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LITERATURE REVIEW

Phytostabilization of massive mine wastes with native phytogenetic resources: potential for sustainable use and conservation of the native flora in north-central Chile

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Abstract

C. Orchard, P. León-Lobos, and R. Ginocchio. 2009. Phytostabilization of massive mine wastes with native phytogenetic resources: potential for sustainable use and conservation of the native flora in north-central Chile. Cien. Inv. Agr. 36(3):329-352. The mining industry has left an important legacy of inadequately abandoned tailing storage facilities (TSFs) in the north-central area of Chile, and they may pose environmental risks. The Chilean government has recently established new regulations governing the closure of TSFs, and these regulations favor the use of environmentally sustainable technologies. Among these technologies is phytostabilization, which can use native plant species that may also have economic and/or subsistence value. Phytostabilization programs based on sustainably maintained native species could also contribute to the conservation of both local flora and regional ecosystems in north-central Chile. The main objective of this study was to use the Coquimbo Region as a case study area to look for added economic value from native plant species that have spontaneously colonized abandoned TSFs and to look for other species that, given their ecological characteristics, may be established on post-operational TSFs by phytostabilization. A review of technical, scientific and ethnobotanic literature on traditional uses and recently discovered uses of selected plant species was performed. The results showed that 68 spontaneously colonizing phytostabilization species have at least one known use, while 420 species with potential for use in phytostabilization (28% of the regional native flora) have various uses. Ornamentation, cattle forage, mellipherous, medicine, crafts and phytochemicals are the main uses identified for the local native flora. Most of the identified species are endemic to Chile (69%). These species are therefore a very valuable phytogenetic resource that can be used in the rehabilitation of massive mine wastes. This unique resource could be lost if these species are not identified and studied in the near future.

Key words: Mine tailings, mining, natural resources, rehabilitation, sustainable management, valuation of natural resources.

Introduction

Mining is an important industrial activity for the Chilean economy, but it poses risks for the environment, the silvoagropecuarian sector and human health, resulting mainly from the production of massive quantities of solid waste. Mining operations may affect water, soil, air, topography, flora and fauna, and they range from small modifications to large ecosystemic degradations (Bell, 1999; Sánchez, 2002; Ginocchio, 2004; Martin and Ruby, 2004). The current growing world demand for metals and the consequent

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loss of biodiversity are threatening the continuity of the ecosystems that we all depend on, especially the poorest rural communities (ICMM, 2006).

The mining industry has had a considerable impact during the 19th century in Norte Chico, Chile. The copper industry consumed huge amounts of firewood in furnaces and thereby set in motion a sustained process of vegetative decay that changed the local landscape irreversibly (Folchi, 2001; Brown *et al.* 2003). Moreover, from 1938 until 1975 the tailings from the Potrerillos mine (III Region of Atacama) were released into Río Salado and the Chañaral Bay. This resulted in the accumulation of tailings more than 10 meters thick covering a surface of around 4 km^2 and the displacement of the coastline by approximately 1 km. Since then, the zone has been exposed, and eolic transportation of the contaminating material has occurred, resulting in one of the most serious cases of contamination in the Pacific Ocean (Dold, 2007).

Among the residuals generated by the mining activity, the tailings represent 50% of the solid waste of the extractive process, and they are responsible for most of the environmental problems generated by mining activities in Chile (Espinoza *et al.*, 1991; López *et al.*, 2003). From 1970, tailings have been compulsorily accrued in artificial dams where suspended solids precipitate, as expressed in the Supreme Decree Nº 86 of the Ministry of Mining of Chile (Rubio, 2007). However, the lack of environmental legislation concerning the post-operations stage of tailing deposits resulted in the inappropriate neglect of a large number of deposits in the semiarid north-central zone of the country (Ginocchio, 2004). Once the tailing dams reach the end of their service life, they begin to dehydrate due to the semiarid Mediterranean climate conditions predominant in central Chile, and this exposes the fine particles to dispersion agents such as wind and rain. Additionally, they may react with water and oxygen to generate acid drainage and metal lixiviation, thereby contaminating nearby water courses and soils (Goodman, 1974; Bell, 1999; Santibáñez, 2006). Nevertheless, the current regulations are intended to rehabilitate the area (Ministry of Mining, 2004, 2007). In addition to highlighting the use of environmentally sustainable technologies, these regulations prevent the dispersion of metals and toxic metalloids into the environment by demanding that mining operations be closed in such a way that tailing deposits are stabilized before they are abandoned.

The rehabilitation of areas degraded by mining has been implemented in various developed countries as an important instrument of public politics in the environmental area. For example, in the United States, France, Italy, Russia, and Canada, the rehabilitation of areas degraded by mining activities is compulsory, and methodologies where environmental stability and sustainability is effectively guaranteed are favored. In the case of South America, mandatory rehabilitation has been increasingly considered in the legal regulations of countries such as Chile, Brazil, Argentina, Peru, Colombia and Uruguay. Even though such legislation is not a public priority in most countries, the inclusion of degraded area rehabilitation among the instruments of environmental management applicable to the mining industry has been growing due to international standardization of environmental regulations in the business sector (International Organization for Standardization, ISO) (Yazbek, 2002).

Among the emerging technologies for the rehabilitation of degraded areas, phytostabilization has proven to be an efficient, environmentally appropriate and relatively low cost approach (Berti and Cunningham, 2000; Petrisor *et al.*, 2004). In relation to mining wastes, phytostabilization consists of setting out metallophyte plants, applying appropriate substrate amendments. Plants that can tolerate the high metal concentrations of the substrate are part of a program of ecological rehabilitation that physically, chemically and biologically stabilizes the substrate and the tailings' toxicity. This technology reduces metal dispersion in the environment, reduces the metal bioavailability for living beings, and returns the substrate to an acceptable ecological condition for diverse future uses (Berti and Cunningham, 2000; Dietz and Schnoor, 2001; Martin and Ruby, 2004; Ginocchio and León-Lobos, 2007). Unlike other existing methods, phytostabilization may be applied over larger areas and presents a favorable cost-benefit ratio. This ratio may be further improved by using metallophyte plants with other uses (added value), which could also benefit the economic development of local communities (Ginocchio, 2004; Petrisor *et al.*, 2004; SONAMI, 2006).

Using native/endemic plants that are adapted to the climatic, geographical and metallogenic conditions of the zone could add value to phytostabilization programs and place this technology ahead of other existing technologies. Many of the native and endemic vegetal species of north central Chile have been traditionally used to meet the needs of rural communities. Local plant species serve as foods, medicines and construction materials, among other things, and they constitute a biological heritage that is strategically situated for rural economical development (Montenegro, 2000; León-Lobos *et al.*, 2007). However, most of these resources are almost unknown and they have not been used at productive scales. Assessment of the Chilean flora, whether by its intrinsic biological value or by the benefit that it may provide, will contribute to its conservation. Just as the sustainable management of wild fauna has promoted the survival of these species, the sustainable management of wild flora may promote the conservation of species of interest and the biological communities they belong to (Primack *et al.*, 2001). Sustainable management that conserves biodiversity can also address economic and subsistence needs. The sustainable use of biodiversity and conservation based on the community (acknowledging the importance of involving the local communities in the conservation schemes) are two contemporaneous conservation tools that are intended to include the socio-economical development of local communities and their direct participation in the politics of wildlife conservation (Campbell, 2000).

In addition to alleviating the impacts generated by mining wastes, the use of vegetal native/endemic species in phytostabilization programs would promote conservation of the flora and ecosystems of north-central Chile (Whiting *et al.*, 2004) through the incorporation of native and endemic species, especially those that are vulnerable or endangered. Therefore, ecological rehabilitation is expected to make an important contribution to biodiversity conservation (Dobson *et al.*, 1997; Young, 2000). Good practices, collaboration among the different sectors involved and innovative thinking should contribute to biodiversity conservation, ensure responsible mining production and minimize the conflicts of interest (IUCN and ICMM, 2004).

In this context, the objective of this study was to identify (through a bibliographical review) native vegetal species of the Region of Coquimbo that could be used in the phytostabilization of post-operative mining tailing deposits, with the goal of promoting this technology over other existing technologies. Although the native flora of the Region of Coquimbo represents a study case, most of the species identified have a distribution range covering other regions of the country where the stabilization of mining tailing deposits is also an urgent need; therefore, the application of this study could be extended to north-central Chile. In addition, the importance of including native/endemic species that may provide added value to the phytostabilization programs for the conservation of the native flora is still under discussion.

Rehabilitation of tailing storage facilities in the Region of Coquimbo through phytostabilization

Metallic mining has consistently contributed to the economic growth of the Region of Coquimbo, Chile, which, since the beginning, has maintained constant production levels. Currently it accounts for 23% of the gross domestic product (GDP) and 80% of regional exports, with copper and iron the most relevant metals (INE, 2008). Villages completely involved in mining, like Andacollo, have historically maintained whole populations deeply linked to the extraction and processing of minerals (Brown *et al.*, 2003). However, the large volume of past and current wastes generated by this industry has resulted in a legacy of around 360 tailing storage facilities distributed throughout the region. Fully 98% of these are located in the coastal strip, in the mid-elevation mountain area and transverse valleys (SERNAGEOMIN, 1990), which coincides with areas of human occupation. Due to the proximity of important agricultural, cattle, residential and ecological sectors to tailing deposits in the Region of Coquimbo, and how disastrous contamination of the scarce water resources would be, it is essential that the tailing deposits present in the region be stabilized effectively in the short and in the long term to protect the substrate from water and eolic erosion that carries toxic material. It is also important to develop natural environmentally sustainable systems that allow the recolonization of native species and that can serve as shelter for the fauna (Vega, 1999).

