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TOWARD MINING SUSTAINABILITY: A SYNTHESIS OF BIODIVERSITY AND ECOSYSTEM SERVICES IN THE MINING INDUSTRY

(Rumo à sustentabilidade da mineração: uma síntese da biodiversidade e dos serviços ecossistêmicos na indústria de mineração)

Relatório Final para o Projeto Biodiversidade e Mineração II

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Resumo

A mineração é uma atividade econômica importante, mas cria impactos socioambientais substanciais. Por meio de incentivos à pesquisa e conformidade com os requisitos legais, as empresas de mineração podem fazer contribuições substanciais para monitorar, minimizar, restaurar e compensar os impactos negativos na biodiversidade e nos serviços ecossistêmicos. Aqui, pretendemos resumir como a biodiversidade e o bem-estar humano foram abordados por estudos em locais de mineração, descrevendo os avanços em direção à mineração sustentável e identificando lacunas de conhecimento e novas vias de pesquisa. Reunimos primeiramente artigos publicados sobre serviços de mineração, biodiversidade e ecossistemas até 2018. Em seguida, analisamos esse corpo de literatura à luz da estrutura da Plataforma Intergovernamental sobre Serviços de Biodiversidade e Ecossistemas (IPBES) e dois componentes principais da Hierarquia de Mitigação proposta para regular os impactos ambientais da indústria de mineração, nomeadamente restauração e compensações. Evidenciamos que os estudos sobre os locais de mineração foram concentrados em alguns países, com pouca pesquisa em áreas tropicais, o que implica em uma baixa representação de cientistas que lidam com o nosso foco nessas regiões. Geralmente, faltam informações práticas nas escalas regional e nacional, onde a maioria das decisões é tomada, dificultando o desenvolvimento de estratégias bem-sucedidas para mineração sustentável. Também faltam estudos que consideraram mais de um componente da estrutura do IPBES. Enquanto o valor da natureza raramente foi abordado, nosso estudo enfatiza a necessidade de mais pesquisas sobre biodiversidade, serviços ecossistêmicos e bem-estar humano. Enfatizamos a importância da restauração da biodiversidade e dos serviços ecossistêmicos, além de ampliar o uso de compensações. Também é necessário investir em métodos e pesquisas para valorização dos serviços ecossistêmicos. Investimentos em centros de pesquisa e pesquisa são necessários para preencher essas lacunas.

Palavras-chave: Degradação do solo. Hierarquia de mitigação. Compensações. IPBES. Desenvolvimento sustentável.

Abstract

Mining is an important economic activity but creates substantial socio-environmental impacts. Through research incentives and compliance with legal requirements, mining companies can make substantial contributions to monitor, minimize, restore and compensate for negative impacts on biodiversity and ecosystem services. Here, we aim to summarize how biodiversity and human welfare have been addressed by studies on mining sites, describing advances towards sustainable mining and identifying knowledge gaps and new avenues of research. We first gathered published papers dealing with mining, biodiversity and ecosystem services up to 2018. We then analyzed these body of literature in the light of the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) framework and two key components of the Mitigation Hierarchy proposed to regulate the environmental impacts of the mining industry, namely, restoration and offsets. We evidenced that studies on mining sites have been concentrated within a few countries, with very little research in tropical areas, which implicates in a low representation of scientists dealing with our focus subject in these regions. Practical information is usually lacking at the regional and national scales, where most decisions are made, hindering the development of successful strategies for sustainable mining. Studies that considered more than one component of the IPBES framework are also lacking. Whereas the value of nature was rarely addressed, our study emphasizes the need for more research on biodiversity, ecosystem services and human welfare. We emphasize the importance of biodiversity and ecosystem services restoration, as well broadening the use of offsets. It is also necessary to invest in methods and research for ecosystem services valuing. Investments in research and research centers are necessary to fill these gaps.

Keywords: Land degradation. Mitigation hierarchy. Offsets. IPBES. Sustainable development.

