Brine Mining. *Environmental Science & Technology Letters* **12**, (2025).
65. Jowitt, S.M. & McNulty, B.A. Geology and Mining: Mineral Resources and Reserves: Their Estimation, Use, and Abuse. *SEG Discovery*, (2021).
66. How IBAT can support biodiversity disclosure. *IBAT Alliance*. https://www.ibat-alliance.org/biodiversity-disclosure
67. Sustainability Fact Book 2024. *Rio Tinto*, (2024). https://www.riotinto.com/en/invest/reports/sustainability-report
68. Mapping Standards and Data Quality for the IUCN Red List Categories and Criteria. *The IUCN Red List of Threatened Species*, (2018). https://nc.iucnredlist.org/redlist/resources/files/1539098236-Mapping_Standards_Version_1.16_2018.pdf
69. Top ten biggest lithium mines in the world. *Mining Technology,* (2019). https://www.mining-technology.com/features/top-ten-biggest-lithium-mines/
70. Rincon Lithium Project. *Rio Tinto*. https://www.riotinto.com/en/operations/projects/rincon
71. Mineral Resource Estimate: Imerys British Lithium Project. *Imerys*, (2023). https://imerysbritishlithium.com/lithium-exploration/mineral-resource-estimate
72. Brooks, T.M. Measuring Terrestrial Area of Habitat (AOH) and Its Utility for the IUCN Red List. *Trends in Ecology & Evolution* **34**, 977-986 (2019).
73. Lamb, I.P. et al. Global threats of extractive industries to vertebrate biodiversity. *Current Biology* **34**, 3673-3684 (2024).

74. Nijnens, J. et al. Energy transition will require substantially less mining that the current fossil system. *Joule* **7**, 2408-2413 (2023).
75. Roberge, J-M. & Angelstam, P. Usefulness of the Umbrella Species Concept as a Conservation Tool. *Conservation Biology* **18**, 76-85 (2004).
76. Smith, A.M. & Sutton, S.G. The Role of Flagship Species in the Formation of Conservation Intentions. *Human Dimensions of Wildlife* **13**, (2008).
77. QGIS Development Team. QGIS Geographic Information System, (2026). https://qgis.org/
78. Posit team. RStudio: Integrated Development Environment for R. Posit Software, (2026). https://posit.co/download/rstudio-desktop/
79. Pebesma, E. Simple Features for R: Standardized Support for Spatial Vector Data. *The R Journal* **10**, 439-446 (2023).
80. Joppa, L.N., Roberts, D.L. & Pimm, S.L. How many species of flowering plants are there? *Proceedings of the Royal Society B: Biological Sciences* **278**, 554-559 (2010).
81. Myers, N.M. et al. Biodiversity hotspots for conservation priorities. *Nature* **403**, 853-858 (2000).
82. Cabernard, L. & Pfister, S. Hotspots of Mining-Related Biodiversity Loss in Global Supply Chains and the Potential for Reduction through Renewable Electricity. *Environmental Science & Technology* **56**, 16357-16358 (2022).
83. Yu, Y. et al. Revealing Hidden Biodiversity Footprints Embedded in Global Mining Supply Chains. *Environmental Science & Technology* **60**, 17234-17246 (2026).
84. Claerhoudt, R. et al. The entanglement between the IUCN Red List and international biodiversity law. *Conservation Biology*, (2026).
85. Tropical Andes – Species. *Critical Ecosystem Partnership Fund*. https://www.cepf.net/our-work/biodiversity-hotspots/tropical-andes/species
86. Barrionuevo, J.S. Frogs at the summits: phylogeny of the Andean frogs of the genus *Telmatobius* (Anura, Telmatobiidae) based on phenotypic characters. *Cladistics* **33**, 41-68, (2017).
87. Chilean Winter Rainfall-Valdivian Forests – Species. *Critical Ecosystem Partnership Fund*. https://www.cepf.net/our-work/biodiversity-hotspots/chilean-winter-rainfall-valdivian-forests/species
88. Vera, M.L. et al. Environmental impact of direct lithium extraction from brines. *Nature Reviews Earth & Environment* **4**, 149-165 (2023).
89. Restricted Areas from Mining. *Rainforest Foundation Norway, Mighty Earth, Greenpeace International & Fern*. (2026). https://www.fern.org/publications-insight/article/restricted-areas-from-mining/
90. *BirdLife International*. Data downloaded April 2025. https://datazone.birdlife.org/.