The various techniques used in tailing stabilization are intended to mitigate either the environmental or visual impacts, and some techniques are more efficient than others. For example, some mining companies in Brazil have responded to the demands for environmental mitigation of waste deposits and exploited areas with reforestation programs based on a few fast-growing exotic species. Specifically, the use of eucalyptus (*Eucalyptus spp*) has been promoted, even though long-term studies have shown that these programs would provoke a successional block due to the negative allelopathic effects of these vegetal species that reduce biodiversity in comparison with natural regeneration or replanting with native species (Primack and Massardo, 2001). This situation is not unknown in Chile, where rehabilitation based on the transplantation of exotic trees such as Australian eucalyptus and acacias have been used as the main tool for stabilizing the massive mining residues in the closure stage. However, the traditional method of forestation has not proven to be a long-term sustainable mechanism that ensures the physical and chemical stabilization of the residues and the integral functionality of the ecosystem. The constant addition of chemical fertilizers is necessary to ensure tree growth. Additionally, the environmental impacts have even been magnified via the mobilization of metals and metalloids through the food chain (Ginocchio, 2004).

Among the technologies used by industrialized countries to treat substrate enriched with metals are: 1) the excavation and disposal of dangerous wastes in landfills; 2) the retaining alternatives (such as cementing and vitrification); 3) chemical extraction; and 4) electrokinetics (Glass, 2000; Martin and Ruby, 2004). However, these techniques are extremely expensive, environmentally invasive and they result in a substrate altered in its physical, chemical and biological properties. These techniques further restrict the usefulness of the substrate, and furthermore, they are generally disapproved of by the local community (Ginocchio and León-Lobos, 2007). The need to apply these treatments may be avoided if the original soil has been removed before the mining activities and is used to recover the degraded area, as is required for surface mining in many developed countries (Dobson *et al*., 1997).

Alternatively, phytostabilization is a technology that reduces the risk of contamination caused by deposits of massive mining wastes by including plants able to tolerate the high concentrations of metals and the appropriate substrate amendments. By this technology, the bioavailable metals are precipitated, absorbed and/or adsorbed by the materials added to the substrate, by plant roots and by microorganisms, where they accrue in innocuous forms (Berti and Cunningham, 2000; Dietz and Schnoor, 2001; Ginocchio and León-Lobos, 2007). The implementation of a radicular system and a vegetal cover on the substrate also allows its physical stabilization, and this hinders the eolic/water dispersion of the particulated material rich in metals towards nearby water courses and soils. In addition, it helps to control the oxygen diffusion and the water percolating through tailings, as it creates a demand by plants, reducing the risk of acid drainage and metal lixiviation (Miller, 1996; Berti and Cunningham, 2000; Martin and Ruby, 2004; Santibáñez, 2006). This technology helps to accelerate the processes of vegetal repopulation (succession) that normally occur in terms of hundreds or thousand of years. Therefore, it accelerates the rebuilding of a natural autosustainable functional system that is integrated to the rest of the environment (Piha *et al*., 1995).

In addition to being tolerant of high concentrations of metals, the plants chosen for phytostabilization should be deficient in their translocation towards aerial tissues. This excluder metallophyte plants avoids the introduction of contaminants into local food chains that could have toxic effects on other living beings (Berti and

Cunningham, 2000; Ginocchio, 2004). Normal levels of metals in aerial vegetal tissues reduce the need to treat harvested structures as dangerous wastes, which reduces costs and simplifies program management (Miller, 1996; Prasad and Freitas, 2003). In addition, the plants should tolerate other adverse conditions presented by tailing deposits, such as scarce nutrients, salinity and the lack of substrate structure, among other things. The plants should be easily set and cared for, fast-growing, and able to develop a dense radicular system so as to generate vegetation cover as fast as possible (Berti and Cunningham, 2000).

Phytostabilization programs developed in Europe and the United States have preferred the use of native/endemic metallophyte plants adapted to the local conditions over exotic species. Exotic species are often invading species that alter the dynamics of wild biological communities and/or agriculture near the work site, and they are not always appropriate to the climatic and geographical conditions of the site, which may increase maintenance costs in the long term (Ginocchio, 2004; Conesa *et al.,* 2007; Mahmud *et al.,* 2008). Metallophyte species are typically endemic to their metallic native areas; therefore, considering that the mineralized substrates where these species develop are the material of interest, they are susceptible to high rates of population decline and even extinction (Whiting *et al*., 2004).

Although the vegetation that spontaneously colonizes mining zones has been studied in other arid and semiarid regions of the world (Conesa *et al*., 2007), knowledge of the metallophyte species of north-central Chile is virtually nonexistent. This lack of knowledge contrasts with the potential richness of metallophyte species in an area where the native and endemic Mediterranean flora have developed naturally and evolved for millions of years in the presence of numerous mineral deposits (Ginocchio and Baker, 2004). However, recent investigations in the Region of Coquimbo have identified vegetal species able to spontaneously colonize abandoned tailing deposits as well as species tolerant to high copper concentrations (Ginocchio *et al*., 2007). On the other hand, it is possible that other species present in the region are also appropriate for planting on mining tailings in the context of phytostabilization technology. Some species have seed dispersion mechanisms that could be hindering their colonization of abandoned tailing dams, which may be currently limited to species dispersed by wind. Birds or other animals scattering seeds probably have avoided these dams due to the lack of 'hangers' to land on or to the inhospitable conditions that these dams sustain. Additionally, even if the seeds reach the tailings, the environmental conditions could inhibit germination.

The Region of Coquimbo harbors the richest collection of vascular plants in the country (Squeo *et al*., 2001a). Among these local plants, many might be appropriate for inclusion in phytostabilization programs for abandoned post-operative tailing storage facilities of the region, including plants with the correct ecological features, the correct adaptability patterns (tolerance to high solar radiation, scarce water and limited nutritional resources) and plants phylogenetically related to metallophyte species from other arid regions of the world (i.e., belonging to the same family or genus). Therefore, the species spontaneously colonizing tailing deposits and the species potentially usable in phytostabilization programs represent valuable phytogenetic resources for the rehabilitation of massive mining wastes, and they could offer productive and support uses, thereby fostering the conservation of these species and the local ecosystems.

Native flora of the Region of Coquimbo: Diversity, state of conservation and alternative uses

Located in the transitional zone between the semiarid Mediterranean region and the desert areas to the north, the Region of Coquimbo gathers a wide range of biogeographical elements, including numerous genera that have experienced significant developmental radiations, as well as relict communities containing species more typical of the temperate southern forests. On the other hand, many species in the region are at their latitudinal limit of distribution; 628 species reach their northern distribution limit in the region while 288 species reach their southern limit (as a whole, 62% of the native regional species). This phenomenon may be explained by the transitional environmental conditions, which are characterized by a semiarid Mediterranean type climate. The wide range of biogeographical elements present is consistent with the high level of regional endemism and the presence of many species susceptible to habitat reduction (Squeo and Arroyo, 2001). Central Chile has been included within the 25 "World Biodiversity Hotspots for Conservation Priority" due to the concentration of endemic species and their exposure to high threat levels (Myers *et al*., 2000). Within this area of high biodiversity, the Region de Coquimbo represents the northern limit.

The native and naturalized flora inhabiting the Region of Coquimbo is composed of 1,727 species, 1,478 of which are native to Chile and 140 are endemic to the region (Marticorena *et al*., 2001). The hemicryptophyte species are predominant in the native regional flora, followed by the phanerophyte species. Fifty percent of the native species of the region belong to only 9 families: Asteraceae (277 species), Poaceae (104), Fabaceae (96), Brassicaceae (50), Apiaceae (43), Boraginaceae (42), Portulacaceae (42), Scrophulariaceae, (42) and Solanaceae (40) (Squeo *et al*. 2001a).

According to the state of conservation categories of the "Red Book of Native Flora and Priority Sites for Conservation: Region of Coquimbo" (Squeo *et al.,* 2001b), 14% of the native flora are found in the Endangered (36 species) or Vulnerable (171 species) categories. However, the proportion of species in these categories could increase as more becomes known about the species in the categories Insufficiently Known and Non-Evaluated. It is noteworthy that there are 127 species (8.6% of the native regional flora) in the category Insufficiently Known (Extinct), as these species are under suspicion of being extinct. Considering that there are 23 endemic species of the region that are unregistered in the last 50 years, in spite of being one of the regions with a great number of collections in Chile, the number of species currently extinct in the Region of Coquimbo could reach 25, which is almost 18% of the endemic flora of the region (Squeo *et al.,* 2001b).

Among the main factors explaining the current state of degradation of the native vegetation are the mining activity of the 19th century (which overexploited the vegetal cover to feed the furnaces), agropecuarian activity, urban expansion and the displacement of the native vegetation by exotic species (Folchi, 2001; Jorquera, 2001; Brown *et al*., 2003). On the other hand, the human agricultural communities occupying the rural areas of the region have caused significant damage to the ecosystems. These damages include overgrazing (especially from goats), dryland cultivation of steep slopes, and high rates of firewood and vegetal coal consumption as fuel (Brown *et al*., 2003). This unplanned use of the natural resources causes a reduction in the vegetal cover, which partly explains the decay present in the scenery and the degree of desertification in the region (Lyon, 1991; Novoa and López, 2001). The non-existent communication between these communities facing precarious subsistence conditions and the rest of the country, or even within the same region, is a block to overcoming the problems that these communities are facing. In this context, the generation of environmentally sustainable activities that provide economic benefits is fundamental (Bustamante, 1994).