LISTA DE FIGURAS

SUMÁRIO

1 INTRODUCTION

Mining is a major economic activity addressing the material needs of a growing global population. As an activity with high environmental impacts, mining involves important trade-offs between the use of natural resources and the conservation of biodiversity and ecosystem services (hereafter BES) (LEI *et al.,* 2016). As mining activity mobilizes substantial economic assets, there are ample opportunities for substantial contributions to monitor, reduce or prevent declines in BES, but support from researchers is needed to inform the measurement and management of mining impacts (ARMSWORTH *et al.,* 2010).

Sustainability consists of pursuing the welfare and well-being of the current generation without compromising the potential of future generations for a better quality of life (WCED, 1987), which requires a proper balance of economic, environmental and social legacies (AZAPAGIC, 2004). A key condition to sustainability is the maintenance of the total stock of natural capital (COSTANZA; DALY, 1992), and it was suggested that the accumulation of human capital is not completely interchangeable with, but limited by natural capital (TOST *et al*., 2018). Thus, environmental limits have to be considered in order to ensure environmental sustainability, meaning that society and the economy are being built on (or incorporated into) the environment (LOWE, 2010). This requires that mineral industry and society should utilize minerals and metals in ways that could maintain or even strengthen the health of the ecosystem, and support the development of human capital (GIURCO; COOPER, 2012). Therefore, the implementation of sustainable development demands the integration of activities in the following three key areas: (i) technical and economic activities that ensure economic growth; (ii) guarantee the protection of natural resources and the environment; 3) care for the employees in their workplace and community development in the area of the mining (DUBIŃSKI, 2013). It is assumed that these areas are of equal importance; thus, the emphasis on an exclusive area (rather than emphasizing the three areas equally) can lead to a crisis in all mining activity.

Society expects that new forms of business, especially in the current times of global change, present a greater environmental commitment, following the Net Positive proposal (Forum for the Future, The Climate Group and WWF-UK, 2014). In this, it is suggested not only that there be no losses of natural capital (the idea of 'no net loss'), but that there is a gain through a genuine positive contribution to society and the environment where business is developed. Thus, in this perspective, it is hoped that the companies become prosperous organizations and that they could offer benefits that go beyond the traditional organizational limits. For example, two principles of this initiative are: (i) robust methods of environmental restoration, and which are socially inclusive, are applied in ecologically important areas; (ii) an inclusive approach is taken at all times, ensuring that affected communities are involved in the process of creating social and/or environmental gains (Forum for the Future, The Climate Group and WWF-UK, 2014).

Mining impacts on BES are reported as primarily related to shifts in land use since mining changes soil structure (DEJUN *et al*., 2016), hydrological processes and water quality (WANG *et al*., 2016) and threatens wildlife (ALVAREZ-BERRÍOS *et al.,* 2016; LI *et al*., 2011). Globally, mining is reported to have impacts on land use and it can have a major effect on degradation of ecosystems specially combined with agriculture and livestock (IPBES, 2018), and can drive deforestation beyond operational boundaries (SONTER *et al*., 2017). However, mining is reported as having lower responsibility in the globally total amount of deforestation than cattle and agriculture (FRANKS, 2015).

The Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) framework considers six key elements about the relationship between nature and society that must be addressed when considering biodiversity and the key ecosystem services delivered by it (DÍAZ *et al.,* 2015): (i) nature (biodiversity and ecosystems); (ii) anthropogenic assets (such as, infrastructure, health facilities, knowledge, technology, economy); (iii) nature's benefits to people (ecosystem goods and services); (iv) institutions and governance and other indirect drivers; (v) direct drivers (natural and anthropogenic, which affect nature directly) and; (vi) good quality of life. With this framework, IPBES aims at 'strengthening the science-policy interface for biodiversity and ecosystem services for the conservation and sustainable use of biodiversity, long-term human well-being and sustainable development' and is an important tool to address impacts on BES (DÍAZ *et al*., 2015, p. 3). Mitigation Hierarchy (ICMM, 2006) also discuss the steps related to impacts and involves (i) the avoidance and/or (ii) minimization of impacts; (iii) restoration (to re-establish an ecosystem's composition, structure or function) and; (iv) offsets (balance of biodiversity loss in one place and/or time by an equivalent biodiversity gain elsewhere).

