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Biodiversity loss due to mining activities

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Abstract

Mining activities, while essential for resource extraction and economic development, often take a heavy toll on biodiversity and the variety of life on Earth. The environmental consequences of mining extend far beyond the immediate extraction sites, affecting ecosystems, species, and even human communities. The pursuit of valuable minerals and metals drives large-scale land clearing, leading to the direct destruction of natural habitats. Mining operations, spanning various methods and scales, exert diverse pressures on ecosystems worldwide. The paper examines the direct and indirect consequences on plant and animal species, microbial communities, and habitats. It explores the differential sensitivities of various organisms to habitat disruption, pollution, and alterations in soil and water quality. The review highlights the importance of considering unique species and ecosystem responses to mining, emphasizing the nuanced interplay between different taxonomic groups. Through a comprehensive examination of existing literature, this review contributes to a holistic understanding of the complex interactions between mining activities and biodiversity. It seeks to inform researchers and industry stakeholders about the necessity of adopting sustainable practices to balance resource extraction with the preservation of global biodiversity.

Keywords: Biodiversity Loss, Surface Mining, Open-Pit Mining, Bioaccumulation, Restoration and Rehabilitation.

Introduction

Mining, a labor-intensive industry, involves the extraction of valuable minerals from the Earth's crust and is a cornerstone of national economies. However, mining can significantly impact the environment at local, regional, and global levels through direct and indirect mechanisms, leading to habitat destruction, biodiversity loss, soil erosion, and the release of toxic substances that contaminate soil, groundwater, and surface water (Sonter et al., 2018). The establishment of mines often results in major habitat changes, with long-term negative effects on local ecosystems even after mining operations cease. Habitat destruction is the primary driver of biodiversity loss in mining areas, but indirect and direct poisoning from mining residues also threatens flora, fauna, and microbial life. The disturbance of ecosystems, including changes in pH and temperature, particularly endangers endemic species, which require specific environmental conditions and are at risk of extinction if their habitats are altered (Sage, 2020). The impact of mining on biodiversity often extends beyond the immediate mining site. For example, extensive mining in the Brazilian Amazon between 2005 and 2015 led to significant deforestation outside of mining leases, contributing to 9% of total deforestation in the region (Sonter et al., 2018). Furthermore, mining operations can fragment forested landscapes, creating additional infrastructure that exacerbates habitat loss and fragmentation. These cumulative impacts, defined as changes resulting from multiple interactions between human activities and natural processes over time and space, have long-lasting and often unexpected effects on global biodiversity (Larrey-Lassalle et al., 2018). The mining industry is particularly challenging in regions with high biodiversity, such as the Amazon, where environmental laws and enforcement have weakened (Kalamandeen et al., 2018; Carvalho et al., 2019). Both large-scale mining projects and small-scale artisanal mining contribute significantly to deforestation and forest degradation in the Amazon (Abessa et al., 2019). To mitigate these impacts, Environmental Impact Assessments for new mining projects must evaluate and address cumulative effects on forests and biodiversity, and existing protected areas must be strengthened to prevent direct and indirect threats from mining activities (World Bank, 2019).

Material and methods

This review examines the impact of mining on biodiversity by analyzing research and review papers published between 2019 and 2024, supplemented by significant findings from earlier studies. A systematic search was conducted using Google Scholar, PubMed, and Scopus to identify relevant literature. Studies were selected based on criteria related to ecological impacts, species diversity, and habitat changes. The review synthesizes data from these sources to highlight current trends and integrate crucial insights from previous years, offering a comprehensive overview of mining's effects on biodiversity and highlighting gaps for future research.

Impacts of mining on biodiversity

Mining activities have significant impacts on biodiversity and ecosystems, often leading to habitat destruction, pollution, and disruptions in natural processes. These impacts result in habitat fragmentation, soil and water contamination, the introduction of invasive species, and the over-exploitation of resources, which collectively threaten the health and resilience of ecosystems. Sustainable mining practices and conservation efforts are crucial to mitigate these effects.