In addition to providing numerous ecosystemic services and helping to strengthen and expand local economies, biodiversity provides a variety of goods that human beings depend on. Such goods include foods, medicines, fibers, wood, valuable species in floriculture and horticulture, raw materials for numerous industries of economic importance such as the pharmaceutical and textile industries, among others. The flora and fauna species of a region, in turn, impact their ecosystems, in part by determining the very characteristic and frequently unique landscapes, which becomes relevant in economies supported by conventional tourism and ecotourism, as in the case of Chile (Squeo and Arroyo, 2001).

It is possible to confirm that most of the vernacular names of the plants in north and north-central Chile refer to the natural attributes of the species, including the plant's use. The forage value of several species is illustrated in names such as "paja vizcachera" (vizcacha hay) and "pasto de cabra" (goat grass). Medicinal value is expressed in names referring to their properties, such as "pingopingo" (healthy). Other uses are expressed in names such as "candela" or "keri," referring to fuel properties and "paja alma," a ritual plant used in the separation of souls and linked with funeral ceremonies (Romo *et al.*, 1999).

Diverse uses have been traditionally assigned to the native flora of the Region of Coquimbo, where the main beneficiaries are the local communities. For the first American inhabitants of desert and semidesertic zones, cactaceae played an important role in sustenance and in the cultural manifestations of nomadic tribes. They were used as food, drink, medicine, raw material for house construction, elaboration of rustic clothing items (shawls), and the making of hunting and fishing weapons as well as other tools. Cactaceae species acquired such importance that in some cultures they became deities. The use of different parts of cactaceae, living or dead, is scarce in the Region of Coquimbo; they are mostly used for crafts, construction of living fences, firewood and food for cattle (Bustamante, 1996). In the case of chaguales (*Puya spp*), their dry floral stems were used in light construction, such as roof and wall coating. Chaguales is also used by fishermen to fabricate net floaters (cardones). In addition, ropes can be made with their fibers (Riedemann *et al.*, 2006).

In addition to these traditional uses, numerous changing industries and markets are now generating new demand for products found in the Chilean flora, both directly and indirectly. This is the case for tara (*Caesalpinia spinosa* Kuntze), which is a legume from which hydrocolloids and tannins are extracted for use in the food, pharmaceutical and cosmetic industries, among others (Pastor *et al.* 1997). Sesquiterpenes with anticarcinogenic activity against lymphocytic leukemia and human nasopharyngeal carcinoma (Silva and Bittner, 1992) have been identified in mitique (*Podanthus ovatifolius* Lag.), which is a medicinal plant whose aromatic infusion is recommended for gonorrhea and urinary tract infections (Wilhelm de Mösbach, 1992). The country has phytogenetic resources of high strategic value in terms of competitiveness and potential for development of new products. Regardless of the above-mentioned uses, the native flora of Chile has still not been systematically searched for bioactive compounds, although it is widely used by local and indigenous communities (León-Lobos *et al.*, 2007).

The species native to the Region of Coquimbo may be used to satisfy various human needs, and they represent a strategic biological resource for the benefit and development of the local communities. However, the number of plants currently used is a small percentage of the total number of known species used in the past. Lack of awareness of the economic and ecological potential of native plants, along with a lack of scientific and technical information, explains why inquires on their cultivation have not been conducted (Lyon, 1991; Montenegro, 2000). Therefore, planting native vegetal species with alternative uses as a component of the rehabilitation of mining tailings could generate a new business for the local communities. Such a business based on non-traditional cultivation of Chilean metallophyte species could benefit and reward small rural villages that have been affected by mining activities while contributing to the sustainability of local mining and the conservation of the native flora.

Native flora of the Region of Coquimbo with potential for phytostabilization programs and alternative uses

Through a review of the scientific, technical and ethnobotanical literature on the uses traditionally given and possibly given to the native species of the Region of Coquimbo, potential uses of the species spontaneously colonizing deposits of abandoned tailings and of species that, due to their ecological features, might establish and grow in deposits of conditioned tailings through the phytostabilization technology were identified.

Among the 73 native species of the region found colonizing deposits of mining tailings (Ginocchio *et al.*, 2007), 68 (93%) have at least one use described (Table 1), with the main uses being ornamental, forage, medicinal, mellipherous, and chemical (Figure 1). Many of these species have more than one use described for them, with up to nine potential uses as in the case of *Echinopsis chiloensis* Friedrich et G.D. Rowley, a columnar endemic cactacea of Chile. Among these native tailing deposits colonizing species presenting some additional benefit, the family Asteraceae is the most represented, with 21 species. The most frequent lifestyles are phanerophyte (with 41 species, 11 trees), followed by hemicryptophyte (11 species) and chamaephyte (10 species).

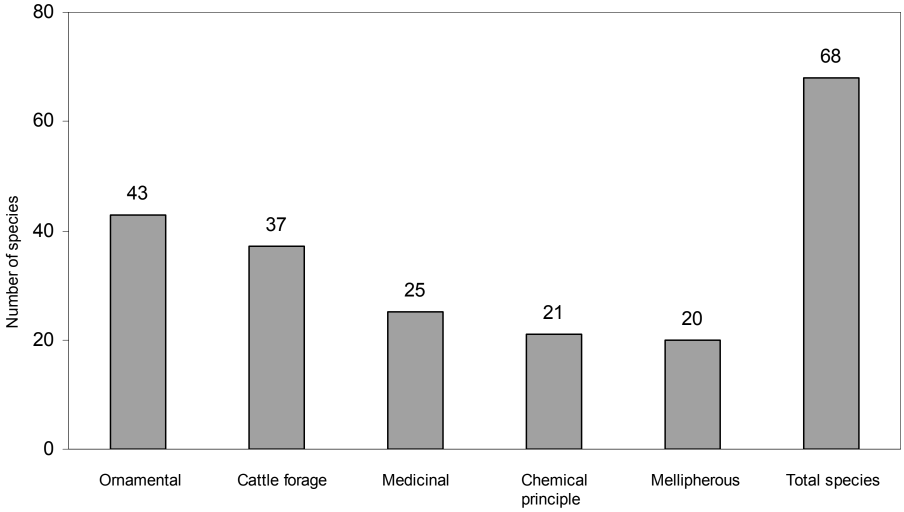

Figure 1. Number of native species of the Coquimbo Region, Chile identified as spontaneous colonizers of abandoned tailing storage facilities and their main uses. Species may have more than one known use. Uses as follow: Alimentary, some of their structures has the property to feed the human; Cattle forage, some of their structures has the property to feed cattle; Medicinal, some of their structures has the power to mitigate a disease in human; Phytochemical, having a substance or active ingredient that alters or modifies the functioning of organs and systems of the human body, which, in turn, can have a medicinal value; Timber/construction, provides raw materials, mainly wood, to build facilities of various kinds, including homes, warehouses or hut; Fuel, used to produce energy as heat, in this case usually wood or coal used to generate heat; Crafts, supply raw materials (fiber, wood, pigments, seeds) for the development works (baskets, hats, figures, etc.) with little intervention of machinery; Soil conservation, its establishment enables the protection of soil resources against physical, chemical and biological degradation; Mellipherous, flora as source of nectar and pollen to *Apis melliphera* (honeybee); Ornamental, species with the potential to be cultivated for their beauty or their incorporation into green areas.

A search of literature regarding the native flora of the Region of Coquimbo identified 420 species (28% of the native regional flora) with potential for use in mining tailing phytostabilization programs that could provide an additional benefit considering their possible anthropic uses (Table 2). The criteria used to select these vegetal species were their general ecological features, their patterns of adaptability and their relation with other species (such as belonging to the same family). Among the patterns of adaptability, the ability to tolerate high radiation, scarce water and limited nutritional resources were considered. Among the main uses identified for these species are ornamental, mellipherous, forage, medicinal, chemical and artisanal (Figure 2). Although 62% of these species have only one use described for them, others have been identified with more than one use, even reaching nine potential uses as in the case of *Puya chilensis* Molina, an endemic bromeliaceous of Chile. The main families composing this group of species are: Asteraceae (65 species), Cactaceae (30 species), Scrophulariaceae (29 species) and Fabaceae (28 species). On the other hand, the most numerous lifestyle corresponds to phanerophyte (159 species from which 17 correspond to trees), followed by hemicryptophyte (83 species) and chamaephyte (63 species).

Ornamental value, which was identified as the main use in both groups of species, may be es-

Table 1. Native plant species of the Coquimbo Region, Chile spontaneously colonizing tailing storage facilities and their uses.