Given the importance of mining in meeting growing societal demands for metals and materials for construction, manufacturing and food (fertilizers), we here review the literature related to current trends in sustainable mining. We also considered the advances on research considering the six components of IPBES framework (see above) and two main components of mitigation hierarchy (restoration and offset). To our knowledge, this is the first attempt to highlight how BES issues have been addressed by mining initiatives, presenting how far we have advanced along the path toward mining sustainability and what must still be addressed in terms of research.

2 MATERIALS AND METHODS

We performed a literature search in late March 2018 using the Scopus (http://portal.isiknowledge.com/) database. To this end, we employed a combination of the keywords 'Mine' OR 'Mining' AND 'Ecosystem AND Service (s)' OR 'biodiversity' OR 'restoration' OR 'sustainability' OR 'sustainable' OR 'offsets' OR 'human AND welfare'. The search accepted these words in the title, abstract or keywords of published, peer-reviewed papers in English. We limited our results to the "Environmental Sciences" and we only analyzed those articles with empirical procedures, thus reviews were not analyzed.

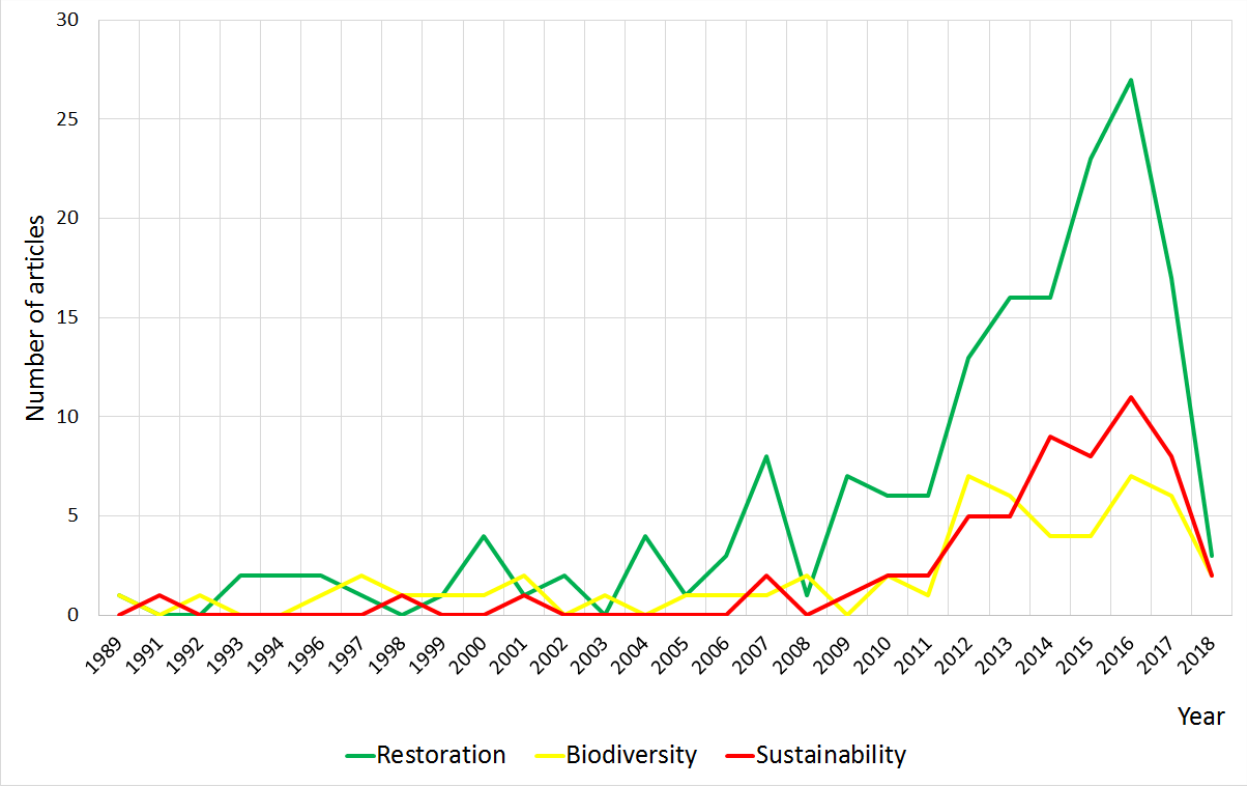
Our first survey resulted on 323 articles that, after deep analysis (excluding those not necessarily related, e.g. other subject or without empirical procedures), we reduced to 280 articles (Tables S1 and S2) that dealt directly with BES within mining activities in an empirical manner. To analyze those articles, a database was created that included a standardized list of articles, which enabled the compilation and quantification of the characteristics of the studies (when information was available at title, keywords or abstract). This first compilation was made to clarify where empirical works were made, the year of publication, journals that published the papers, main theme or focus from the work and based on IPBES framework and Mitigation Hierarchy, whose dimensions were considered here. The data was used to point the progress within this research topic dealing with BES, considering strong and weak points. The first 25 most cited articles were analyzed deeper as they represented the most impacting articles on the area. For those, we also considered the ecosystem, type of mining and level of analysis (local or landscape for example) besides its content.

