

# ENVIRONMENTAL SERVICES ASSOCIATED WITH THE RECLAMATION OF AREAS DEGRADED BY MINING: POTENTIAL FOR PAYMENTS FOR ENVIRONMENTAL SERVICES<sup>1</sup>

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## 1. Introduction

Brazil is characterized by an impressive geodiversity which confers a substantial capacity for mineral production, placing the country on a par with the major world powers in mining such as the USA, Russia, Canada, Australia, and South Africa. The growth of demand within the world mineral sector, which started at the beginning of the present century and followed upon the adverse market conditions experienced in the 1980s and 1990s, has revealed a new and enduring challenge to the mineral sector: the promotion of sustainability (CABRAL JUNIOR *et al.*, 2008).

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According to Nunes (2006), since mineral resources are vital to the quality of human life, sustainable development depends on mining. However, while the products of mining have brought a series of socioeconomic benefits and improvements to the urban environment (INSTITUTO DE PESQUISAS TECNOLÓGICAS, 2003; HERRMANN, 2007); mining activities have been severely criticized for their negative impacts on the environment (INSTITUTO BRASILEIRO DO MEIO AMBIENTE E DOS RECURSOS NATURAIS RENOVÁVEIS, 1990), not only for the extent of the associated damage but also for its severity. Porto and Milanez (2009) have pointed out that mining activities have been responsible for social and environmental conflicts, which in many cases have aggravated situations of environmental injustice. As an example, the social and environmental conflicts that have flared up in the state of Santa Catarina may be highlighted. Here disputes in areas where there are old mines for underground coal mining have become obstacles to sustainable local development (RUIZ *et al.*, 2014).

The reclamation of degraded areas, with a view to converting previously mined areas to new, sustainable uses, is, according to Neri and Sánchez (2010), one of the crucial stages in the life cycle of a mining operation. Given the significance of the negative impacts of mining (MECHI; SANCHES, 2010), Article 225 of the Constitution of Brazil places the responsibility for the reclamation of degraded areas (RDA) with the mine operator (BRASIL, 1988), and requires the elaboration by the operator of a Plan for its recovery (PRDA<sup>i</sup>) when the productive phase of the operation comes to its conclusion (BRASIL, 1989). With regard to the importance of the provision of financial resources for the reclamation of the degraded area, Oliveira Neto and Petter (2005) have emphasized the need for the establishment of criteria for negotiations between the polluter (mine operator) and the affected community. Despite this, there is no specific legislation in Brazil to ensure the provision of financial collateral for the decommissioning plan of a mine (ALMEIDA; LIMA, 2008). Beyond the financial issues, there are other interests that guide the planning for the decommissioning of a mine, including the reclamation of the degraded environment, with the objective of achieving a positive balance for the region. There is a need to guarantee safeguards for shareholders, public authorities, the supply chain, local communities, and future generations, with regard to socioeconomic impacts and associated environmental liabilities (SÁNCHEZ, 2011). The net result is a positive spiral of growth and development.

As has been discussed by Prno and Slocombe (2012), communities located close to mining operations have manifested their discontent with conventional approaches to the extraction of natural resources, and are demanding a larger share in the distribution of the accrued benefits. For Porto and Milanez (2009), the development model of Brazil, which is strongly based on the production of commodities, should be considered environmentally unsustainable and socially unjust. They argue that the productive processes are incapable of breaking the installed social metabolism, the processes can only minimize or compensate for part of the social and environmental impacts that they trigger. Seen in this light, the development model of Brazil is contributing directly to the intensification of economic, social, and environmental conflicts. On the other hand, the current situation does open the possibility for discussions that could lead to

the evolution of relations between the mine operator and the affected community based on more just and sustainable bases.

According to Jenkins and Yakovleva (2006), the companies of the mining sector are increasingly recognizing the importance of the search for and dissemination of their practices which address social responsibility. Kapelus (2002) and Jenkins (2004) have emphasized that this concern has developed in recent years as a means to revert the questionable reputation of the mining sector in the area of social responsibility, principally with regard to relationships with local communities, given the profound disturbances caused by mining.

The social and environmental responsibilities of the mining sector should extend beyond the minimum: searching for financial collateral for the decommissioning of mines, avoiding social and environmental conflicts, and recovering the degraded environment. There is a need for advances, to maximize the benefits rendered to society and to the affected natural environment in the post-mining stage, through the provision of new uses for areas once occupied by mining operations. Ecosystem services (ES) are the benefits that, directly or indirectly, have a positive influence on the quality of human life, through the functions of the ecosystems (COSTANZA *et al.*, 1997). Improvements in the processes applied to degraded areas of former mining operations during the reclamation phase (RDA), which contemplate and expand the offering of ES, will add value to the reclamation project.

The importance of promoting benchmarking in the evaluation of practices for the reclamation of mines has been highlighted by Neri and Sánchez (2010). They have demonstrated that even mining operations that possess a certificate of environmental management devote little attention to the planning of the reclamation of degraded areas, despite the gains that reclamation brings to the local biodiversity.

The role and value of ES in the planning phase of mining operations has been discussed in the literature. ES promote a better distribution of the benefits to the local communities, and in this way contribute to a reduction in social and environmental conflicts and consequently in feelings of social injustice that tend to surround mining operations. Bian and Lu (2013) have demonstrated, with the support of remote-sensing tools, how changes in land use arising from mining operations affect the natural environment and the offering of ES during the time over which the mineral resources are exploited. The International Finance Corporation of the World Bank Group (INTERNATIONAL FINANCE CORPORATION, 2012) has endorsed the suggestion that ES should be considered in the designing of environmental impact studies (EIS). Adopting this suggestion, a number of recent studies have been dedicated to the evaluation of the addition of ES to the traditional practices for the execution of an EIS for the mining sector; examples include Rosa and Sánchez (2015), and Damigos *et al.* (2015).

The global panorama laid out in the previous paragraphs draws attention to the possibility of inserting the Brazilian mining sector into the current general discussions concerning ES and payments for environmental services (PES) in Brazil. Following this logic, improvements in RDA techniques for mining could increase the benefits, understood as ES, realized upon the cessation of mining activities beyond the reclamation actions required under current environmental legislation.