Scientific name	Family	Origin[1]	Conservation status[2]	Uses[3]
Acacia caven	Mimosaceae	N	FP	2,3,4,5,6,7,9,10
Adesmia argentea	Papilionaceae	E	FP	2,8,9,10
Adesmia confusa	Papilionaceae	E	IC (V?)	2,9
Adesmia microphylla	Papilionaceae	E	FP	2,9
Atriplex repanda	Chenopodiaceae	E	FP	2
Baccharis linearis	Asteraceae	N	FP	2,4,8,10
Baccharis marginalis	Asteraceae	E	FP	3,4,9
Baccharis pingraea	Asteraceae	N	FP	3,4,9
Bromus berterianus	Poaceae	N	FP	1,2
Bromus catharticus	Poaceae	N	FP	1,2,3
Carpobrotus aequilaterus	Aizoaceae	N	V	1,3,10
Cestrum parqui	Solanaceae	N	FP	3,4,6,7
Chenopodium ambrosioides	Chenopodiaceae	N	FP	2,3,4,7
Chorizanthe glabrescens	Polygonaceae	E	IC (E?)	7
Cistanthe arenaria	Portulacaceae	N	FP	10
Cordia decandra	Boraginaceae	E	FP	1,2,4,6,7,9,10
Cortaderia rudiuscula	Poaceae	N	IC (V?)	10
Cristaria glaucophylla	Malvaceae	E	FP	2,10
Distichlis spicata	Poaceae	N	FP	2,3
Echinopsis chiloensis	Cactaceae	E	FP	1,2,3,4,5,6,7,9,10
Encelia canescens	Asteraceae	N	FP	2,9,10
Ephedra gracilis	Ephedraceae	E	FP	3,4,10
Equisetum bogotense	Equisetaceae	N	FP	3,4,7,10
Equisetum giganteum	Equisetaceae	N	FP	3,10
Frankenia chilensis	Frankeniaceae	N	FP	2,10
Gymnophyton robustum	Umbelliferae	E	FP	10
Haplopappus angustifolius	Asteraceae	E	FP	2,3
Haplopappus bezanillanus	Asteraceae	E	V	2
Haplopappus cerberoanus	Asteraceae	E	FP	2
Haplopappus chrysanthemifolius	Asteraceae	E	V	2
Haplopappus macraeanus	Asteraceae	E	IC (E?)	2
Haplopappus parvifolius	Asteraceae	E	FP	2
Haplopappus reticulatus	Asteraceae	E	FP	2
Haplopappus saxatilis	Asteraceae	E	IC (FP?)	2
Heliotropium stenophyllum	Boraginaceae	E	FP	2,4,10
Lithrea caustica	Anacardiaceae	E	FP	1,3,4,6,7,8,9
Lycium chilense	Solanaceae	N	FP	10
Malesherbia linearifolia	Malesherbiaceae	E	FP	10
Maytenus boaria	Celastraceae	N	V	1,2,3,4,5,7,9,10
Mentzelia albescens	Loaseceae	N	FP	10
Muehlenbeckia hastulata	Polygonaceae	N	FP	1,2,3,7,9,10
Nolana albescens	Nolanaceae	E	IC (V?)	10
Nolana crassulifolia	Nolanaceae	E	FP	10
Nolana sedifolia	Nolanaceae	E	FP	10
Ophryosporus paradoxus	Asteraceae	E	FP	10
Ophryosporus triangularis	Asteraceae	E	FP	10
Otholobium glandulosum	Papilionaceae	N	FP	1,10
Plantago hispidula	Plantaginaceae	E	FP	2
Pleocarphus revolutus	Asteraceae	E	FP	3,4,10
Polypogon australis	Poaceae	N	FP	2
Prosopis chilensis	Mimosaceae	N	V	1,2,5,6,7,8,9,10
Proustia ilicifolia	Asteraceae	E	FP	3,4,5,8,10
Quillaja saponaria	Rosaceae	E	V	3,4,5,9,10
Salix humboldtiana	Salicaceae	N	FP	2,3,7,10
Sarcocornia fruticosa	Chenopodiaceae	N	FP	10
Schinus latifolia	Anacardiaceae	E	FP	1,2,3,4,5,7,9,10
Schinus molle	Anacardiaceae	N	FP	3,4,5,6,7,10
Schinus polygama	Anacardiaceae	N	FP	1,2,3,4,5,7,10
Scirpus asper	Cyperaceae	N	FP	2,5,7
Scirpus pungens	Cyperaceae	N	V	2
Senecio adenotrichius	Asteraceae	E	FP	9,10
Senecio bridgesii	Asteraceae	E	FP	9,10
Senecio cerberoanus	Asteraceae	E	V	9,10
Senecio murinus	Asteraceae	E	FP	9,10
Senna cumingii	Caesalpiniaceae	E	FP	2,7,9,10
Solanum pinnatum	Solanaceae	E	FP	4,10
Tessaria absinthioides	Asteraceae	N	FP	1,2,3,4,5,10
Typha angustifolia	Typhaceae	N	FP	2,3,5,7

[1] E, endemic to Chile, N: native to Chile.

[2] FP, out of danger, IC(E?): insufficiently known (extinct?), IC(FP?): insufficiently known (out of danger?), IC(V?): insufficiently known (vulnerable?), V: vulnerable

[3] 1: alimentary, 2: cattle forage, 3: medicinal, 4: phytochemical, 5: timber/construction, 6: fuel, 7: crafts, 8: soil conservation, 9: mellipherous, 10: ornamental.

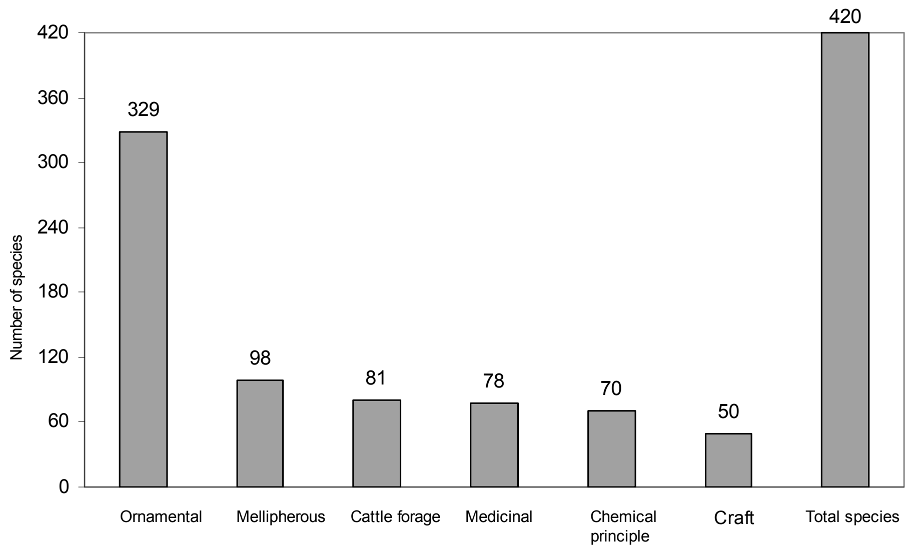

Figure 2. Number of native species of the Coquimbo Region, Chile, with potential for use in tailing storage facility phytostabilization projects according to their known primary uses. Species may have more than one known use. Uses as follow: Alimentary, some of their structures has the property to feed the human; Cattle forage, some of their structures has the property to feed cattle; Medicinal, some of their structures has the power to mitigate a disease in human; Phytochemical, having a substance or active ingredient that alters or modifies the functioning of organs and systems of the human body, which, in turn, can have a medicinal value; Timber/construction, provides raw materials, mainly wood, to build facilities of various kinds, including homes, warehouses or hut; Fuel, used to produce energy as heat, in this case usually wood or coal used to generate heat; Crafts, supply raw materials (fiber, wood, pigments, seeds) for the development works (baskets, hats, figures, etc.) with little intervention of machinery; Soil conservation, its establishment enables the protection of soil resources against physical, chemical and biological degradation; Mellipherous, flora as source of nectar and pollen to *Apis melliphera* (honeybee); Ornamental, species with the potential to be cultivated for their beauty or their incorporation into green areas.

timated when these species are cultivated for commercial purposes or are incorporated into projects of public and private spaces. Species of ornamental value could certainly embellish the vegetal community developing on mining tailing deposits, but if the landscape esthetics are not valued, this would be useless, unless the individuals are transplanted to places where they are really appreciated, which would damage the stabilization of the mentioned substrate. On the other hand, for many of the species identified with an ornamental use, this relates to their flowering. It is noteworthy that the plants growing in adverse conditions possibly do not flower due to the high concentrations of metals and the lack of essential nutrients for the development of reproductive structures. Excluding ornamental use as an additional benefit, the number native species found spontaneously colonizing abandoned tailing storage facilities with some additional use is 56, or 77% of the registered species. On the other hand, the number of native species not growing in tailing deposits but (due to their ecological aspects) potentially usable in phytostabilization programs that present interesting additional uses is 237, or 16% of the native regional flora.

Among the uses identified, some of these demand direct intake of vegetal structures by human beings or animals, as with food, medicine and forage. Bearing in mind that the species growing in deposits of mining tailings could mobilize metals towards aerial structures to be consumed, thereby generating toxic effects on other living beings and introducing contaminants into the food chain (Berti and Cunningham, 2000; Ginocchio, 2004), it is essential that the vertical movement of metals in the species to be included in phytostabilization programs be evaluated. This consideration is also applicable in the case of the mellipherous use, considering that nectar may be a way for metals to enter the beehive, and therefore a source of honey contamination (Fernández *et al.*, 1994).

Special attention was paid to species described in the reviewed literature as relevant to soil conservation as that could grow on degraded terrains and help retain soil. In total, 28 species have been identified for replanting degraded terrains, mainly phanerophytes. For example, cactaceae are an excellent means of soil protection due to their wide and superficial radical systems, their adaptability to thin and degraded soils, and their resistance to climatic factors (Bustamante, 1996). On the other hand, species belonging to the Fabales order are also noteworthy because of their ability to fix atmospheric nitrogen through a symbiosis with bacteria of the genus *Rhizobium*. Among the species found colonizing deposits of mining tailings with additional uses, three species of the order Fabales are found (one of the Caesalpiniaceae family and two of the Mimosaceae family; Table 1). Among the species with potential for phytostabilization and with uses described in the literature, 35 species of the Fabales order are found (four of the Caesalpiniaceae family, 28 of the Fabaceae family and three of the Mimosaceae family; Table 2). Due to scarce nitrogen in tailings, these species could be crucial to the generation of functional and autosustainable ecosystems for the phytostabilization of post-operative tailing deposits. It is noteworthy that species belonging to the genera *Acacia* and *Prosopis* have been reported to be successful colonizers of mining tailings in the western United States (Mendez and Maier, 2008).