3 RESULTS AND DISCUSSION

Characteristics of analyzed papers

The main topics (sustainability, biodiversity and restoration) increased in papers from 1998 to 2018 (Fig. 1). “Sustainability” has been quoted on 21% within our survey (n=58). The BES approach (represented by biodiversity in our study, since the broad concept of ecosystem service was inserted on all papers analyzed) is a relatively new and increasingly popular policy framework (DAILY *et al.,* 2009) but, despite increasing interest, little progress in practical approaches to address BES protection has resulted since BES impacts continue to grow (BUTCHART *et al*. 201; GUERRY *et al*., 2015). Papers dealing with “sustainability” in mining evidenced a major increase after 2009 and, considering some variation among years and themes, we observed that after 2014 this theme began to be emphasized among papers, surpassing the “biodiversity” theme.

Figure 1. Number of papers published from 1998-2018 including restoration, biodiversity, sustainability and within mining industry in peer-reviewed scientific journals.

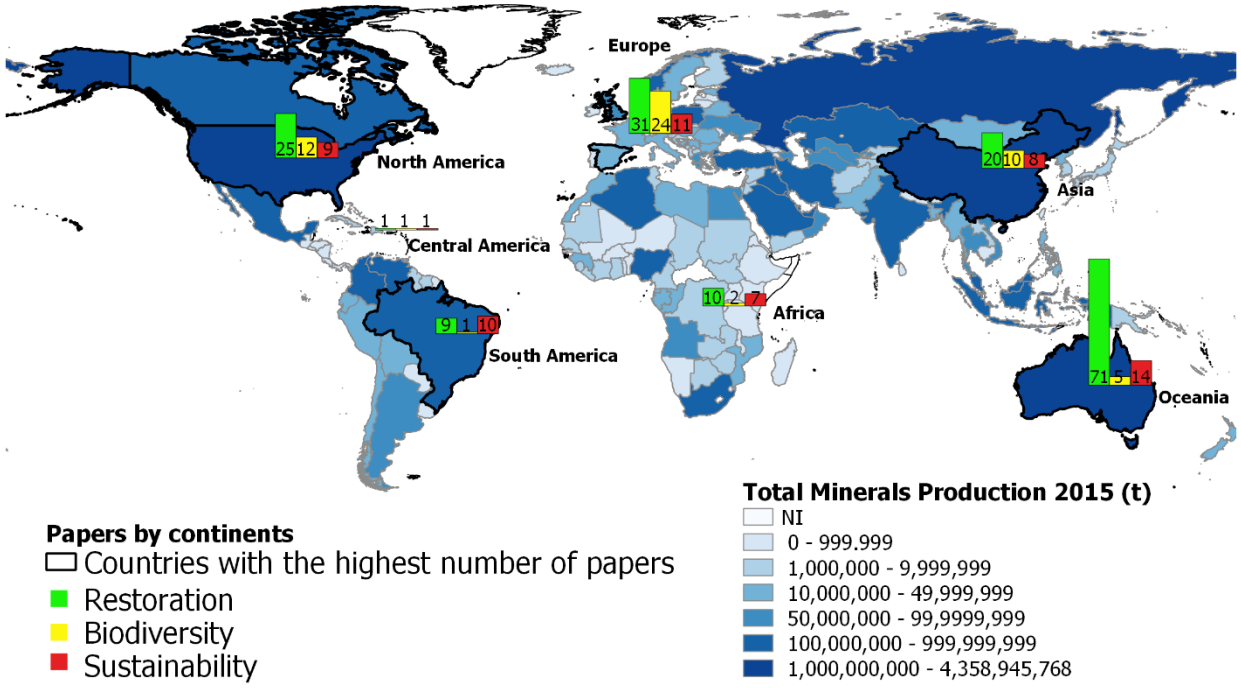


Fonte: Elaborado pelo autor.

The majority of studies included in our analyses were conducted in Australia (30%, n=85), followed by United States (10%, n=27) (Fig. 2). According to the designation of "developed" and "developing" countries from the United Nations system (following criteria used by Reichl et al. 2016), 79% of the

countries investigated here were developed countries out of a total of 42 countries (some papers referred to more than one country). Interestingly, these results do not match the regions where most mining activities occur; Asia and North America are the first and second most active continents, respectively. Nor do these results match development status, with developing countries representing the primary areas of mining activity (IREICH *et al.,* 2016). However, one publication concerning extractive mines pointed out that the most well studied region was Australia, more specifically the Alcoa bauxite mines in Western Australia's at the ecosystem of jarrah forests (*Eucalyptus marginata*) (PRICE *et al*., 2005), most likely because it is an important biodiversity hotspot.