The objective of this article is to discuss the potential for associating environmental services with techniques for the reclamation of areas degraded by mining in the light of current trends in PES in Brazil. To this end, the article has the following structure: section 2 is a brief review of the literature addressing the difference between the terms “ecosystem services” and “environmental services” in which reference is made to payment programs for the provision of these services. Section 3 is a brief literature review of the context within which a national policy regarding the establishment of programs for PES is evolving in Brazil. Study methods are presented in section 4. Section 5 is divided into three parts; a scheme of classification of ES applied to RDA based on the practices adopted is first developed. This forms the basis for two subsections, which in an analytical manner reflect upon the following: the current situation of the identification of ES related to conventional post-mining RDA techniques (section 5.1), and possible ES that could be associated with post-mining RDA recognizing the current national trends on PES in Brazil (section 5.2). These reflections are followed by a discussion section (section 6) and conclusions (section 7).

## 2. Ecosystem services or environmental services?

The terms ecosystem services and environmental services, and consequently how these services are paid for, are encountered in the literature as either synonyms or distinct designations (WUNDER, 2015). In a recent review of definitions related to payments for the provision of such services, Derissen and Latacz-Lohmann (2013) have indicated that there is a crucial difference in the usage of these two terms in the scientific literature. According to Derissen and Latacz-Lohmann (2013), ecosystem services are related to the benefits generated for people that are obtained from ecosystems. This definition concurs with that adopted by Costanza *et al.* (1997), by the Millennium Ecosystem Assessment (2005), and by the Food and Agriculture Organization of the United Nations (2015); it is the definition accepted by the majority of authors writing in the contemporary scientific literature. Derissen and Latacz-Lohmann (2013) conceptualize environmental services as the benefits to the quality of life of people associated with the adoption of practices for the management of natural resources, in other words arising from human intervention. This definition has also found wide acceptance and has been adopted by various authors in the literature, including Chomitz, Brenes and Constantino (1999), Kroeger (2013), Schomers and Matzdorf (2013), and Wunder (2015).

In contrast, Balvanera *et al.* (2012), in a review of the state of the art regarding “ecosystem services” in Latin America, have used the term “payment for ecosystem services” when referring to payment schemes instead of utilizing the term “payment for environmental services”. “Payment for environmental services” is more usually encountered in Brazilian legislation addressing the issue and in studies that deal with the subject in Brazil (BRASIL, 2007; GUEDES; SEEHUSEN, 2011; MORAES, 2012; PAGIOLA, VON GLEHN; TAFFARELLO, 2013).

Guedes and Seehusen (2011), in a publication that discusses the PES for the Atlantic Rainforest of Brazil, opted to use the term “environmental services”, arguing

that this term covers not only “ecosystem services” (provided to man by ecosystems) but also services provided by ecosystems that are managed by man. According to Guedes and Seehusen (2011), ecosystems managed by man represent sustainable practices that can have a positive influence on the offering of services, in this case environmental services.

At the federal level in Brazil, the legislative proposal that covers the topic of environmental services and the possibility of funding for its promotion (BRASIL, 2007) and the federal decree that regulates the operation of the National Fund for Climate Change Actions, a possible source of resources for PES related to activities that promote carbon sequestration (BRASIL, 2010), have both adopted the term “environmental services” instead of “ecosystem services.” The adoption of the term “environmental services” has also occurred in current state-level PES programs, such as those in the states of Acre (2010), Paraná (2012), Espírito Santo (2012), Santa Catarina (2010), and Rio de Janeiro (2011). There is a distinct prevalence of the term “environmental services” in local discussions over payments for environmental services, probably due to the fact that the legal framework of Brazil has linked, for the purposes of participation in PES schemes, the adoption of management practices to the generation of associated environmental benefits.

Given the preceding, within the present article the designation “environmental services” has been utilized, because this better matches the context within which the propositions concerning mining, reclamation of degraded areas and related environmental services are being discussed. However, throughout the text, when citations to references on the topic appear, the nomenclature adopted by the original authors has been maintained.

### 3. Payment for environmental services in Brazil: contextualization

Consensus on the concept of Payments for Environmental Services (PES) has not been reached. Even the nomenclature is not homogeneous across the scientific literature, with some authors, such as Engel, Pagiola and Wunder (2008), Legrand, Froger and Le Coq (2013), and Démurger and Pelletier (2015), referring to “payments for environmental services”, whereas others, for example Farley and Costanza (2010), Schomers and Matzdorf (2013), and Matthies *et al.* (2015), have opted for “payments for ecosystem services.”

To understand better the nomenclature, the usage by different authors can be examined. Thus, Farley and Costanza (2010) consider payments for ecosystem services (PES) as a mechanism for the management of ecosystems through the utilization of economic incentives. Wunder (2005, p. 3), a pioneering author in the framing of how PES function, has linked PES with the satisfaction of five criteria: a PES is “1. a voluntary transaction where 2. a well-defined ES (or a land use likely to secure that service) 3. is being ‘bought’ by a (minimum one) ES buyer 4. from a (minimum one) ES provider 5. if and only if the ES provider secures ES provision (conditionality).”

This definition has been analyzed and criticized by various authors. For Farley and Costanza (2010), who considered the logic of the ecological economics, Payments for Environmental Services (in this case referred to as Payments for Ecosystem Services) should prioritize ecological sustainability and the fair distribution of the payments. This is in contrast to the approach from environmental economics, which places the ES within

a market model, with emphasis on the efficiency of the ES. Muradian et al. (2010) have reservations in relation to the use of the market model, given the complexities associated with the issues of distribution, social integration and power relations. Starting from these pretexts, Muradian et al. (2010) recognize the variety of contexts and institutional environments in which PES schemes may operate, this leads them to defend a different approach in which political issues are considered. The importance of taking into consideration the complexity of ecological sustainability and its associated uncertainties has been highlighted by Romeiro (2006), who has pointed out that some ES cannot be substituted and that ecosystems do have functional limits. This implies that risks of irreversible ecosystem loss do exist, which will affect the provision of services by the lost ecosystems. Pascual et al. (2010) draw out the importance of the balance between equality and efficiency in PES schemes, with an emphasis on social perceptions about economic justice versus fairness in the distribution of the payments.

Andrade and Romeiro (2013) have emphasized that the valuation of ES, an important step in the definition of the value to be considered in PES schemes, should be broad, taking into account criteria linked to sustainability, not just economic, but also ecological and social. They further contend that, due to the complexity of the processes within ecosystems and their interactions with human variables, the valuation should be based on a transdisciplinary approach. Andrade and Romeiro (2013) argue that this non-reductionist valuation process prevents the neglect of the values and the contributions of ES to human well-being, for it integrates the objectives of ecological sustainability, social justice and economic efficiency. From this perspective, Andrade and Romeiro (2013) suggest that the valuation needs to encompass not only market prices, but also non-economic values associated with the ecosystems. This implies the consideration of the interdependencies that exist between the components of the natural capital and the visions that different groups of individuals hold regarding the various categories of ES with their respective cultural and ethical dimensions. Andrade and Romeiro (2013) therefore highlight that valuation models need to be dynamic, subject to constant refinement, so that they can best represent the interactions between the natural and human environments. Models that are dynamic will facilitate the negotiation process for PES schemes, making the schemes more transparent.