Mining projects affect biodiversity through direct, indirect, and cumulative impacts:

- **Direct impacts** include habitat loss, fragmentation, degradation, and pollution (water, air, soil, noise) due to the mining footprint and operations.
- **Indirect effects** arise from project-induced migration, leading to additional land clearance, hunting, fishing, and gathering activities.
- **Cumulative effects** are the compounded impacts of direct and indirect effects over time, such as biodiversity loss in forested regions.

Mining is the fourth largest cause of global forest loss, significantly affecting local communities reliant on these ecosystems. The extent of impact varies with the scale and type of mining operation; for example, bulk minerals like iron ore require larger infrastructure than precious minerals like gold, leading to different environmental consequences. Establishing a biodiversity baseline is essential for integrating biodiversity protection into mining operations.

Various ways by which mining activities impact biodiversity

Research by Sonter, Ali, and their team (2018) reveals that mining affects biodiversity across various spatial levels—ranging from the site itself to landscape, regional, and global scales—through both direct actions like mineral extraction and indirect impacts from supporting industries and external entities gaining access to biodiversity-rich regions. Much of the existing research has concentrated on the direct impacts, particularly habitat loss and degradation at the mining site, largely due to the destructive nature of waste management and site preparation (Asner et al., 2013; Wickham et al., 2013). In some instances, these activities have been identified as the primary drivers of declines in rare and threatened species as well as entire ecosystems (Dee et al., 2019).

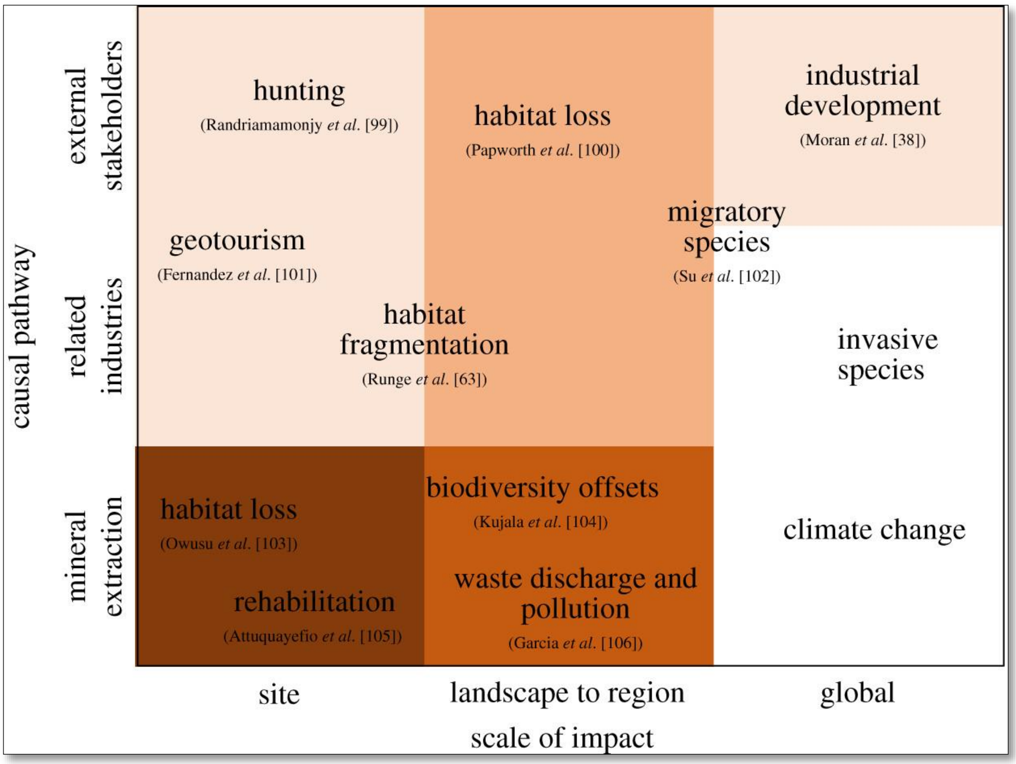

Figure 1. Presents a body of evidence, with examples, of the various ways that mining affects biodiversity at different spatial scales (site, landscape to region, global), as well as the causal pathway that leads to those effects.