Figure 2. Map of locations where studies including biodiversity, sustainability and restoration within mining industry were developed



Fonte: Elaborado pelo autor

We also evidenced that studies on mining sites have been concentrated within a few countries (less than 42), with very little research in tropical areas, as noted by other authors (SEPPELT *et al.*, 2011). Thus, there is not only a research gap in terms of where most mining activities take place but also a possible low representation of scientists dealing with the topic in these mining regions. Due its importance to local and global economies and its potential threat to natural resources, investment in research considering this sector will likely continue to grow, especially in areas where larger mining companies are located.

Not all information about mine types and ecosystems were available. Most cited papers at our review included studies with all three key topics (sustainability, biodiversity and restoration) and we noticed differences on mining types (bauxite, coal, quarry, lignite, pyrite) and ecosystem types (varying from mosaic landscapes to forests). Differences can be directly related to some particularities found on

different management practices and ecosystems. Restoration practices, for example, are related to the manipulation of soil fertility but in some ecosystems, such as Brazilian savannas, restoration is ineffective for improving plant growth (SILVEIRA *et al*., 2016). Also in Brazil, iron mines are usually associated with montane savanna vegetation, an ecosystem that is poorly understood, adding additional difficulties to addressing mining impacts and the protection of BES (SOUZA-FILHO *et al.*, 2019). The inadequate representation of some ecosystems may thus put some regions at higher risk.