Finally, Wunder himself (2015, p. 241), some 10 years after his original exposition on PES, has revisited his definition of PES, taking into consideration the criticisms and analyses which have appeared in the scientific literature. From these starting points, Wunder (2015, p. 241) proposes the concept of an ideal model for PES, including the following alterations to his previous definition, a PES is: “(1) voluntary transactions (2) between service users (3) and service providers (4) that are conditional on agreed rules of natural resource management (5) for generating offsite services.”

Independent of the framing of a definition of PES, the fact is that PES schemes have been put into practice since the 1990s, each with specific features, regarding objectives, adopted institutional arrangements, inclusion of governmental prerogatives and responses to the concerns of local populations (ELOY, COUDEL; TONI, 2013). The principal PES schemes which have been documented around the world fall into the following ES cat-

egories: carbon capture or retention, conservation of biodiversity, conservation of water resources, and conservation of natural beauty (WUNDER *et al.*, 2009). Balvanera *et al.* (2012) have performed a survey covering Latin America, and found that few services are considered in schemes of PES, notably there is a predominance of ES related to carbon and water. The first instances of PES schemes in Brazil follow this same line, being focused upon the conservation of water resources, the maintenance of native forests, and the adoption of agroecological practices (ELOY, COUDEL; TONI, 2013).

However, the current situation in Brazil reveals signs of a diversification in the ES which appear in the PES schemes that are now in operation or are in the proposal phase. From an analysis of the regulatory instruments accompanying government supported PES schemes proposed up to the end of 2012, it can be perceived that there are schemes of wide scope, such as found in the proposal for a National Policy on PES (BRASIL, 2007), which considers ES of any type, and others that are specific, including programs in the states of Acre, Santa Catarina, Rio de Janeiro, Espírito Santo, and Paraná. Among the cases where the ES are specified, there are explicit schemes related to the following objectives: retention or capture of carbon (ACRE, 2010; RIO DE JANEIRO, 2011; PARANÁ, 2012), conservation of biodiversity (ACRE, 2010; SANTA CATARINA, 2010; RIO DE JANEIRO, 2011; PARANÁ, 2012), soil conservation (ACRE, 2010; SANTA CATARINA, 2010), water conservation (ACRE, 2010; SANTA CATARINA, 2010; RIO DE JANEIRO, 2011; ESPÍRITO SANTO, 2012; PARANÁ, 2012), conservation of natural beauty (ACRE, 2010; SANTA CATARINA, 2010), and conservation of natural resources (ESPÍRITO SANTO, 2012).

Beyond payment schemes that specifically target ES, there are in Brazil government programs and projects that follow the same principles as PES schemes. These include programs related to soil conservation (SÃO PAULO, 1993, 1997; EXTREMA, 2005; OLIVEIRA; ALTAFIN, 2008), water conservation (SÃO PAULO, 1993, 1997; EXTREMA, 2005; ACRE, 2008; MINAS GERAIS, 2008; OLIVEIRA; ALTAFIN, 2008; SÃO PAULO, 2009, 2010), retention or capture of carbon (ACRE, 2008; BRASIL, 2008; OLIVEIRA; ALTAFIN, 2008; SÃO PAULO, 2009, 2010; BRASIL, 2010; BRASIL, 2011a), conservation of biodiversity (ACRE, 2008; MINAS GERAIS, 2008; OLIVEIRA; ALTAFIN, 2008; SÃO PAULO, 2009, 2010; BRASIL, 2011a), and conservation of natural resources (AMAZONAS, 2007; ACRE, 2008; BRASIL, 2008; BRASIL, 2011a, 2011b). In relation to the mechanisms of payment for the ES, this may be financial, through remuneration when practices that generate ES are adopted (EXTREMA, 2005; AMAZONAS, 2007; BRASIL, 2007; ACRE, 2008; BRASIL, 2008; MINAS GERAIS, 2008; OLIVEIRA; ALTAFIN, 2008; SÃO PAULO, 2009, 2010; BRASIL, 2010; SANTA CATARINA, 2010; BRASIL, 2011a, 2011b; RIO DE JANEIRO, 2011; ESPÍRITO SANTO, 2012; PARANÁ, 2012), or non-monetary, for example by fomenting activities that generate ES (SÃO PAULO, 1993, 1997; BRASIL, 2007; OLIVEIRA; ALTAFIN, 2008; ACRE, 2010).

Thus, it can be perceived that within Brazil there are developments in the regulatory framework at all levels, federal, state and municipal, for the implementation of PES schemes related to the following objectives: reduction of emissions of greenhouse gases

(GHG)/carbon stock increases, conservation of biodiversity, soil and water conservation, conservation of natural beauty, and conservation of natural resources. The principal activities represented within these schemes are focused on the preservation and conservation of forests, through increasing forest coverage and improving the connectivity between forest fragments, linked to the adoption of practices that conserve soil and water.

The target audiences for the PES schemes operating in Brazil generally fall into one of two categories: those who adopt best productive practices, and those who promote the conservation of natural resources and RDA. Notable members of the first category are small producers, family producers, the inhabitants of rural and forest settlements, and traditional communities (ACRE, 2008; SANTA CATARINA, 2010). Rural landowners and facilitators, particularly those with activities encouraging the conservation of forests and water resources, are found in the second category (ACRE, 2010; SANTA CATARINA, 2010; RIO DE JANEIRO, 2011; ESPÍRITO SANTO, 2012; PARANÁ, 2012).

It may further be noted that, for the PES schemes which have been evaluated, the payment is not related to the quantity of ES effectively generated. An explanation for this situation has been suggested by Eloy, Coudel and Toni (2013), who indicate that the majority of the schemes consider the maintenance of natural vegetation as a proxy for ES delivery, which reduces the interest in quantifying the ES generated. Brazil is in the initial stages of developing a regulatory framework for PES, and these findings point to the importance of relating payment to an activity which leads to the conservation or restoration of an ES. This appreciation concurs with that of Kroeger (2013), who has defended the view that difficulties such as the quantification of the improvements to human life provided through PES should not impede the dissemination of PES schemes. Kroeger (2013) explains that as understanding of the quantification issues evolves, so this knowledge can be incorporated into existing PES schemes.

#### 4. Method

The research reported in this article was of an exploratory nature and followed a qualitative approach. The instruments utilized were a bibliographic review, followed by a content analysis of the papers identified as relevant. Since the study was exploratory and guided exclusively by bibliographic research, the choice of the keywords for review followed exactly the constructs of the research, so that the established objective could be achieved.