As in the case of species spontaneously colonizing abandoned tailing deposits, among the species with potential for phytostabilization programs and with identified uses, the family Asteraceae is the most represented. Coincidently, this family is the most numerous in the native flora of the Region of Coquimbo. Therefore, it is impossible to infer that the Asteraceae family gathers species that are more rustic, plastic or tolerant to metals, nor that the species of this family are the most used.

On the other hand, in both groups of species (species found on tailings and species with potential for phytostabilization programs), phanerophytes are the most represented life form. This fact becomes relevant when considering which tree and bush-like species could simplify the management of an ecological rehabilitation site, as these are perennial species not requiring annual germination like terophyte species. It is not impossible that species able to grow in managed mining tailings could not generate viable seeds, or that germination is hindered when facing adverse tailing conditions. In any case, planting other life forms, which is essential in successional processes, represents a fundamental aspect of successful phytostabilization of post-operative tailing deposits.

Among the native species spontaneously colonizing tailing deposits presenting some additional benefit, 56% (38 species) are endemic to Chile (Marticorena *et al.*, 2001), which is relevant as they are a valuable genetic resource for relieving environmental problems related to the mining sector, and they could be lost if they are not identified or studied in time (Ginocchio and Baker, 2004). Only two of these are endemic to the Region of Coquimbo; *Haplopappus bezanillanus* Reiche and *Chorizanthe glabrescens* Benth. However, ecotypes from the remaining 36 endemic species (as well as from the other native species) able to tolerate high metal concentrations could have possibly developed in the region, and they could be absent in other regions of the country. It is worth highlighting the high percentage of endemism among the species with potential for phytostabilization programs identified by their ecological aspects. Seventy-one percent (297 species) are endemic to Chile, and 33% are endemic to the region (Marticorena *et al.* 2001). As with the species spontaneously colonizing abandoned tailing deposits, these species are a unique resource for the country (and the region), with ecological features and identified uses that make them a valuable resource for phytostabilization programs. Therefore, there is an urgent need for further studies.

Most of the species growing in tailing storage facilities with identified uses are not endangered, with eight species in the category of vulnerable and six insufficiently known (Table 1). In the case of the species that, according to their ecological features, could grow in managed tail-

Table 2. Native plant species of the Coquimbo Region, Chile with potential for use in mine tailing storage facility phytostabilization projects and their uses

Scientific name	Family	Origin[1]	Conservation status[2]	Uses[3]
Adenopeltis serrata	Euphorbiaceae	E	V	3,8,10
Adesmia bedwellii	Fabaceae	E	FP	2,5,8,9,10
Adesmia littoralis	Fabaceae	E	EP	2,8,9,10
Alona coelestis	Nolanaceae	E	FP	4
Alona filifolia	Nolanaceae	E	FP	4
Alona rostrata	Nolanaceae	E	FP	4
Alonsoa meridionalis	Scrophulariaceae	N	FP	10
Alstroemeria angustifolia	Alstroemeriaceae	E	IC (EP?)	10
Alstroemeria crispata	Alstroemeriaceae	E	FP	10
Alstroemeria diluta	Alstroemeriaceae	E	FP	10
Alstroemeria hookeri	Alstroemeriaceae	E	V	10
Alstroemeria kingii	Alstroemeriaceae	E	FP	10
Alstroemeria leporina	Alstroemeriaceae	E	V	10
Alstroemeria magenta	Alstroemeriaceae	E	FP	10
Alstroemeria magna	Alstroemeriaceae	E	IC (V?)	10
Alstroemeria magnifica	Alstroemeriaceae	E	FP	10
Alstroemeria modesta	Alstroemeriaceae	E	IC (V?)	10
Alstroemeria pallida	Alstroemeriaceae	E	IC (FP?)	10
Alstroemeria pelegrina	Alstroemeriaceae	N	V	10
Alstroemeria pulchra	Alstroemeriaceae	E	IC (V?)	10
Alstroemeria schizanthoides	Alstroemeriaceae	E	FP	10
Alstroemeria spathulata	Alstroemeriaceae	E	IC (V?)	10
Alstroemeria spectabilis	Alstroemeriaceae	E	IC	10
Alstroemeria umbellata	Alstroemeriaceae	E	IC (E?)	10
Alstroemeria werdemnnii	Alstroemeriaceae	E	IC	10
Anisomeria coriacea	Phytolaccaceae	E	V	3,4,10
Anisomeria littoralis	Phytolaccaceae	E	FP	10
Argemone hunnemannii	Papaveraceae	N	FP	10
Argemone rosea	Papaveraceae	E	FP	10
Argemone subfusiformis	Papaveraceae	N	FP	3,10
Argylia adscendens	Bignoniaceae	E	FP	3,4
Argylia farnesiana	Bignoniaceae	E	IC (V?)	4
Argylia geranioides	Bignoniaceae	E	FP	4
Argylia potentillifolia	Bignoniaceae	E	FP	4
Argylia radiata	Bignoniaceae	N	FP	3,4,10
Aristolochia bridgesii	Aristolochiaceae	E	FP	3,10
Aristolochia chilensis	Aristolochiaceae	E	FP	3,4,10
Armeria maritima	Plumbaginaceae	N	V	10
Astephanus geminiflorus	Asclepiadaceae	E	FP	3,10
Astragalus amatus	Fabaceae	E	V	9
Astragalus arnottianus	Fabaceae	N	FP	9
Astragalus bellus	Fabaceae	N	IC (E?)	9
Astragalus berterianus	Fabaceae	E	IC (FP?)	9
Astragalus berteroi	Fabaceae	E	IC (V?)	9
Astragalus bustillosii	Fabaceae	N	FP	9
Astragalus chamissonis	Fabaceae	N	IC (FP?)	9
Astragalus coquimbensis	Fabaceae	E	IC (FP?)	9
Astragalus cruckshanksii	Fabaceae	N	FP	9
Astragalus curvicaulis	Fabaceae	E	IC (E?)	9
Astragalus dodtii	Fabaceae	E	IC (E?)	9
Astragalus edmonstonei	Fabaceae	E	IC (V?)	9
Astragalus limariensis	Fabaceae	E	FP	9
Astragalus looseri	Fabaceae	N	FP	9
Astragalus nudus	Fabaceae	E	FP	9

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Scientific name	Family	Origin[1]	Conservation status[2]	Uses[3]
Astragalus paposanus	Fabaceae	E	IC (E?)	9
Astragalus pehuenches	Fabaceae	N	IC (E?)	9
Astragalus pissisii	Fabaceae	E	IC	9
Astragalus schinetorum	Fabaceae	E	IC (EP?)	9
Astragalus vagus	Fabaceae	N	IC (V?)	9
Astragalus vesiculosus	Fabaceae	N	FP	9
Atriplex coquimbana	Chenopodiaceae	E	EP	2
Atriplex costellata	Chenopodiaceae	E	IC	2
Atriplex deserticola	Chenopodiaceae	N	FP	2,8,10
Atriplex leuca	Chenopodiaceae	E	NE	2
Atriplex mucronata	Chenopodiaceae	E	IC	2
Atriplex oreophila	Chenopodiaceae	N	FP	2
Atriplex vallenarensis	Chenopodiaceae	E	IC (E?)	2
Azara celastrina	Flacourtiaceae	E	V	5,9,10
Azara dentata	Flacourtiaceae	E	IC (V?)	4,5,9,10
Azara petiolaris	Flacourtiaceae	E	FP	5,9,10
Azara serrata	Flacourtiaceae	E	IC	5,9,10
Baccharis confertifolia	Asteraceae	E	FP	4,7
Baccharis juncea	Asteraceae	N	FP	2
Baccharis macraei	Asteraceae	E	IC (V?)	4
Baccharis paniculata	Asteraceae	E	FP	4
Baccharis rhomboidalis	Asteraceae	N	IC	4
Baccharis salicifolia	Asteraceae	N	FP	10
Bahia ambrosioides	Asteraceae	E	FP	2,3,4,9,10
Balsamocarpon brevifolium	Caesalpiniaceae	E	EP	3,4,7,10
Berberis actinacantha	Berberidaceae	E	FP	1,4,7,10
Berberis chilensis	Berberidaceae	E	FP	1,4,7,10
Berberis empetrifolia	Berberidaceae	N	FP	1,4,7,10
Berberis glomerata	Berberidaceae	E	FP	1,4,7,10
Bromus cebadilla	Poaceae	N	FP	2
Bromus setifolius	Poaceae	N	FP	2
Buddleja globosa	Buddlejaceae	N	FP	3,4,7,10
Bulnesia chilensis	Zygophyllaceae	E	FP	7,8,10
Caesalpinia angulata	Caesalpiniaceae	E	V	3,8,10
Caesalpinia spinosa	Caesalpiniaceae	N	EP	1,2,3,4,5,7,8,10
Calandrinia cachinalensis	Portulacaceae	E	FP	10
Calandrinia lamprosperma	Portulacaceae	E	IC	10
Calandrinia litoralis	Portulacaceae	E	V	3,10
Calceolaria abscondita	Scrophulariaceae	E	IC (V?)	10
Calceolaria ambigua	Scrophulariaceae	E	IC (V?)	10
Calceolaria andina	Scrophulariaceae	E	FP	10
Calceolaria arachnoidea	Scrophulariaceae	E	FP	7,10
Calceolaria biflora	Scrophulariaceae	N	FP	10
Calceolaria cana	Scrophulariaceae	E	FP	10
Calceolaria collina	Scrophulariaceae	E	IC (E?)	10
Calceolaria corymbosa	Scrophulariaceae	E	V	9,10
Calceolaria densifolia	Scrophulariaceae	E	IC (E?)	10
Calceolaria filicaulis	Scrophulariaceae	N	NE	10
Calceolaria glandulifera	Scrophulariaceae	E	V	10
Calceolaria glandulosa	Scrophulariaceae	E	FP	4,10
Calceolaria hypericina	Scrophulariaceae	N	FP	4,10
Calceolaria integrifolia	Scrophulariaceae	N	FP	10
Calceolaria kingii	Scrophulariaceae	E	IC (V?)	4,10
Calceolaria latifolia	Scrophulariaceae	E	IC (E?)	4,10
Calceolaria lepida	Scrophulariaceae	E	FP	4,10
Calceolaria montana	Scrophulariaceae	N	IC (V?)	10