Biodiversity and ecosystem services and the IPBES framework

Papers addressing "sustainability" usually presented some type of ecosystem service valuation, including monetary and non-monetary valuation (frameworks, cultural or esthetical value) or both. Of these, methodologies include the following: (1) non-monetary – interviews, ecosystem service maps, asset surveys through censuses, databases or literature searches; (2) monetary – willingness to pay, choice modeling experiments, contingent valuation, market value methods, opportunity-cost methods, and travel-cost methods. The use of both methodologies (monetary and non-monetary) along with multiple services is not only laborious but also time consuming, which is likely why we did not observe these two features frequently in the literature. In contrast, ecosystem services are usually based on intangible resources, with a gradient of decreasing tangibility as one moves from direct use values (encompassing direct consumptive use values such as the value of timber, fish or other resources that ecosystems provide) to non-direct use (existence and bequest values) (HOUDET *et al.,* 2012). Historically, ecosystem service values have been largely invisible to markets (BAYON; JENKINS, 2010), which might also explain the lack of such analysis. Investments in research with multiple investigators presenting different skills (ecology, economic, engineering) should be prioritized to account for multiple variations and detailed ecosystem service valuation. As previously noted, the greatest challenge seems to be removing the asymmetry of economic systems that reward the production of marketed commodities but not the provision of non-market ecosystem services or the sustainable use of natural capital that supports these services (GUERRY *et al.* 2015; ISBELL *et al.,* 2017). We are still underestimating the value of ecosystem services, which may complicate comparisons across place, time or scale, but such valuation is an important metric to help on decision-making process.

As mining sector includes multiple dimensions, we expect that most papers presented the majority of the six IPBES components described in its framework (DÍAZ *et al.*, 2015), but surprisingly only 18% from the papers (n=50) referred to all six IPBES components. All of them were related to "Sustainability". Most papers dealt with one to three IPBES components, which reveal an unbalanced approach between nature and society. Gathering multiple perspectives should be a target of mining projects, and a balance between these two important concepts should be pursued. When multiple and complementary approaches are integrated into projects, initiatives tend to be more durable and more reliable from a societal perspective (PRETTY, 2003). If an effective commitment to social and economic components of business is explicitly made, it is more likely that companies will seek to fully implement the practice of sustainable development (DASHWOOD, 2014). It has also been stressed that domestic regulation and governance are key to increasing corporate social responsibility (ANDREWS, 2016), emphasizing the important role of the public sector in defining the regulatory framework. Accounting for this balance also promotes a better distribution of benefits to the local communities and, consequently, contributes to a reduction in social and environmental conflicts that can follow mining operations (SOUZA *et al.*, 2016).

Furthermore, approaches that focus on a single sector and a narrow set of objectives tend to fail to include a different set of consequences that are inherent to decision-making. Different approaches combined among services and their links to ecosystem processes are critical in attempting to maintain ecosystem health, human well-being, institutions and governance systems (Millennium Ecosystem Assessment, 2005). Mining projects themselves have important social consequences, as they alter human assets and economic dimensions. If multiple integrated approaches of this valuation are not included, the consequences for human life could be masked. Considering services as a series of components rather than single services can help maintain ecosystems in a more intact form and can reduce the ecological vulnerability that will likely result from emphasizing single services (Redford and Adams, 2009).

Restoration and offsets and the Mitigation hierarchy

Restoration was presented in most papers (n=167; 60%). Many restoration studies referred to restoration as the recovery of vegetal community, and methods to achieve this end involved plowing and seeding, succession, abandoned areas without management (spontaneous colonization), or observation and comparison to natural areas (n=48). These studies seem to be insufficient, at least with regard to the exploration of the variety of available revegetation strategies and ecosystem types (SOUZA *et al*., 2016, MONTOYA *et al.,* 2012).

No study dealt with recovery focusing on ecological processes or BES, and only one study was related to general biodiversity through the evaluation of key species in different situations. An important goal of restoration should be to recover BES rather than only a subset of species. However, as the current understanding of ecological processes underlying this recovery is often incomplete and poorly integrated, restoration projects are sometimes compromised (MONTOYA *et al.,* 2012). Most studies (40%) only mentioned restoration as an important attribute to consider; however, no analysis was conducted with this objective. The remaining studies did not mention restoration at all.