To provide data to support the evaluation of the current state of the identification of ES related to adopted and potential practices for the RDA of former mining operations, searches were performed within the following digital databases: Scielo, *Science Direct*, Infoteca maintained by Embrapa, and Dedalus. The search period was defined as the years 2000 to 2012. *Science Direct* provides access to the scientific literature in English, and the selected keywords were *recovery*, *degraded area* and *mining*. The other databases hold information on publications in Portuguese, and were accordingly searched with the keywords *recuperação* (recovery), *áreas degradadas* (degraded areas) and *mineração* (mining). The result of these searches was the identification of eight articles.



In the search for material from which to develop an assessment of possible ES that could be added to existing techniques for the RDA of former mining operations, given the current panorama of PES in Brazil, the searches described in the previous paragraph were widened. Thus, the period was extended to cover 1990 to 2012, and *mining (mineração)* was dropped from the list of keywords. The same databases were searched, and a total of 43 papers were obtained.

The next stage was the utilization of the framework developed by Bardin (2007) to conduct a content analysis of the articles, which provided a systemic ordering of the information. Content analysis is a technique which allows a systematic and objective evaluation of the content of communications, even technical articles, which is not restricted to a description of the contents, but draws inferences about the communication, seeking to identify the causes and effects of the message (MARTINS; THEÓPHILO, 2009).

The content analysis, following the precepts of Bardin (2007), was applied to the following types of articles:

a) studies that have verified the environmental benefits (services) generated by the RDA of former mining operations in Brazil (eight studies in total). The keywords of the bibliographical database searches were utilized as coding categories. The articles were subsequently submitted to qualitative analysis by means of two grouped categories created according to a semantic criterion (themes), these were techniques adopted in the RDA of former mining operations and management employed. This was followed by the inference phase of the data treatment for the categories, which permitted the identification of the associated environmental service.

b) studies that reported on the use of RDA techniques, both adopted and potential, in general RDA projects (not restricted to RDA projects for mining). The intent was the identification of a broader range of environmental benefits (services). The keywords of the bibliographical database searches were utilized as coding categories. The articles were subsequently submitted to qualitative analysis utilizing only one grouped category under a single semantic criterion (theme), which was the techniques adopted in the RDA. Thereafter, the inference step was performed for identification of the ES. Since the studies were not limited to mining, the power of the analysis was increased.

## **5. Environmental services associated with the reclamation of areas degraded by mining**

The RDA is the phase in mining activities which envisions the mitigation of and/or compensation for the negative impacts caused to the natural environment and the affected population. Therefore, it may be considered that the RDA of former mining operations can generate benefits for the environment and for society, since the RDA permits the reestablishment and/or the improvement of characteristics of the ecosystem which was degraded by the mining activities. In this context, the RDA of mining operations fits into the broader field of ES, and the RDA techniques analyzed in this section, which are principally of revegetation, have identified some ES.

A consolidation of the results of the bibliographic research on RDA for mining operations appears in Table 1, which highlights the RDA practices adopted for different mining activities, and the possible ES identified through the content analysis. Table 2 takes a broader view of RDA practices, in that it is not restricted to mining operations and the associated ES. The objective here is to highlight the applicability of this more extensive set of practices in the context of mining operations, and also to identify the ES gained through the implementation of the practices.

The results of the research lead to an appreciation of the link between RDA practices and the generation of associated ES. In Table 1, the presentation is limited to conventional RDA practices for mining operations and other productive activities, while Table 2 examines RDA techniques with the potential for the use in mining. This synthesis, in Tables 1 and 2, of the data extracted from the bibliographic research provides a starting point for a discussion of a PES scheme which might eventually be proposed for the mining sector in Brazil.

**Table 1. ES identified in RDA practices for mining operations.**

Adopted post-mining RDA technique	Management adopted to encourage restoration of ecosystem services	Mining operation responsible for degradation	Environmental services identified	Reference
Revegetation with native species	Mineral fertilization, subsoiling, and topsoil replacement	Extraction of bauxite	Increase in soil organic matter content; biological reconstitution of the soil; increased production of dry matter from green fertilization, increased nutrient turnover (nitrogen, phosphorus and potassium)	Moreira (2004)
	Planting of native species	Extraction of sand	Substrate quality improvement; facilitation of natural regeneration	Almeida (2010)
	Planting of native species	Extraction of sand	Facilitation of forest regeneration (high plant survival rate)	Knapik and Maranhão (2007)
	Natural regeneration with conservation of surrounding fragments	Extraction of gold	Attraction of disperser fauna; facilitation of secondary succession	Rodrigues, Martins and Barros (2004)
	Planting of <i>Bracatinga</i> ( <i>Mimosa scabrella</i> ), with land grading, addition of fertilizers and litter, and installation of artificial perches	Extraction of clay	Facilitation of forest regeneration (greater soil coverage by tree stands, facilitation of seed introduction from other areas, facilitation of seed dispersal, promotion of natural regeneration)	Regensburger (2004)
Revegetation with exotic commercial species	Planting of <i>Acacia mangium</i>	Extraction of bauxite	Species diversity increase of arbuscular mycorrhizal fungi in recovered substrate	Caproni <i>et al.</i> (2005)
Bioremediation	Use of rhizobacteria, producers of endospores, linked with planting of <i>Tibouchina urvilleana</i> , in an area degraded by mining waste	Extraction of coal	Reduction of soil and water contamination; facilitation of plant growth in areas contaminated by heavy metals; reduction of rhizosphere toxicity from heavy metals	Pereira and Castro-Silva (2010)
	Use of cyanobacteria	Extraction of gold	Reduction of soil and water contamination	Souza (2007)

Source: Constructed by the authors, through bibliographic research and content analysis.