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Scientific name	Family	Origin[1]	Conservation status[2]	Uses[3]
Calceolaria morisii	Scrophulariaceae	E	V	10
Calceolaria paposana	Scrophulariaceae	E	IC	10
Calceolaria petioalaris	Scrophulariaceae	E	FP	10
Calceolaria picta	Scrophulariaceae	E	EP	10
Calceolaria pinifolia	Scrophulariaceae	N	FP	10
Calceolaria polifolia	Scrophulariaceae	E	FP	4,10
Calceolaria pubescens	Scrophulariaceae	E	IC (E?)	10
Calceolaria quadriradiata	Scrophulariaceae	E	IC (E?)	10
Calceolaria robusta	Scrophulariaceae	E	EP	10
Calliandra chilensis	Mimosaceae	E	FP	10
Calydorea xiphioides	Iridaceae	E	IC (FP?)	1,10
Centaurea cachinalensis	Asteraceae	E	FP	3,4,9,10
Centaurea chilensis	Asteraceae	E	FP	2,3,4,9,10
Centaurea floccosa	Asteraceae	E	V	2,3,4,9,10
Chaetanthera chilensis	Asteraceae	E	IC (V?)	10
Chaetanthera glabrata	Asteraceae	E	FP	10
Chaetanthera microphylla	Asteraceae	N	V	10
Chenopodium chilense	Chenopodiaceae	N	IC (V?)	3
Chenopodium frigidum	Chenopodiaceae	N	FP	3
Chenopodium macrospermum	Chenopodiaceae	N	IC (E?)	3
Chenopodium petiolare	Chenopodiaceae	N	FP	3
Chorizanthe commissuralis	Polygonaceae	N	FP	7
Chorizanthe dasyantha	Polygonaceae	E	IC (E?)	7
Chorizanthe frankenioides	Polygonaceae	E	EP	7
Chorizanthe kingii	Polygonaceae	E	V	7
Chorizanthe paniculata	Polygonaceae	E	V	7
Chorizanthe peduncularis	Polygonaceae	E	V	7
Chorizanthe vaginata	Polygonaceae	E	IC (E?)	3,7,10
Chorizanthe viridis	Polygonaceae	E	FP	7
Chuquiraga oppositifolia	Asteraceae	N	FP	2,10
Chuquiraga ulicina	Asteraceae	E	FP	10
Cissus striata	Vitaceae	N	FP	3,5,10
Cistanthe amarantoides	Portulacaceae	E	IC	10
Cistanthe coquimbensis	Portulacaceae	E	FP	10
Cistanthe grandiflora	Portulacaceae	E	FP	3,10
Cistanthe longiscapa	Portulacaceae	E	FP	10
Cistanthe salsoloides	Portulacaceae	N	FP	10
Clarkia tenella	Onagraceae	N	FP	10
Colletia hystrix	Rhamnaceae	N	FP	4,10
Colletia ulicina	Rhamnaceae	E	NE	10
Colliguaja dombeyana	Euphorbiaceae	E	FP	2,3
Colliguaja integerrima	Euphorbiaceae	N	FP	2,3,7,8,9
Colliguaja odorifera	Euphorbiaceae	E	FP	2,3,7,8,9,10
Colliguaja salicifolia	Euphorbiaceae	E	IC (FP?)	2,3,7,8,9
Convolvulus chilensis	Convolvulaceae	E	FP	2
Copiapoa coquimbana	Cactaceae	E	FP	9,10
Copiapoa pendulina	Cactaceae	E	IC (E?)	9,10
Copiapoa pseudocoquimbana	Cactaceae	E	IC	9,10
Cristaria argyliifolia	Malvaceae	E	IC	10
Cristaria aspera	Malvaceae	E	V	10
Cristaria cyanea	Malvaceae	E	IC	10
Cristaria dissecta	Malvaceae	N	FP	10
Cristaria gracilis	Malvaceae	E	IC	10
Cristaria multiflora	Malvaceae	E	FP	10
Cruckshanksia hymenodon	Rubiaceae	N	FP	10
Cruckshanksia montiana	Rubiaceae	E	V	10

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Scientific name	Family	Origin[1]	Conservation status[2]	Uses[3]
Cruckshanksia pumila	Rubiaceae	E	FP	10
Cuscuta chilensis	Cuscutaceae	N	FP	3,9
Cynanchum boerhaviifolium	Asclepiadaceae	E	FP	10
Cynanchum viride	Asclepiadaceae	E	FP	10
Dinemagonum gayanum	Malpighiaceae	E	V	10
Dioscorea bryoniifolia	Dioscoreaceae	E	V	10
Dioscorea fastigiata	Dioscoreaceae	E	IC	1,4,10
Diostea juncea	Verbenaceae	N	IC (FP?)	10
Diplolepis menziesii	Asclepiadaceae	E	IC (V?)	10
Dodonaea viscosa	Sapindaceae	N	V	3,10
Echinopsis coquimbana	Cactaceae	E	FP	1,3,5,6,7,9,10
Echinopsis litoralis	Cactaceae	E	V	1,3,5,6,9,10
Echinopsis nigripilis	Cactaceae	E	IC (E?)	3,5,6,9,10
Echinopsis skottsbergii	Cactaceae	E	FP	2,3,4,5,6,9,10
Echinopsis spinibarbis	Cactaceae	E	IC (EP?)	3,5,6,9,10
Ephedra breana	Ephedraceae	N	FP	1,2,3,6,8,10
Ephedra chilensis	Ephedraceae	N	FP	10
Erigeron fasciculatus	Asteraceae	E	V	2
Eriosyce aurata	Cactaceae	E	V	9,10
Eriosyce chilensis	Cactaceae	E	V	9,10
Eriosyce curvispina	Cactaceae	E	FP	9,10
Eriosyce heinrichiana	Cactaceae	E	V	9,10
Eriosyce ihotzkyana	Cactaceae	E	IC	9,10
Eriosyce kunzei	Cactaceae	E	EP	9,10
Eriosyce lapampaensis	Cactaceae	E	IC	9,10
Eriosyce limariensis	Cactaceae	E	IC (V?)	9,10
Eriosyce senilis	Cactaceae	E	IC (V?)	9,10
Eriosyce subgibbosa	Cactaceae	E	FP	9,10
Eriosyce tenebrica	Cactaceae	E	IC (V?)	9,10
Eriosyce villosa	Cactaceae	E	IC (V?)	9,10
Errazurizia multifoliolata	Fabaceae	E	FP	10
Eryngium paniculatum	Apiaceae	N	FP	8,10
Escallonia pulverulenta	Escalloniaceae	E	FP	3,5,9,10
Eulychnia acida	Cactaceae	E	FP	1,2,3,5,6,7,9,10
Eulychnia breviflora	Cactaceae	E	EP	2,5,6,7,9,10
Eulychnia castanea	Cactaceae	E	FP	1,5,9,10
Fabiana imbricata	Solanaceae	N	FP	3,4,10
Fabiana viscosa	Solanaceae	E	FP	2,3,10
Fagonia chilensis	Zygophyllaceae	N	FP	10
Flourensia thurifera	Asteraceae	E	FP	2,10
Fuchsia lycioides	Onagraceae	E	FP	2,3,7,9,10
Geoffroea decorticans	Fabaceae	N	V	1,3,5,7,9,10
Geranium core-core	Geraniaceae	N	FP	3,9,10
Glandularia origenes	Verbenaceae	N	FP	3
Glandularia porrigens	Verbenaceae	E	IC (V?)	10
Glandularia sulphurea	Verbenaceae	N	FP	10
Gnaphalium viravira	Asteraceae	N	FP	3,4,10
Gochnatia foliolosa	Asteraceae	E	FP	4,9,10
Guindilia trinervis	Sapindaceae	N	FP	10
Gutierrezia gayana	Asteraceae	E	FP	10
Gutierrezia resinosa	Asteraceae	E	FP	2,3,4
Haplopappus arbutoides	Asteraceae	N	FP	2
Haplopappus baylahuen	Asteraceae	N	FP	2,3,4
Haplopappus decurrens	Asteraceae	E	IC (FP?)	2
Haplopappus deserticola	Asteraceae	E	IC (V?)	2,4
Haplopappus elatus	Asteraceae	E	IC (E?)	2