We found only seven studies that translated an approach based on ecological theory into actual restoration practices that can be easily used by different stakeholders by incorporating multiple or integrated approaches. Additionally, only one was empirical and directed to a specific area, while others were based on opinion or review. Through adequate strategies, it is possible to guarantee the success of restoration programs, which is crucial for the maintenance of natural capital (BLIGNAUT *et al.,* 2014). However, we did not observe strategies focusing on restoration that could be applied to different places considering different aspects of BES.

Restoration strategies are related to a long and difficult process and thus should be monitored and evaluated in long-term programs to observe how much time is necessary for ecosystem restoration and its BES, and to assess the progress and emergence of BES during the process (DOHERTY *et al.,* 2011; EVANS *et al*., 2013; MONTOYA *et al.,* 2012; SERA, 2016). These features could also help future studies. Basic and important principles should also be accounted for to consider an appropriate reference ecosystem, the level of resilience and degradation, and applied strategies to consider social aspects to enhance the success of restoration initiatives (SERA, 2016).

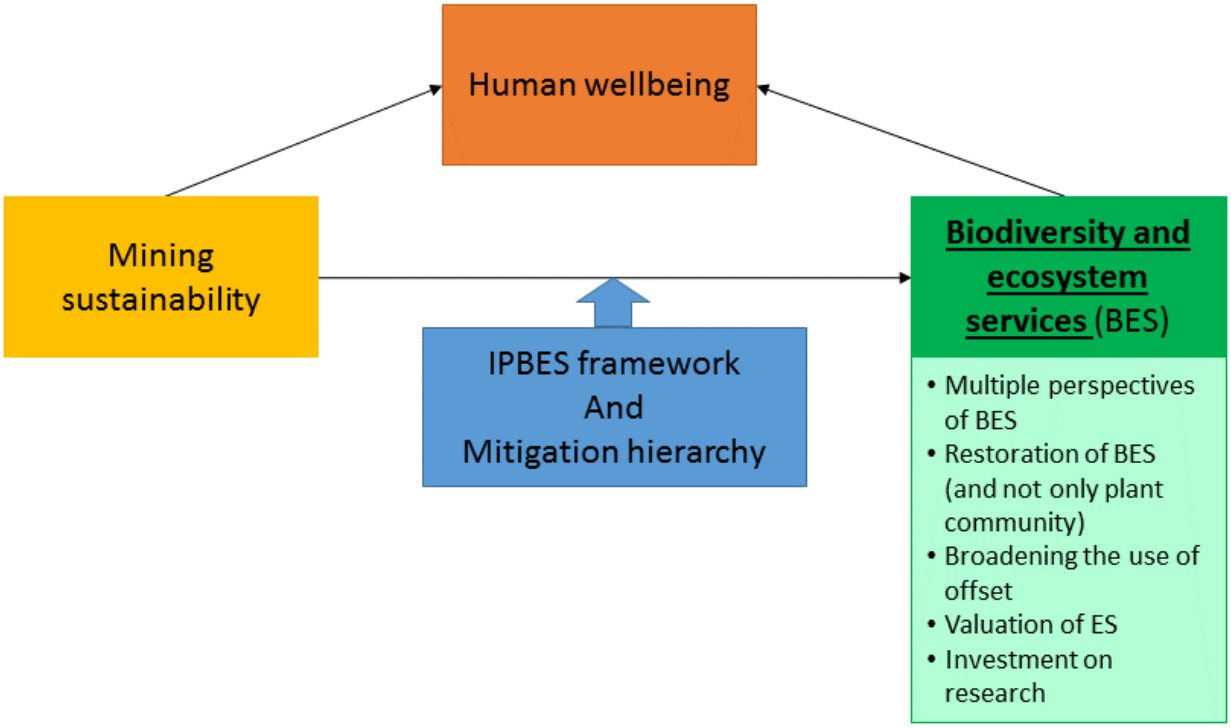
Despite the use of offsets since the 1970s and their popularity in conservation (BULL *et al.,* 2013), we found only three papers in which biodiversity offsets were evaluated. Theoretical and practical problems related to biodiversity offsets were already described (BULL *et al.,* 2013), including the idea that under some conditions, offsets may be not appropriate, e.g., when facing overwhelming ecological uncertainty.