**Table 2. ES associated with general RDA practices, displaying potential for implementation in RDA for mining.**

RDA technique	Identified environmental services	References
Revegetation	Increased nutrient levels and litter in the soil	Grubb (1995); Kobayashi (2004); Macedo <i>et al.</i> (2008); Jeddi and Chaieb (2012)
	Productivity restoration; erosion reduction	Parrotta (1992); Montagnini (2000);
	Biodiversity increase; acceleration of regeneration process	Guariguata, Rheingans and Montagnini (1995); Kuusipalo <i>et al.</i> (1995); Hagggar, Wightman and Fisher (1997); Keenan <i>et al.</i> (1997); Lugo (1997); Parrotta, Turnbull and Jones (1997); Powers, Hagggar and Fisher (1997); Keenan <i>et al.</i> (1999); Ashton <i>et al.</i> (2001); Carnevale and Montagnini (2002); Jeddi and Chaieb (2012)
	Diversification promotion for arbuscular mycorrhizal fungi; facilitation of ecological succession	Newsham, Fitter and Watkinson (1995); Guerrero, Rivillas and Rivera (1996); Alguacil <i>et al.</i> (2011)
	Facilitation of plant establishment; facilitation of nutrient and water absorption; protection against root pathogens (all resulting from mycorrhizal fungus diversification)	Newsham, Fitter and Watkinson (1995)
	Reestablishment of soil carbon stocks; carbon sequestration; water quality improvement	Macedo <i>et al.</i> (2008)
	Facilitation of biodiversity reconstitution; attraction of disperser fauna; facilitation of ecological succession; provision of timber for commercialization	Cusack and Montagnini (2004)
Revegetation with exotic commercial species	Facilitation of development of plant species less tolerant of adverse conditions; provision of forestry products	McNamara (2006)
	Soil condition improvements; facilitation of development of plant species less tolerant of adverse conditions	Lamb and Tomlinson (1993); Jeddi and Chaieb (2012);
	Increase/conservation of biodiversity	McNamara (2006); Jeddi and Chaieb (2012)
	Water resource protection; increased resilience to negative environmental impacts	McNamara (2006)
Bioremediation	Soil and water decontamination	Roitman, Travassos and Azevedo, (1987); Melo and Azevedo (1998); Accioly and Siqueira (2000); Pires <i>et al.</i> (2003); Sprocati <i>et al.</i> (2006); Soares and Casagrande (2007); Souza (2007)
Revegetation for community forest management	Improved production of forest resources; supply of timber and non-timber products	Kobayashi (2004); Nawir, Murniati and Rumboko (2007)

**Table 2 ES associated with general RDA practices, displaying potential for implementation in RDA for mining (continued)**

RDA technique	Identified environmental services	References
Revegetation with agroforestry systems (AFSS)	Supply of agroforestry products	Brienza Júnior, Vieira and Yared (1995); Amador (1999); Armando <i>et al.</i> (2002); Fávero, Lovo and Mendonça (2008)
	Carbon sequestration	Jose (2009); Aerts and Honnay (2011)
	Improved nutrient flux	Wadt (2003); Fávero, Lovo and Mendonça (2008); Jose (2009); Aerts and Honnay (2011)
	Improved water quality	Jose (2009); Aerts and Honnay (2011)
	Habitat provision for perturbation tolerant species; facilitation of germplasm preservation of sensitive species; facilitation of connectivity between forest remnants; pest control; plant pollination and seed dispersion; flood mitigation; soil property improvements – physical, chemical and biological; limitation of airborne particulate and odor dispersion; sound pollution reduction	Jose (2009)
Soil bioengineering	Avoiding soil erosion	Pinheiro (1971); Fernandes (2004); Galas (2006); Holanda, Rocha and Oliveira (2008)
	Reduction in quantity of water reaching the soil; reduction of positive pore pressure / elevation of suction pressure; increased soil-root cohesion	Lemes (2001)
	Development facilitation for riparian vegetation	Holanda, Rocha and Oliveira (2008)

Source: Constructed by the authors, through bibliographic research and content analysis.

## 5.1 Conventional RDA techniques in mining and their associated ES

Revegetation has been predominantly adopted for medium and large mines situated in rural zones of Brazil. The purpose has been to attenuate the visual impact of the former mine workings (BITAR, 1997) or to satisfy legal requirements for the reclamation of areas which have been mined (SANTO; SÁNCHEZ, 2002). Evans *et al.* (2013) have argued that revegetation of areas degraded by mining is a long and difficult process, that requires periodic monitoring and evaluation, to assess both progress and the appearance of intermediate ES delivered by the reclamation. Regular following of the reclamation permits adaptation of the management of the area to promote the success of the RDA program, so that lost ES are restored. Evans *et al.* (2013) cited the following list of ES as associated with the revegetation of areas degraded by mining: 1. regulation of water quality and quantity, 2. soil formation and increased infiltration capacity, 3. carbon sequestration, 4. nitrogen fixation, 5. aquatic habitat protection, 6. erosion control, 7. facilitation of increased biodiversity, 8. increased resilience, 9. food production, and 10. habitat provision for wildlife.

### Revegetation with native species

There have been studies of revegetation of mining areas with native species, such as those performed by Moreira (2004) e Almeida (2010), which have demonstrated ES

related to improvements in the physicochemical and biological conditions of the soil. Knapik and Maranhão (2007), Almeida (2010), Rodrigues, Martins and Barros (2004), and Regensburger (2004) have identified ES linked to the facilitation of land coverage by vegetation. The ES identified in these studies are listed in Table 1.

Studies which have evaluated the performance of revegetation as a measure for general RDA (not specifically for the mining sector) corroborate the findings of Table 1 concerning the identification of associated ES. Many authors have mentioned the capacity of rejuvenated vegetation to effect improvements in the physicochemical and biological properties of the soil; examples can be found in articles by Parrotta (1992), Grubb (1995), Montagnini (2000), Kobayashi (2004), Macedo *et al.* (2008), and Jeddi and Chaieb (2012).

Proof of the potential of revegetation with either native or exotic species to facilitate the development of land coverage by vegetation can be found in various studies, such as those by Kuusipalo *et al.* (1995), Guariguata, Rheingans and Montagnini (1995), Haggar, Wightman and Fisher (1997), Lugo (1997), Parrotta, Turnbull and Jones (1997), Powers, Haggar and Fisher (1997), Keenan *et al.* (1997), Keenan *et al.* (1999), Ashton *et al.* (2001), Carnevale and Montagnini (2002), and Jeddi and Chaieb (2012). Newsham, Fitter and Watkinson (1995), Guerrero, Rivillas and Rivera (1996), and Alguacil *et al.* (2011) have pointed out the importance of heterogeneity within the diversity of the plant species utilized in a revegetation program in order that ES related to the facilitation of the development of land coverage by plants are promoted.

Table 2 presents a complete listing of the ES identified through content analysis of the cited studies. Comparison of the lists of associated ES presented in Table 1 (RDA for mining) and Table 2 (general RDA) suggests that additional ES could be associated with revegetation programs for areas degraded by mining. Specific examples are the ES observed by Macedo *et al.* (2008) which are related to improvements in the quality of water resources and increases in carbon stocks, and those pointed out by Cusack and Montagnini (2004), which are linked to biodiversity and the supply of timber products.