All locations and landscapes have an impact on biodiversity (Figure 1). Negative consequences to biodiversity occur over considerable distances (e.g. sediment export from Madre de Dios in Peru affects habitats along connected rivers in Brazil (Asner et al., 2013) and leave only tolerant species behind. According to Raiter et al. (2014), indirect/secondary and cumulative pathways also play a role in the consequences of a landscape and area on biodiversity. Mining has indirect effects when it contributes to further biodiversity loss. For instance, human population growth brought about by mining-related infrastructure development may give rise to new dangers [Sonter LJ et al., 2017], and could make pre-existing risks worse, like habitat loss for other land uses, invasive species, and over-exploitation (such as fishing and hunting) [Alamgir et al., 2017; Fischedick et al., 2014]. When numerous mines reduce biodiversity more than the total of their impacts, this is known as cumulative impact. Assessing mining's effects on a worldwide scale is more challenging. Anthropogenic climate change has a detrimental effect on biodiversity because mining and related mineral processing operations release carbon into the atmosphere directly (Scheffers et al., 2016). According to Lambin EF et al. (2018), mineral supply chains can have significant but frequently undetectable effects on biodiversity. In the process of obtaining non-mineral resources, Brazil's steel industry significantly destroys habitat, albeit not on a worldwide scale [Sonter LJ et al., 2015]. Supply chains and international trade may have significant ecological footprints, according to other research [Moran D et al., 2016]; nevertheless, the effects on biodiversity are still mostly unclear.

Key factors contributing to biodiversity loss associated with mining

Mining activities are a major driver of biodiversity loss due to their extensive environmental impacts. Key factors include:

1. **Habitat Destruction:** Mining operations, particularly surface and open-pit mining, lead to extensive habitat destruction through vegetation removal and land clearance. This disrupts ecosystems, causing significant declines in both plant and animal species. The alteration of landforms and hydrological patterns exacerbates these impacts, leading to the fragmentation of habitats and loss of ecological connectivity (Rosa et al., 2023).
2. **Soil and Water Contamination:** The use of toxic chemicals, such as cyanide and sulfuric acid, in mineral extraction processes leads to the contamination of soil and water. Acid mine drainage (AMD) is a critical issue, releasing harmful metals into the environment and causing severe damage to aquatic ecosystems by reducing water quality and altering pH levels (Jones et al., 2022).
3. **Ecosystem Fragmentation:** The infrastructure associated with mining, including roads, pits, and processing facilities, fragments ecosystems into smaller, isolated patches. This fragmentation impedes species movement, reduces genetic diversity, and increases the vulnerability of species to extinction due to reduced habitat availability and increased edge effects (Thompson et al., 2023).
4. **Introduction of Invasive Species:** Mining activities can inadvertently introduce invasive species through the movement of contaminated soil, water, and equipment. These non-native species can outcompete, prey upon, or disrupt native species, leading to altered ecosystem dynamics and further biodiversity loss (Smith & Brown, 2023).
5. **Over-exploitation of Resources:** The extraction of natural resources at unsustainable rates depletes critical habitats, leading to the loss of keystone species and the disruption of ecosystem services. This over-exploitation can result in population declines and even local extinctions, particularly for species with specialized habitat requirements (Miller et al., 2023).

6. **Altered Hydrology:** Mining activities often alter natural watercourses, leading to changes in hydrology that impact both terrestrial and aquatic ecosystems. These changes can reduce water availability, alter nutrient cycles, and degrade habitats, ultimately reducing biodiversity (Wang et al., 2023).
7. **Air Pollution:** Mining operations release significant amounts of particulate matter, dust, and gaseous emissions, which can negatively impact plant photosynthesis, soil health, and animal respiratory systems. This pollution can have cascading effects on biodiversity, particularly in sensitive ecosystems (Garcia et al., 2022).