Biodiversity data are not always available; particularly for tropical regions, the knowledge gap is still very large (KIER *et al*., 2005; WEGE *et al.,* 2015). Moreover, even when available, these data often require critical evaluation by researchers, as they may contain inaccuracies in terms of taxonomy and/or georeferencing, which affect the analysis. Determining the area where offsets will be implemented is also not a trivial task and should rely on spatial methods. A clear set of socio-environmental criteria is necessary, e.g., the use of proper metrics to measure biodiversity, defining how long offset schemes will prevail, managing uncertainties (BULL *et al*. 2013), assessing ecological equivalence in biodiversity (QUETIER; LAVOREL, 2011), and including the effects of climate change (GALIK; JACKSON, 2009). By considering multiple measures of spatial prioritization, the area to be chosen may have a greater chance of preserving BES. The low representation of offsets in reviewed papers may indicate a knowledge gap on this topic for mining projects or may reflect theoretical and practical problems related to offset feasibility; this area requires further investigation.

4 CONCLUDING REMARKS AND FUTURE STEPS

Mining has an important role as providing resources for human development but the impacts on environment, especially on biodiversity and ecosystem services delivered by it, must be addressed. Our synthesis reveals key gaps: studies are concentrated in a few countries with very little research in tropical areas; restoration is by far the most studied theme although mainly considered as the recovery of the vegetation and not from the ecosystems services; only a few papers deals with multiple dimensions considered at the IPBES framework. In that manner some opportunities for future studies (Fig. 3) are (i) gathering multiple perspectives when dealing with biodiversity and ecosystem services; (ii) considering the restoration of BES rather than that of the plant species community only; (iii) broadening the use of offsets in the context of mitigation hierarchy; (iv) investing in methods and research to provide methodologies and metrics that effectively capture the value of a particular ecosystem service, specifically relating it to human well-being and; (v) investing in research and research centers, especially those focusing on multidisciplinary perspectives and on developing world, including partnership between public and private sectors. These initiatives are important to mining sustainability aiming ensuring economic growth, protection of natural resources and the environment, as well social development. This responsibility implies the notion of a positive legacy of the entrepreneurial activity, which contributes to the well-being of future generations, during and after the end of the mining activity.

Figure 3. Biodiversity and Ecosystem Service (BES) in the context of mining sustainability, and the suggested future steps on BES research.



Fonte: Elaborado pelo autor.

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SUPPORTING INFORMATION

1. Locality: place where the study was developed. When there was no specific location (reviews, for example), we considered the country of the first author (*).
2. Type of study: here, we used five categories (empirical, meta-analysis, modeling, review and other). Other refers to studies related to opinion or studies based on databases.
3. Main focus: some papers could be fitted to multiple issues, but in general, this category indicates the main issue of the paper.
4. ES evaluated/restored – Level (or Level only): in this category, we considered the focus of the analysis of the paper and considered the scale. To avoid any debate on scale definition, we considered three main scales: local – sampling or study based on specific location in the landscape, sites or locations in a city, space or country; landscape – study of a large area (not specific sites) such as the entire country or multiple countries (e.g., reviews or research using databases); or non-specific location – study using a general approach.
5. MEA (2015) ES – categories of ES based on MEA and biodiversity (as another category) if the paper also deals with biodiversity.
6. Restoration (direct) – if restoration is mentioned or discussed in the paper.
7. Restoration method – if the previous category was positive (direct restoration), we determined whether any restoration method was suggested.
8. Value – if the paper deals with value, what type of value is discussed: economic (monetary) or non-monetary.
9. IPBES framework – category of IPBES framework for the paper.