## Revegetation with exotic commercial species

One great barrier encountered in revegetation with native species is the lack of species which are able to tolerate the adverse conditions encountered in degraded areas. An option in these instances is the use of exotic species better adapted to these hostile locations. Once these species have improved the soil conditions, the reintroduction and development of species less tolerant to the adverse conditions becomes possible (LAMB; TOMLINSON, 1993).

An example can be found in work by Caproni *et al.* (2005), where they identified ES related to improvements in the substrate conditions resulting from revegetation of an area degraded by mining with an exotic species of the leguminous acacia shrub (*Acacia mangium*). The observations made by Caproni *et al.* (2005) are consistent with an earlier study by Silva *et al.* (1994), who had found that the planting of leguminous trees in degraded areas increased the diversity of species of arbuscular mycorrhizal fungi and the number of spores from these fungi, as well as the development of ectomycorrhizal

associations with the fungi. Acting in concert, these fungus-based services assisted in the improvement of the substrate conditions.

In addition to the ES associated with the planting of acacia that are presented in Table 1, various authors have pointed out that acacia can be used to overcome the ecological and economic impasses of RDA programs, in the process generating other ES. As an example, there is the study by McNamara *et al.* (2006), which identified ES related to the facilitation of the development of land coverage by vegetation and to the supply of forestry products by means of planting the land with the acacia species *Acacia auriculiformis*. McNamara *et al.* (2006) have further highlighted that RDA techniques which associate the employment of exotic commercial species with the development of native vegetation are in addition capable of promoting ES related to water conservation, biodiversity, soil conditions, and natural resources in general. Jeddi and Chaieb (2012) have identified ES related to the improvement of biodiversity, of soil conditions, and of the development of plant cover resulting from revegetation with the species *Acacia salicina*. Table 2 also presents the ES which were identified in these studies.

It is important to point out that although implantation with monocultures of exotic species of rapid growth may be an important option in reaching some objectives of an RDA program, this monoculture technique cannot meet all the demands of plans directed to the generation of ES. Additional actions are required to deliver ES such as water course protection and biodiversity conservation (SAYER; CHOKKALINGAM; POULSON, 2004; KANOWSKI; CATTERALL; WARDELL-JOHNSON, 2005).

## Bioremediation

Landscape reshaping and soil management are necessary and indivisible steps in any RDA project for areas affected by mining. This is especially true in revegetation programs for degraded areas, where decontamination of the soil and water resources are essential steps required to guarantee the chemical stability of the area and must precede the revegetation. The preferred method of stabilizing degraded land prior to revegetation is through bioremediation.

The increase in areas contaminated by organic compounds has led to a search for efficient methods for their decontamination, with key factors in method selection being cost, time and the ease of execution of the technique (WAIHUNG, CHUA; LAM, 1999). Among the available measures, bioremediation deserves highlighting. In bioremediation, plants and microorganisms, for example bacteria and fungi, are utilized to degrade contaminants present in the soil or in subterranean water (ACCIOLY; SIQUEIRA, 2000; PIRES *et al.*, 2003; SOUZA, 2007). Even though bioremediation may not be capable of completely eliminating all contaminants, it does offer immobilization of heavy metals. This establishes bioremediation as a viable approach for the decontamination of soil and water, with the bioaccumulation of heavy metals reducing the risk of these metals entering the food chain (SPROCATI *et al.*, 2006).

Phytoremediation is one example of a bioremediation strategy, which, according to Soares and Casagrande (2007), involves the employment of plants and their associated

microbial communities in the soil, as well as management practices. Among the symbiotic relationships that exist between bacteria and plants, those involving rhizobacteria are especially important in bioremediation, for these bacteria act in the absorption and accumulation of metals (ROITMAN; TRAVASSOS; AZEVEDO, 1987; MELO and AZEVEDO, 1998).

ES identified as attributes of bioremediation from the content analysis of general RDA studies are presented in Table 2. From the studies which specifically addressed the RDA from mining, Souza (2007) and Pereira and Castro-Silva (2010) have identified that bioremediation offers ES related to improvements in soil conditions and water resource quality. Pereira and Castro-Silva (2010) have further highlighted ES related to the facilitation of land coverage by vegetation. The ES identified from the analysis of RDA studies that targeted mining are presented in Table 1.

## 5.2 Systems and techniques with potential for use in RDA for mining and their associated ES

Examination of Table 1 alongside Table 2 suggests that the studies performed to investigate the potential of revegetation in the reclamation of areas degraded by mining are insufficient, at least in regard to exploring a variety of revegetation strategies. As examples, there are two types of revegetation schemes for RDA which appear in Table 2 that could be adapted and studied for application in the mining sector: revegetation for community management and revegetation with agroforestry systems (AFSs). Revegetation for community management is distinguished from conventional revegetation by its consideration of the needs and interests of the community that it will support, a premise in schemes for the community management of natural resources (BENATTI; McGRATH; OLIVEIRA, 2003). Given the presence of trees in productive operations, agroforestry systems stand out for their ability to offer benefits in two spheres. AFSs generate commercial products and income, while at the same time they offer ES in the form of land coverage by vegetation and the maintenance of ecological functions (RIGHI, 2015). Seen from this perspective, the combination of production and ES offered by revegetation under an agroforestry system offers the best exploitation of the natural resources (BRIENZA JÚNIOR; VIEIRA; YARED, 1995).

Kobayashi (2004) and Nawir, Murniati and Rumboko (2007) have highlighted the ES generated by revegetation for community management, citing services related to the restoration of land productivity, and to the supply of timber and non-timber products; their findings are presented in Table 2. Brienza Júnior, Vieira and Yared (1995), Amador (1999), Armando *et al.* (2002), and Fávero, Lovo and Mendonça (2008) have drawn attention to the ES generated by AFSs, which are related to the supply of agroforestry products. Additional ES, related to improvements in soil conditions, have been pointed out by Fávero, Lovo and Mendonça (2008) and Jose (2009). Beyond these ES, Jose (2009) has detailed others related to increasing carbon stocks, conservation of air and water resource quality, and to the conservation of biodiversity. Wadt (2003) and Aerts and Honnay (2011) support the conclusions concerning the links between revegetation

through AFSs and some of the ES identified in the previously cited articles. Wadt (2003) and Aerts and Honnay (2011) assert that forests containing a diversity of tree species are generally more productive, and possess a greater capacity for carbon sequestration and for improving regulating services, such as those associated with water quality and nutrient flow.