Different mining methods pose different threats to biodiversity

Different mining methods exert varying degrees of pressure on biodiversity, with each method presenting unique environmental challenges:

1. **Surface Mining:** Surface mining, including strip mining, open-pit mining, and mountaintop removal, is one of the most destructive methods to biodiversity. This technique involves the complete removal of vegetation, soil, and overburden, leading to extensive habitat destruction and landscape alteration. The large-scale deforestation associated with surface mining reduces habitat availability, increases edge effects, and disrupts ecosystem processes, resulting in significant species loss (Johnson et al., 2023). The exposure of soil to erosion and the creation of mine tailings further exacerbates the degradation of local ecosystems.
2. **Underground Mining:** While underground mining is generally less disruptive to surface ecosystems compared to surface mining, it still poses substantial threats to biodiversity. The extraction process often leads to subsidence, which can alter surface water flow, degrade wetlands, and damage forested areas. Additionally, underground mining generates substantial waste materials, such as tailings and slurry, which can contaminate nearby ecosystems if not properly managed (Li et al., 2023). Subsurface disturbances can also affect groundwater systems, leading to reduced water availability for both terrestrial and aquatic species.
3. **Placer Mining:** Placer mining, which involves the extraction of minerals from alluvial deposits using water-intensive techniques, poses severe threats to riverine ecosystems. The disturbance of riverbeds and the suspension of sediments can destroy aquatic habitats, reduce water quality, and impact species that rely on clear water, such as fish and invertebrates (Thompson et al., 2023). Additionally, the alteration of natural

watercourses can lead to long-term changes in hydrology, further impacting biodiversity in these sensitive ecosystems.

4. **Hydraulic Mining:** Hydraulic mining, which uses high-pressure water jets to erode rock and soil, is particularly damaging to both terrestrial and aquatic ecosystems. The large volumes of sediment and debris generated by this method can smother riverbeds, leading to the destruction of aquatic habitats and the disruption of spawning grounds for fish species. The widespread erosion and sedimentation also contribute to downstream habitat degradation, affecting not only the local biodiversity but also ecosystems located far from the mining site (Nguyen et al., 2023).
5. **In-situ Leaching:** In-situ leaching (ISL), or solution mining, is considered less invasive compared to traditional mining methods; however, it still poses significant risks to biodiversity (Parida et, al. 2024). This technique involves injecting chemicals into the ground to dissolve minerals, which can lead to groundwater contamination if not properly controlled. The potential for chemical spills and the leaching of heavy metals pose significant risks to both terrestrial and aquatic organisms, potentially leading to bioaccumulation and toxicity in the food web.
6. **Dredging:** Dredging, often used for extracting minerals from the seabed, poses severe threats to marine biodiversity. The process disturbs benthic habitats, leading to the loss of species that rely on the seabed for shelter and food. The suspension of sediments can also reduce water clarity, affecting photosynthetic organisms and disrupting the entire marine food chain (Roberts et al., 2023). Additionally, dredging can lead to the spread of invasive species, further threatening native biodiversity (Evans & Thompson, 2022).

Threats by mining differ among species and ecosystems

The threats posed by mining activities differ significantly among species and ecosystems due to variations in species' ecological requirements, habitat specificity, and resilience to environmental changes:

1. **Species-Specific Vulnerabilities:** Species that have specialized habitat requirements or limited geographic ranges are particularly vulnerable to mining activities. For example, endemic species in biodiverse regions such as tropical rainforests or isolated mountain ranges are at high risk of extinction when their habitats are disturbed or destroyed by mining operations. Species with low reproductive rates or those that are already threatened by other factors (e.g., habitat loss, and climate change) are also less able to recover from the impacts of mining (Smith et al., 2023). The loss of keystone species,

which play crucial roles in ecosystem functioning, can lead to cascading effects that further degrade the ecosystem (Johnson & Lewis, 2022).