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Scientific name	Family	Origin[1]	Conservation status[2]	Uses[3]
Haplopappus foliosus	Asteraceae	E	FP	2,3,4,6,9,10
Haplopappus hirtellus	Asteraceae	E	FP	2
Haplopappus illinitus	Asteraceae	E	IC (E?)	2
Haplopappus integerrimus	Asteraceae	E	EP	2,10
Haplopappus ischnos	Asteraceae	E	IC (V?)	2
Haplopappus linifolius	Asteraceae	E	FP	2
Haplopappus litoralis	Asteraceae	E	V	2
Haplopappus meyenii	Asteraceae	E	EP	2
Haplopappus paucidentatus	Asteraceae	N	IC	2
Haplopappus philippii	Asteraceae	E	NE	2
Haplopappus phyllophorus	Asteraceae	E	IC	2
Haplopappus pinea	Asteraceae	E	IC (FP?)	2
Haplopappus platylepis	Asteraceae	E	V	2
Haplopappus pulchellus	Asteraceae	E	FP	2
Haplopappus reicheanus	Asteraceae	E	IC (FP?)	2
Haplopappus remyanus	Asteraceae	E	FP	2
Haplopappus rengifoanus	Asteraceae	E	V	2
Haplopappus rigidus	Asteraceae	N	IC	2,3
Haplopappus scrobiculatus	Asteraceae	N	FP	2
Haplopappus stelliger	Asteraceae	E	NE	2
Haplopappus uncinatus	Asteraceae	E	IC (V?)	2
Haplopappus velutinus	Asteraceae	E	FP	2,4
Helenium aromaticum	Asteraceae	N	FP	3,10
Heliotropium chenopodiaceum	Boraginaceae	E	FP	10
Heliotropium curassavicum	Boraginaceae	N	FP	10
Heliotropium geissei	Boraginaceae	E	IC (E?)	10
Heliotropium longistylum	Boraginaceae	E	IC (V?)	10
Heliotropium megalanthum	Boraginaceae	E	IC (V?)	10
Heliotropium myosotifolium	Boraginaceae	E	IC (V?)	10
Heliotropium paronychioides	Boraginaceae	N	FP	10
Heliotropium sinuatum	Boraginaceae	E	FP	10
Homalocarpus dichotomus	Apiaceae	E	FP	10
Hypochaeris scorzonerae	Asteraceae	E	FP	10
Jubaea chilensis	Palmae	E	EP	1,5,7,10
Junellia selaginoides	Verbenaceae	E	FP	10
Junellia spathulata	Verbenaceae	N	IC (V?)	10
Kageneckia angustifolia	Rosaceae	E	EP	5,6,9,10
Kageneckia oblonga	Rosaceae	E	V	3,4,5,6,7,9,10
Krameria cistoidea	Krameriaceae	E	FP	1,2,3,4,7,10
Larrea nitida	Zygophyllaceae	N	FP	3,4,7,10
Leucheria cerberoana	Asteraceae	E	FP	10
Leucocoryne coquimbensis	Alliaceae	E	FP	10
Leucocoryne dimorphopetala	Alliaceae	E	V	10
Leucocoryne ixioides	Alliaceae	E	V	10
Leucocoryne purpurea	Alliaceae	E	V	2,10
Leucocoryne violacescens	Alliaceae	E	IC (V?)	10
Llagunoa glandulosa	Sapindaceae	E	FP	2,7,10
Lobelia excelsa	Campanulaceae	E	FP	4,10
Lobelia oligophylla	Campanulaceae	N	FP	10
Lobelia polyphylla	Campanulaceae	E	FP	4,10
Lomatia hirsuta	Proteaceae	N	IC (EP?)	3,5,7,10
Lupinus microcarpus	Fabaceae	N	FP	9,10
Lycium stenophyllum	Solanaceae	N	IC (V?)	10
Maihueniopsis grandiflora	Cactaceae	E	IC (V?)	2,9,10
Maihueniopsis wagenknechtii	Cactaceae	E	V	2,9,10
Malesherbia fasciculata	Malesherbiaceae	E	FP	9,10

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Scientific name	Family	Origin[1]	Conservation status[2]	Uses[3]
Malesherbia humilis	Malesherbiaceae	N	FP	10
Margyricarpus pinnatus	Rosaceae	N	FP	1,3,4,7,10
Menonvillea linearis	Brassicaceae	E	V	10
Mentzelia bartonioides	Loasaceae	N	FP	10
Mentzelia chilensis	Loasaceae	E	FP	3,10
Mentzelia ignea	Loasaceae	N	IC (V?)	10
Mentzelia pinnatifida	Loasaceae	E	FP	10
Mirabilis elegans	Nyctaginaceae	N	IC (V?)	10
Montiopsis sericea	Portulacaceae	E	FP	10
Monttea chilensis	Scrophulariaceae	E	EP	2,7,8,9,10
Mutisia rosea	Asteraceae	E	IC (V?)	3,10
Mutisia sinuata	Asteraceae	N	FP	3,10
Myrceugenia obtusa	Myrtaceae	E	IC (E?)	10
Myrceugenia rufa	Myrtaceae	E	V	10
Nicotiana acuminata	Solanaceae	N	FP	10
Nicotiana solanifolia	Solanaceae	E	IC	10
Nolana acuminata	Nolanaceae	E	V	10
Nolana baccata	Nolanaceae	E	IC (FP?)	10
Nolana divaricata	Nolanaceae	E	FP	10
Nolana glauca	Nolanaceae	E	IC	10
Nolana paradoxa	Nolanaceae	E	FP	10
Nolana rupicola	Nolanaceae	EE	V	10
Nolana salsoloides	Nolanaceae	E	IC (E?)	10
Ochagavia carnea	Bromeliaceae	E	IC (V?)	10
Oenothera acaulis	Onagraceae	N	FP	3,10
Oenothera affinis	Onagraceae	N	V	10
Oenothera coquimbensis	Onagraceae	E	FP	10
Oenothera stricta	Onagraceae	N	FP	10
Olsynium junceum	Iridaceae	N	IC (E?)	10
Olsynium philippii	Iridaceae	E	FP	10
Olsynium scirpoideum	Iridaceae	N	FP	10
Opuntia berteri	Cactaceae	N	FP	2,9,10
Opuntia glomerata	Cactaceae	N	V	2,9,10
Opuntia miquelii	Cactaceae	E	FP	2,9,10
Opuntia ovata	Cactaceae	N	FP	2,4,9,10
Opuntia tunicata	Cactaceae	N	NE	2,9,10
Oxalis arenaria	Oxalidaceae	N	IC	10
Oxalis briquetii	Oxalidaceae	E	NE	10
Oxalis compacta	Oxalidaceae	N	FP	10
Oxalis coquimbana	Oxalidaceae	E	IC (V?)	10
Oxalis erythrorhiza	Oxalidaceae	N	IC (E?)	10
Oxalis gaudichaudii	Oxalidaceae	E	IC	10
Oxalis gigantea	Oxalidaceae	E	FP	2,7,10
Oxalis glutinosa	Oxalidaceae	E	IC (V?)	10
Oxalis illapelina	Oxalidaceae	E	IC (V?)	10
Oxalis laxa	Oxalidaceae	N	FP	10
Oxalis maritima	Oxalidaceae	E	V	7,10
Oxalis micrantha	Oxalidaceae	N	FP	10
Oxalis ovalleana	Oxalidaceae	E	IC	10
Oxalis paniculata	Oxalidaceae	E	IC (E?)	10
Oxalis perdicaria	Oxalidaceae	N	FP	10
Oxalis rosea	Oxalidaceae	E	FP	1,2,7,10
Oxalis san-romanii	Oxalidaceae	N	FP	10
Oxalis squarrosa	Oxalidaceae	E	FP	10
Oxalis succulenta	Oxalidaceae	E	IC	10
Oxalis tarapacana	Oxalidaceae	E	IC	10