In addition to revegetation, Coelho (2005) has indicated that soil bioengineering has potential as an RDA technique for mining operations. Soil bioengineering or natural engineering may be regarded as an alternative technology, which employs ecological criteria to solve problems of areas that suffer under the action of natural or anthropogenic erosion processes. In application, the technology of soil bioengineering consists of pooling living systems (plants or parts of plants) such as the roots, trunks and branches of trees with inert elements for example crushed rock, gravel, stones, timber, and concrete. Focusing on the living material, the stalks and roots of plants are used as structural and mechanical elements for the containment, protection and strengthening of the soil (FERNANDES, 2004).

According to Pinto (2009), particular advantages of soil bioengineering in RDA are the low implementation costs of the techniques and the minimal use of heavy equipment. Costs are low because the techniques favor the utilization of locally available materials, while the lack of need for the use of heavy equipment and limited disturbance of the ground permit the execution of soil bioengineering in places where access is difficult.

Pinheiro (1971), Coelho (2005), Galas (2006), Lemes (2001), and Holanda, Rocha and Oliveira (2008) have described the ES associated with soil bioengineering which are related to improvements in the soil conditions. Holanda, Rocha and Oliveira (2008) have in addition highlighted ES related to the facilitation of the development of land coverage by vegetation, which can be associated with soil bioengineering techniques. The ES identified in the studies that examined soil bioengineering as a measure in RDA are presented in Table 2.

## 6. Discussion

Table 1 may be considered an identification, based on the recent literature, of the ES offered by RDA practices which are currently applied to mining. The identified ES are related to improvements in the conditions (physical, chemical, and biological) of the soil/substrate, improvements in the quality and quantity of water resources, and the facilitation of the development of coverage of the land by vegetation.

A comparison of Table 1 with Table 2 leads to the conclusion that the ES provided by the RDA techniques applied in mining are not the totality of the ES that could be generated. A partial explanation can be found in the principal negative environmental impacts which are invariably most recognized as the consequences of mining activities. These impacts are loss of soil, loss of vegetation, pollution, and alterations in the quality and quantity of water resources. Thus, it can be understood why studies on RDA in mining are directed at the recovery of the following targets: soil environmental conditions, water resources, and land coverage by vegetation.



As can be seen by an inspection of Table 2, general studies of RDA, meaning those not specifically for the mining sector, have identified a greater range of ES associated with the adopted techniques. There is then the potential for the application of additional RDA practices in mining so that more ES can be generated. An examination of the ES offered by general RDA practices identifies that in addition to the most recognized ES, listed at the end of the previous paragraph, RDA for mining could offer ES related to the following: restoration of land productivity, facilitation of biodiversity, increasing carbon stocks, and supplying of timber and non-timber products.

The analysis performed within the present research illustrates that there are opportunities in the mining sector for RDA initiatives that will expand the range of associated ES, offering a diversification in the ES that could be provided in RDA projects for mining. Recognizing these possibilities, there are two directions open to mining companies. They could opt to recover their degraded areas using techniques that maximize the ES currently generated, inserting their reclamation projects into existing PES schemes, or they could request the creation of PES schemes specifically designed for the mining sector.

Andrade and Romeiro (2013) have examined the valuation of an ES from the viewpoint of Ecological Economics, and indicated that an essential stage in the process is the performance of an ecosystem evaluation, in which an explicit enumeration of the ES resulting from human activities is derived. Proceeding from this premise, the identification of the ES potentially associated with RDA techniques for mining is an initial, but fundamental step, for the inclusion of these ES in a PES scheme aimed at the mining sector. The objective here is to ensure that ES generated through an RDA project for mining do not become invisible. Eloy, Coudel and Toni (2013) have pointed out the ES valuation problems encountered in management practices that promote sustainable use. They explain that practices which foster non-use (for instance, the preservation of natural vegetation) are more easily related to the generation of ES than management systems that promote sustainable use. Managed systems require a more complex monitoring so that the generated ES can be identified and included in the valuation. Projecting these arguments on to RDA for mining, the importance of the identification of the possible ES generated by an RDA program becomes apparent.

Although there is a legal obligation for companies to have RDA programs, it would be possible to develop PES schemes to encourage the adoption of RDA measures which would promote ES. Financial incentives could give impetus to the use of best practices, increasing the environmental benefits rendered by reclamation and conservation programs. In this respect, the so-called legal reserves of Brazil, which is land set aside for the conservation and preservation of native fauna and flora, provide an example. According to Oliveira and Bacha (2003), in 1998 less than 10% of rural properties had registered land under the legal reserve scheme, and in general the fraction of land area of each property allocated as legal reserve was less than 10%. Based on this experience, Oliveira and Bacha (2003) concluded that it is difficult to obtain compliance with legal requirements without economic stimuli.

This need for economic stimuli to ensure the adoption of best practices is widely reflected in PES schemes already operating in Brazil. Thus, some schemes foresee remu-

neration or other support for the recovery and conservation of the legal reserve and areas designated for permanent preservation. Two examples of schemes in this category are the Socio-Environmental Development Program for Production by Rural Families (Programa de Desenvolvimento Socioambiental da Produção Familiar Rural; OLIVEIRA; ALTAFIN, 2008) and the National Program for the Recovery and Conservation of Land Coverage by Vegetation (Programa Nacional de Recuperação e Conservação da Cobertura Vegetal; BRASIL, 2008). Many schemes contemplate payments and/or support for actions linked to the conservation of permanent preservation areas, examples here include the following state-level programs: Watershed Program of the State Technical Advisory Committee (Programa Estadual de Microbacias Hidrográficas da Coordenadoria de Assistência Técnica Integral; SÃO PAULO, 1993, 1997; NEVES NETO; HESPANHOL, 2009), Green Grants (Bolsa Verde; MINAS GERAIS, 2008), Forest Remnants Program (Programa de Remanescentes Florestais; SÃO PAULO, 2009, 2010), and the State PES Program (Programa Estadual de PSA; RIO DE JANEIRO, 2011).

It should be emphasized that such PES schemes complement the obligatory command and control actions that exist for the conservation of areas that are legally protected (SANTOS *et al.*, 2012). The schemes are not the only manner in which best practices for environmental recovery are fomented, but they can act as an incentive to the adoption of best practices.

A similar line of reasoning, applied to the mining sector, serves to emphasize the potential contributions of PES programs in the encouragement of best RDA practices within the Brazilian mining sector. The findings of Teixeira (1992) and Bitar (1997) corroborate this view. Both Teixeira (1992) and Bitar (1997) found that, despite the fact that RDA by mining is a legal requirement, the obligations are not always fulfilled. Jesus and Sánchez (2013) have observed that in many cases the implementation of a reclamation plan that satisfies the criteria of the relevant environmental agency does not guarantee satisfactory reclamation.