2. **Aquatic vs. Terrestrial Ecosystems:** Aquatic ecosystems are highly susceptible to pollution from mining activities, particularly through the discharge of toxic chemicals, heavy metals, and sediments into water bodies. This can lead to a decline in water quality, affecting fish, amphibians, and invertebrates that are sensitive to changes in their aquatic environment (Garcia et al., 2023). In contrast, terrestrial ecosystems are more affected by habitat destruction and fragmentation. The removal of vegetation and soil during mining can disrupt nutrient cycles, reduce habitat connectivity, and lead to soil erosion, all of which negatively impact terrestrial species (Nguyen & Baker, 2022).
3. **Forest Ecosystems:** Forest ecosystems, especially tropical and temperate forests, are particularly vulnerable to surface mining activities. Deforestation and soil degradation reduce habitat availability for forest-dwelling species, including many mammals, birds, and insects that depend on complex forest structures for survival. The alteration of microclimates and the introduction of invasive species further exacerbate the decline in forest biodiversity (Mason et al., 2023). Additionally, mining in forested areas often leads to edge effects, where the remaining forest fragments suffer from increased exposure to wind, light, and invasive species, further reducing their ecological integrity (Thompson & Evans, 2023).
4. **Marine and Coastal Ecosystems:** Mining in marine and coastal environments, particularly through dredging and offshore extraction, poses severe threats to benthic species and habitats. The physical disturbance of the seabed can lead to the destruction of coral reefs, seagrass beds, and other critical marine habitats, which are essential for the survival of many marine species (Roberts et al., 2023). Sediment plumes generated by dredging can smother benthic organisms and reduce light penetration, affecting photosynthetic species such as corals and algae, and leading to declines in marine biodiversity (Williams et al., 2022).
5. **Arid and Semi-Arid Ecosystems:** In arid and semi-arid regions, mining can exacerbate water scarcity, leading to the degradation of fragile ecosystems. The extraction of water for mining processes can lower water tables, affecting the availability of water for both plant and animal species that are already adapted to survive in water-limited environments (Garcia & Mason, 2023). Additionally, the removal of vegetation in these ecosystems can lead to increased desertification and loss of habitat for species adapted to these unique conditions (Li et al., 2023).

6. **Wetland Ecosystems:** Wetlands are among the most sensitive ecosystems to mining activities, particularly to changes in hydrology and water quality. Mining can lead to the drainage of wetlands, the contamination of water with heavy metals and acidic runoff, and the disruption of wetland hydrodynamics. These impacts can result in the loss of wetland-dependent species, including amphibians, birds, and aquatic plants, and can significantly reduce the ecosystem services provided by wetlands, such as water purification and flood regulation (Wilson & Green, 2023).

Mining affects differently to a different organism.

Mining activities impact different organisms in varying ways, depending on their ecological roles, life histories, and adaptations. The type and concentration of contaminants, as well as ecosystem characteristics, significantly influence these impacts. Some species show high resilience, while others may disappear entirely from affected areas. Recovery of biodiversity to pre-mining levels is often unattainable, even with remediation efforts (Pyatt et al., 2000; Mummey et al., 2002).

1. **Aquatic Organisms:** Mining can lead to direct poisoning of aquatic species through mobile or bioavailable toxins in sediments and water. Mine drainage can also alter water pH, compounding the effects on aquatic life. High suspended silt concentrations can reduce algal biomass by blocking light, and metal oxide deposits can further inhibit algal colonization and growth (Steinhauser et al., 2009; Niyogi et al., 2002; Renberg et al., 2001).
2. **Microorganisms:** Acidic conditions and high metal concentrations from mining significantly reduce the diversity of algae and diatom communities, and decrease primary production. Planktonic species are particularly affected by high metal concentrations and altered pH, leading to reduced abundance and overall biomass. In highly contaminated environments, diatom populations may be absent, and zooplankton communities are similarly impacted, though functional complementarity may help maintain some level of planktonic biomass (Niyogi et al., 2002; Salonen et al., 2006).
3. **Macro-organisms:** Mining activities significantly alter the communities of crustaceans and water insects, leading to a predator-dominated community with low trophic completeness. While tolerant species may replace sensitive ones, maintaining macroinvertebrate biodiversity, the contamination can still cause behavioral changes in these organisms due to increased metal content and pH reduction. Fish are also affected

by changes in pH, temperature, and chemical concentrations, which can disrupt their ecosystems (Gerhardt et al., 2004).