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Scientific name	Family	Origin[1]	Conservation status[2]	Uses[3]
Oxalis tortuosa	Oxalidaceae	E	FP	10
Oziroe biflora	Hyacinthaceae	N	FP	10
Pasithea caerulea	Hemerocallidaceae	N	FP	10
Perezia carthamoides	Asteraceae	N	FP	3,4,10
Perityle emoryi	Asteraceae	N	IC (V?)	3,4,10
Peumus boldus	Monimiaceae	E	V	1,3,4,6,7,9,10
Phacelia brachyantha	Hydrophyllaceae	N	V	10
Phacelia secunda	Hydrophyllaceae	N	FP	10
Phrodus microphyllus	Solanaceae	E	FP	10
Pleurophora pungens	Lythraceae	E	FP	10
Plumbago caerulea	Plumbaginaceae	N	FP	10
Podanthus mitiqui	Asteraceae	E	FP	2,3,4,10
Polyachyrus carduoides	Asteraceae	E	FP	2
Polyachyrus fuscus	Asteraceae	N	FP	4,10
Polyachyrus poeppigii	Asteraceae	E	FP	10
Porlieria chilensis	Zygophyllaceae	E	V	2,4,5,7,10
Pouteria splendens	Sapotaceae	E	EP	10
Prosopis flexuosa	Mimosaceae	N	EP	8,9,10
Prosopis strombulifera	Mimosaceae	N	FP	7,8,9,10
Proustia cuneifolia	Asteraceae	E	FP	3,4,8,10
Proustia pyrifolia	Asteraceae	E	EP	5,6,10
Pteromonnina pterocarpa	Polygalaceae	N	V	10
Puya alpestris	Bromeliaceae	N	IC (E?)	5,7,8,9,10
Puya berteroniana	Bromeliaceae	E	FP	1,3,5,6,7,8,9,10
Puya chilensis	Bromeliaceae	E	FP	1,2,3,4,5,7,8,9,10
Puya coerulea	Bromeliaceae	E	NE	5,7,8,9,10
Puya gilmartiniae	Bromeliaceae	E	IC (E?)	5,7,8,9,10
Puya venusta	Bromeliaceae	E	FP	5,7,8,9,10
Quinchamalium chilense	Santalaceae	N	FP	3,4,10
Ranunculus peduncularis	Ranunculaceae	N	IC (V?)	3,10
Retanilla trinervia	Rhamnaceae	E	FP	2,3,4,6,9,10
Satureja gilliesii	Labiatae	E	FP	3,4,9,10
Schizopetalon bipinnatifidum	Brassicaceae	E	FP	10
Schizopetalon maritimum	Brassicaceae	E	FP	10
Schizopetalon walkeri	Brassicaceae	E	V	10
Senecio eruciformis	Asteraceae	N	FP	3,9,10
Senecio murorum	Asteraceae	E	FP	4,9,10
Senna candolleana	Caesalpiniaceae	E	FP	3,5,10
Sicyos baderoa	Cucurbitaceae	N	FP	10
Sisyrinchium arenarium	Iridaceae	N	FP	10
Sisyrinchium graminifolium	Iridaceae	N	V	7,10
Sisyrinchium striatum	Iridaceae	N	V	3,10
Skytanthus acutus	Apocynaceae	E	EP	2,4,9,10
Solanum heterantherum	Solanaceae	E	FP	10
Solanum ligustrinum	Solanaceae	N	FP	3,4,10
Solanum remyanum	Solanaceae	E	IC (V?)	10
Sophora macrocarpa	Fabaceae	E	EP	4,7,10
Sphacele chamaedryoides	Labiatae	E	IC (E?)	10
Sphacele salviae	Labiatae	E	FP	3,7,9,10
Sphaeralcea obtusiloba	Malvaceae	E	FP	2,3,10
Stachys eremicola	Labiatae	E	V	9
Stachys grandidentata	Labiatae	E	FP	9,10
Stachys pannosa	Labiatae	E	IC (V?)	9
Stachys philippiana	Labiatae	E	IC (V?)	9,10
Suaeda foliosa	Chenopodiaceae	N	FP	10
Tecophilaea violiflora	Tecophilaeaceae	E	FP	10

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Scientific name	Family	Origin[1]	Conservation status[2]	Uses[3]
Tetraglochin alatum	Rosaceae	N	FP	10
Tetragonia angustifolia	Aizoaceae	E	IC	10
Tetragonia maritima	Aizoaceae	E	FP	10
Tetragonia ovata	Aizoaceae	E	IC (V?)	10
Teucrium bicolor	Labiatae	E	FP	3,4,10
Teucrium nudicaule	Labiatae	E	FP	10
Tillandsia capillaris	Bromeliaceae	N	FP	10
Tillandsia geissei	Bromeliaceae	E	IC (EP?)	10
Tillandsia landbeckii	Bromeliaceae	N	FP	10
Trevoa quinquenervia	Rhamnaceae	E	V	2,4,6,8,9,10
Trichopetalum plumosum	Lomandraceae	E	FP	10
Triptilion gibbosum	Asteraceae	E	FP	10
Triptilion spinosum	Asteraceae	E	IC	4,10
Tristerix verticillatus	Loranthaceae	N	FP	4,7,9
Tropaeolum azureum	Tropaeolaceae	E	FP	10
Tropaeolum brachyceras	Tropaeolaceae	E	V	10
Tropaeolum hookerianum	Tropaeolaceae	E	V	10
Tropaeolum jilesii	Tropaeolaceae	E	IC (E?)	10
Tropaeolum kingii	Tropaeolaceae	E	FP	10
Tropaeolum looseri	Tropaeolaceae	E	FP	10
Tropaeolum polyphyllum	Tropaeolaceae	N	FP	10
Tropaeolum sessilifolium	Tropaeolaceae	E	FP	10
Tropaeolum tricolor	Tropaeolaceae	E	FP	10
Tweedia birostrata	Asclepiadaceae	E	FP	10
Tweedia stipitata	Asclepiadaceae	E	FP	10
Vicia vicina	Fabaceae	E	IC (V?)	2,10
Viola polypoda	Violaceae	E	V	10
Viviania crenata	Vivianiaceae	E	FP	2,10
Viviania marifolia	Vivianiaceae	N	FP	2,3,10
Zephyra elegans	Tecophilaeaceae	E	FP	10

[1]E, endemic to Chile; N, native to Chile.
[2]FP: out of danger, IC(E?): insufficiently known (extinct?), IC(FP?): insufficiently known (out of danger?), IC(V?): insufficiently known (vulnerable?), V: vulnerable.
[3]1: alimentary, 2: cattle forage, 3: medicinal, 4: phytochemical, 5: timber/construction, 6: fuel, 7: crafts, 8: soil conservation, 9: mellipherous, 10: ornamental.

ing deposits and that have additional uses, 19 are in danger of extinction, 56 are in a state of vulnerability and 120 are insufficiently known (Table 2). It is noteworthy that in these two groups of species, 31 species have been cataloged as insufficiently known and are suspected of being extinct (Marticorena *et al*., 2001), as this reduces the number of species potentially utilizable in phytostabilization projects. The inclusion of endangered and vulnerable species in phytostabilization programs could undoubtedly aid their conservation, as long as sustainable management is carried out.

It is worth mentioning that the main objective is the stabilization of mining tailings, and that the additional use of the species for another purpose should not interfere with that goal. Within the uses proposed for the flora to be used in phytostabilization of mining tailings, there are several involving the use of vegetative structures that are important or essential for the plant's survival, such as food, forage, medicine, phytochemicals, timber/construction, fuel and handicrafts. In these cases, it becomes crucial to provide a sustainable plan for harvesting the structures of interest, so that the utilization of the species does not detract from the stabilization of the mining wastes.

Final considerations

Even though many of the uses described for the vegetal species of the Region of Coquimbo are restricted to disappearing indigenous cultures or rural local subsistence communities, there is real potential for the use of the native regional flora. Ongoing study of the plants has made evident the existence of high-value chemical compounds. This potentiates the generation of new markets where the flora traditionally used by indigenous cultures and local communities reach consumers at commercial levels. In this way, sustainably managed native flora could contribute to their own conservation by creating value. It is worth noting that even though there may be significant economic and subsistence benefits to conserving the native flora, if those benefits are not sensed or valued as significant by local users, support for the conservation of that resource will be absent (Campbell, 2000).

The added value provided to a phytostabilization program by a sustainably managed native vegetal species with additional uses would favor this technology over other methods used to stabilize mining wastes. Using such a program to rehabilitate areas contaminated by mining activities and to restore local ecosystems might also preserve and enhance biodiversity. However, more extensive studies are required before the potential uses we identified can be developed to a productive level. Additionally, to select the best species for use in post-operative mining tailing phytostabilization programs, the tolerances and metal accumulation capacities of these species must be determined with biotests.

In order to enrich the quality of life of the rural population of the region, as well as to enhance biodiversity and ecosystem productivity, it is necessary to attempt to alleviate the environmental problems generated by mining activities. Mining rehabilitation through phytostabilization presents an opportunity to address all these aspects as a whole.

Resumen

C. Orchard, P. León-Lobos y R. Ginocchio. 2009. Fitoestabilización de desechos mineros masivos con recursos fitogenéticos nativos: Potencial para el uso sustentable y la conservación de la flora nativa de la zona centro-norte de Chile. Cien. Inv. Agr. 36(3):329-352. La minería metálica ha dejado una gran cantidad de depósitos de relaves en la zona centro-norte de Chile inadecuadamente abandonados, significando un riesgo para el ambiente. Por ello, la actual normativa minera chilena enfatiza la estabilización de estos depósitos para su adecuado cierre, favoreciendo el uso de tecnologías ambientalmente sustentables. Entre ellas se encuentra la fitoestabilización, tecnología que puede ser favorecida al incorporar especies que proporcionen usos económicos y de subsistencia. La incorporación de especies nativas en programas de fitoestabilización y su aprovechamiento sustentable podrían aportar, también, en la conservación de la flora nativa y de los ecosistemas de la zona centro-norte de Chile. En esta investigación, se indagó sobre los usos alternativos que podrían tener las especies nativas que han colonizando espontáneamente depósitos de relaves abandonados y de otras especies que, dadas sus características ecológicas, podrían establecerse sobre tranques de relaves post-operativos en el marco de la tecnología de fitoestabilización, tomando la Región de Coquimbo como caso de estudio. Se realizó una revisión de la literatura científica, técnica y etnobotánica sobre los usos tradicionales y aquellos que se han descubierto recientemente de las especies nativas de la Región. Los resultados indicaron que 68 especies colonizadoras espontáneas tienen al menos un uso conocido, mientras que 420 especies con potencial de utilización en programas de fitoestabilización, un 28% de la flora nativa regional, presentan posibles usos que brindarían un beneficio adicional a la estabilización de estos depósitos. Entre los principales usos identificados se encuentran el ornamental, forrajero, apícola, medicinal, principio químico y artesanal. Un 69% de estas especies son endémicas de Chile, constituyendo un valioso recurso fitogenético en la mitigación de problemas ambientales relacionados con el sector minero, que podrían perderse si no se identifican y estudian a tiempo.

Palabras clave: Manejo sustentable, minería, rehabilitación, tranques de relaves, valoración de recursos naturales.

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