PES schemes designed for the mining sector could encourage the mine operating companies to adopt reclamation techniques which would be more beneficial to the natural environment and to the population affected by the mining activities. Such schemes would tend to improve the image of the sector, which is commonly linked to the negative impacts generated by mining activities, and add value to their actions in the area of social responsibility. Kapelus (2002), Jenkins (2004), and Jenkins and Yakovleva (2006) have highlighted the gaining of a positive image as a paradigm which the sector should strive to attain.

The results of the present research indicate that the ES which could potentially become associated with RDA for mining operations match those contemplated in PES schemes which are currently active in Brazil and in PES schemes in the proposal phase. This reinforces a basic proposition of this article, that there are opportunities for the insertion of the mining sector into the broad context of PES in Brazil.

Although there is still a need to identify the range of ES associated with RDA for mining, there can be little doubt that the deployment of PES that cover the activities of the mining sector will be a way to extend the services beyond the current boundaries. Balvanera *et al.* (2012) have described RDA for mining as having a reductionist focus,

with a predominance of services directed at water supply and carbon mitigation. Expansion will be a sign that the PES schemes are fulfilling the conditions established by Wunder (2015) as the societal expectations from PES.

## 7. Conclusions

The current situation in Brazil presents a scenario with the potential for diversification in the ES which is offered during the reclamation phase of mining operations. The results from an analysis of the literature demonstrate the following: i) the conventional RDA practices – revegetation with native plants, revegetation with exotic plants, and bioremediation – used by the mining sector generate a variety of ES; ii) other practices which have not usually been implemented by the mining sector, such as revegetation for community forest management, revegetation under agroforestry systems, and soil bioengineering, could be adopted with the potential addition of further, relevant ES; and iii) the substantiation of the potential for a diversified offering of ES sets a framework within which to examine conjectures about the feasibility of proposals for the deployment of PES schemes for the Brazilian mining sector. A targeted PES scheme is one option for encouraging best RDA practices, another means is the insertion of the actions into programs which already exist. Indeed, there are PES schemes which remunerate actions that generate the ES, both identified and potential, associated with RDA for mining. In this context, attention should focus principally on those schemes which address ES related to soil and water conservation, biodiversity conservation, increasing carbon stocks, and conservation of natural resources.

So that PES associated with the mining sector can eventually become a reality, whether through insertion into existing schemes or by the deployment of a specific scheme, studies addressing the following are necessary:

- diversification of the reclamation techniques applied to areas degraded by mining, based upon techniques that are in general use (not limited to mining).
- evaluation of the results of reclamation techniques applied to areas degraded by mining. Immediate objectives should be the identification of the ES which are in practice generated by different techniques, and the discernment of the contexts where they will be most successful. In the longer term, these evaluations may confirm the potential for ES generation by different techniques available for the reclamation of areas degraded by mining.
- deepening of knowledge about ES related to soil and water conservation, biodiversity conservation, increasing of carbon stocks, conservation of natural resources, land productivity restoration, and the supply of timber and non-timber products. Each of these ES have the potential to become associated with RDA for mining.
- development of criteria for the designing of a PES scheme specifically for the mining sector, taking into account the characteristics of mining operations encountered in Brazil.

- development of mechanisms for the identification, monitoring and evaluation of the ES generated by the full range of current and potential reclamation techniques, recognizing the different mining contexts under which they might be applied in Brazil.

## Note

i PRAD is the acronym for *Plano de Recuperação de Áreas Degradadas* in Portuguese language.

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# ENVIRONMENTAL SERVICES ASSOCIATED WITH THE RECLAMATION OF AREAS DEGRADED BY MINING: POTENTIAL FOR PAYMENTS FOR ENVIRONMENTAL SERVICES

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**Abstract:** This paper discusses the potential of associating environmental services (ES) with techniques for reclaiming degraded areas (RDA) used in the mining sector, considering the current trends in payments for environmental services (PES) in Brazil. A literature review with content analysis generated results which identified the ES generated for eight cases of RDA in mining. As an example, ES related to soil enhancement were found. A more extended review of general RDA techniques confirmed the potential for associating other ES to RDA techniques used in mining, an example here is the enhancement of carbon stocks. Support for actions could come from existing PES schemes, particularly for cases where the ES identified as associated with an RDA technique are related to soil and water conservation. Concluding remarks indicate that there is a potential scenario for ES diversification in the reclamation stage of mining operations. A first step towards accomplishing this diversification envisages the creation of a PES scheme specific to the mining sector. Further studies are needed to develop criteria for fostering a PES scheme specifically for the reclamation phase of mining operations in Brazil.

**Keywords:** Environmental services, Reclamation of degraded areas, Mining, Payment for environmental services.

**Resumo:** O artigo discute o potencial de associação de serviços ambientais (SA) a técnicas de recuperação de áreas degradadas (RAD) por mineração, à luz da tendência atual de pagamento por serviços ambientais (PSA) no Brasil. A partir de revisão bibliográfica e análise de conteúdo, os resultados indicam que há: identificação de alguns SA para RAD por mineração – como os relacionados à melhoria do solo, potencial para agregação de

outros – como os associados ao aumento dos estoques de carbono e esquemas de PSA que remuneram os SA também identificados em RAD por mineração – como os relativos à conservação do solo e da água. Conclui-se que existe um cenário potencial de oferta diversificada de SA na fase de recuperação de empreendimentos minerários – primeiro passo para ensinar sua participação em esquemas de PSA. Estudos complementares são necessários para desenvolver critérios para um provável esquema de PSA específico para o setor minerário.

**Palavras-chave:** Serviços ambientais, Recuperação de áreas degradadas, Mineração, Pagamento por serviços ambientais.

**Resumen:** Este artículo discute el potencial de asociación de los servicios ambientales (SA) y las técnicas de recuperación de áreas degradadas (RAD) por minerías, considerando la tendencia actual de pagos por los servicios ambientales (PSA) en Brasil. A partir de la literatura y del análisis de contenido, los resultados indican que existe: identificación de algunos SA para la RAD por minerías – como los relacionados con el mejoramiento del suelo; potencial para agregar otros SA a la RAD por minerías – como los relacionados con el aumento de las reservas de carbono y esquemas de PSA que remuneran los SA también identificados en RAD por minerías – como los relativos a la conservación del suelo y el agua. La conclusión de la investigación es que existe potencial para una oferta diversificada de servicios ambientales en la fase de recuperación de minerías – primer paso para plantear un esquema de pagos por servicios ambientales. Sin embargo, son necesarios más estudios para desarrollar criterios para un probable esquema de PSA para el sector de minería brasileño.

**Palabras-clave:** Servicios ambientales, Recuperación de áreas degradadas, Minerías, Pagos por servicios ambientales.

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