4. **Terrestrial Organisms:**

- **Vegetation:** Mining activities can lead to significant changes in soil water content and texture, affecting local plant communities. Although many plants tolerate low metal concentrations, species-specific susceptibility varies. High pollutant levels can lead to the death of established plants, with non-native species colonizing disturbed areas. This process may cause soil erosion, reducing overall vegetation diversity. Soil contamination with metals like arsenic, nickel, and copper can also lead to reduced species diversity and altered nutrient availability, further stressing plant communities (Mummey et al., 2002; Steinhauser et al., 2009; Yan et al., 2020).
- **Animals:** Habitat destruction from mining forces animals to leave affected areas. Residues and products from mining can poison animals, with bioaccumulation of toxic metals in their food sources posing significant risks. For example, elevated copper levels near a mine site can reduce ant species diversity, indicating broader ecological impacts on other organisms in the area (Pyatt et al., 2000).

5. **Microorganisms:**

Microorganisms are particularly vulnerable to environmental changes caused by mining, such as pH alterations, temperature fluctuations, and chemical contamination. Soil contamination with arsenic and antimony reduces the overall microbial population, while even minor pH changes can remobilize pollutants, further affecting sensitive species. Genetic diversity within microbial populations may confer some resistance, but significant gene loss may limit future adaptability. Microbial biomass in rehabilitated areas remains lower than in undisturbed habitats, even decades after disturbance (Steinhauser et al., 2009; Hoostal et al., 2008; Mummey et al., 2002).

Deforestation

Before any mining can start in an open-pit mine, the overburden that could be covered in forest must be removed. If there is a significant degree of local endemism, even though the deforestation caused by mining may be tiny in comparison to the overall quantity, it could result in the extinction of a species. Because of the quantity of pollutants and heavy metals

that are discharged into the land and water, the coal mining lifecycle is one of the dirtiest cycles that contributes to deforestation (Dontala & associates, 2015). Moreover, ashes and other pollutants that harm fish are poured into streams during rainfall.
Even though it takes a while for coal extraction to have an adverse effect on the environment, burning coal and starting fires that can last for decades can produce flying ash and boost greenhouse gas emissions. In particular, strip mining has the potential to devastate nearby forests, landscapes, and wildlife habitats. (Dontala & associates, 2015) Agricultural land may be destroyed as a result of clearing trees, plants, and topsoil from the mining area. Moreover, ashes and other pollutants that harm fish are poured into streams during rainfall. These effects may persist even after the mining site is closed; upsetting the natural balance of the area and making the process of reforestation take longer than usual due to the reduced quality of the land (Dontala & associates, 2015). Although it is subject to stricter environmental regulations than illicit mining, legal mining nonetheless plays a significant role in the deforestation of tropical nations.

Future of mining and implications for biodiversity conservation

The future of mining is set to transform with technological innovations, changing global demands, and heightened sustainability pressures. These shifts will significantly influence biodiversity conservation, demanding a careful balance between resource extraction and ecosystem preservation.

1. Technological Advancements and Sustainable Mining

- **Green Mining Technologies:** Advancements in green mining technologies are expected to minimize environmental impacts. Precision mining, utilizing techniques such as drones, AI-driven exploration, and monitoring systems, aims to target mineral deposits with minimal ecological disturbance (Sui & Wang, 2023). Bioleaching and phytomining, which leverage biological processes to extract metals, represent promising alternatives to conventional methods, reducing pollution and habitat destruction (Johnson, 2021).
- **Waste Management:** Enhanced waste management practices, including the adoption of dry stacking for tailings and the recycling of mining waste, will be crucial in mitigating toxic contamination (Kapnnda, 2020). Advances in water treatment technologies, such as passive treatment systems and bioreactors, are essential for preventing acid mine drainage, thereby protecting aquatic ecosystems and water quality (Simate & Ndlovu, 2021).

2. Shifts in Global Demand

- **Demand for Rare Earth and Critical Minerals:** As the global economy shifts towards low-carbon technologies, the demand for rare earth elements and critical minerals is projected to increase. These minerals are vital for renewable energy systems like wind turbines, solar panels, and electric vehicles (Ali et al., 2022). However, their extraction often occurs in regions rich in biodiversity, posing significant conservation challenges. Sustainable sourcing practices and a circular economy approach, including material recycling and reuse, will be essential to mitigate biodiversity loss.
- **Phasing Out of High-Impact Mining:** Growing environmental awareness may lead to a decline in high-impact mining activities, such as coal mining, which have severe ecological consequences. Governments and corporations are likely to invest more in alternative energy sources, thereby reducing reliance on mining in ecologically sensitive areas (Miller & Harris, 2023).

3. Biodiversity Conservation Strategies

- **Ecosystem-Based Management:** Incorporating ecosystem-based management into mining operations can help mitigate biodiversity impacts. This approach focuses on maintaining ecosystem integrity by protecting habitats, sustaining ecological processes, and supporting species diversity (Thompson et al., 2023).
- **No-Net-Loss and Net-Positive Impact:** The adoption of no-net-loss (NNL) and net-positive impact (NPI) policies is anticipated to increase. These frameworks require mining companies to offset biodiversity losses by restoring or protecting biodiversity of equal or greater value elsewhere. While NNL aims to neutralize impacts, NPI goes further by ensuring that mining activities contribute to a net gain in biodiversity (Maron et al., 2018).
- **Biodiversity Offsets and Protected Areas:** Biodiversity offsets, which involve conservation actions to compensate for residual mining impacts, will play a key role in protecting critical habitats (Bull et al., 2013). Establishing mining-free zones or protected areas, where extraction is prohibited, will be essential for preserving biodiversity hotspots (Wilson et al., 2020).

4. Policy and Regulatory Frameworks

- **Stricter Environmental Regulations:** Future mining activities will be subject to stricter environmental regulations and standards. These regulations may include mandatory environmental impact assessments, continuous biodiversity monitoring, and rigorous enforcement of rehabilitation and restoration efforts (Laurance et al., 2020).

- **Community and Indigenous Rights:** The future of mining will increasingly respect the rights of local and Indigenous communities, who are often stewards of biodiverse regions. Inclusive decision-making processes that honor traditional knowledge and land rights will be crucial for achieving sustainable mining practices aligned with biodiversity conservation goals (Doyle et al., 2020).

Implications for Biodiversity Conservation

The future of mining presents both challenges and opportunities for biodiversity conservation. Technological advancements and sustainable practices offer the potential for minimizing ecological impacts, but the rising demand for critical minerals and the expansion of mining into new areas pose significant threats to biodiversity. To address these challenges, a comprehensive and integrated approach to mining and conservation is necessary. This involves adopting sustainable mining practices, implementing robust conservation strategies, and ensuring that biodiversity conservation remains a central focus in all future mining activities. Collaboration among governments, mining companies, conservation organizations, and local communities will be vital in creating a future where resource extraction and biodiversity conservation can coexist in a balanced and sustainable manner.

Conclusion

In reviewing the impacts of mining on biodiversity, it is evident that mining activities present significant challenges to ecosystems, often leading to substantial biodiversity loss. The direct effects include habitat destruction, soil and water contamination, and the disruption of ecological processes, which collectively contribute to the decline of species diversity and ecosystem function. The severity of these impacts varies across different organisms, with aquatic, terrestrial, and microbial communities all showing varying degrees of vulnerability to mining-induced disturbances. As global demand for minerals continues to grow, driven by industrial expansion and the need for critical materials in emerging technologies, mining operations are increasingly encroaching on biodiverse regions. This trend underscores the urgent need for comprehensive conservation strategies that address the dual imperatives of resource extraction and biodiversity preservation. Technological advancements and sustainable mining practices offer some potential for mitigating these impacts. However, achieving meaningful conservation outcomes will require the implementation of stringent environmental regulations, the adoption of ecosystem-based management approaches, and the integration of biodiversity conservation into the planning and execution of mining activities. This review concludes while mining is an essential activity for economic development, its ecological footprint demands careful management to prevent irreversible biodiversity loss. A balance must be struck between the exploitation of natural resources and the preservation of ecosystems, ensuring that biodiversity conservation remains a central focus in the future of mining.

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