4th Biorem Meeting

Krakow, October 11th 2013

Book of Abstracts

W. Adlassnig & I. K. Lichtscheidl (Eds.)

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Introduction

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Mining for metal ores may cause devastating effects on the environment due to the production of huge barren spoil heaps, contaminated drainage and toxic dust. In many countries of the developing world, mining activities are carried out with little concern for the consequences and accordingly people and the environment suffer seriously. The ÖAD-Appear project BIOREM aims to develop strategies for the monitoring of metal pollution in mining areas and for the bioremediation of contaminated sites. In order to successfully implement these solutions in developing countries, especially Nicaragua, academic curricula are developed for the training of scientists who will carry out these measures.

Besides academic training and transfer of knowledge with local communities and stakeholders, basic and applied research activities play a key role for achieving the project aims of BIOREM. Ecologists, botanists, geologists, mycologists and microbiologists from Nicaragua, Perú, Poland, Romania and Austria unite their forces in order to clarify the behavior of metals in the respective contaminated habitats and search for novel monitoring and remediation techniques. The results of these research activities are presented to the project partners, the scientific community and the broader public in a series of scientific meetings, held twice a year at the home institutions of the project partners.

Since our kickoff meeting in Vienna/Austria, BIOREM has organised conferences in Huaraz/Peru and Managua/Nicaragua. Now, the participants of the project come together in Krakow/Poland kindly hosted by Katarzyna Turnau from the Institute of Environmental Sciences at the Jagiellonian University in Krakow in order to share their progress, to discuss their findings and to decide about further measures. Therefore, the editors and organisers of this conference wish all participants an inspiring meeting, successful presentations and fruitful discussions!

W. Adlassnig
(Editor)

Irene Lichtscheidl
(on behalf of the organising commitee)

Cyanide Compounds in Mine Tailings: Degradation, Risks and Uncertainties - Observations and Efforts of Biorem Field Research in Nicaragua and Peru

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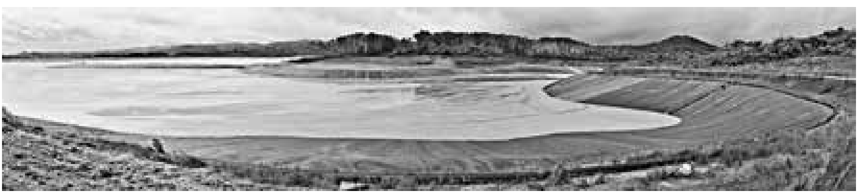
The Biorem-Cooperation between the University of Vienna, Austria (Cius), and the *Universidad Nacional Autónoma de Nicaragua* (Laboratory of Microbiology and *Centro de Investigaciones Geocientíficas* - Cigeo), and the *Universidad Nacional Santiago Antunez de Mayolo* in Huaraz, Perú (*Facultad de Ciencias del Ambiente*) is focused on bioremediation of contaminated sites, and funded by the Appear program for education, research and development. One Biorem research objective is the use microorganisms and plants to develop cost-efficient and sustainable measures for soil and water remediation at contaminated sites, especially of mining areas in Perú and Nicaragua. During *Biorem* field research, we were confronted with the environmental problem of mining residuals, especially of cyanide (CN^-) compounds in mine tailings, in Perú, Nicaragua and Romania. In this contribution, the state of scientific research on CN^- is reviewed, and the shortcomings in our understanding of the toxicity of CN^- and its environmental impacts are discussed.

CN^- is of great economic importance for gold and silver mining as it enables the economical feasible leaching of low grade ore bodies. However, CN^- is highly toxic (oral LD50 in humans: 1.5 mg · kg-1), and the release of CN^- into the environment causes serious ecological effects, as observed, e. g., after a dam break in Baia Mare/Ro in 2000. However, the only feasible substitute for CN^- is the equally toxic Hg, which is prefentially used in small mining enterprises both in Nicaragua and Perú. Therefore, artisanal



mining causes conflicts between environmental, economic and social interests as well.

The need for a proper understanding of the effects of CN^- was confirmed by our meetings and discussions with experts for environmental safety of the B2Gold mining company in Nicaragua, as well as the Antamina company and Barrick Gold Corporation in Perú. They claimed that CN^- is rapidly degraded to harmless compounds under aqueous conditions; however, contrasting claims have been published as well. CN^- was also observed to break down into compounds that are potentially toxic to fish and other aquatic organisms. The degradation pathways depend crucially on the chemistry of the matrix, the temperature, the humidity and other parameters, and not all of them are understood in detail, especially with regard to mine waste environments. Though many of these compounds are generally less toxic than CN^- itself, they may persist for long periods of time, and some of them remain extremely toxic. Some of these compounds are reported to be stored or accumulated by plants and fish. Mine operators monitoring their CN^- output are not required to test for all possible degradation products as well. Thus, these compounds are deposited in an uncontrolled way despite the potential environmental impacts.

Cyanide is an organic nitrogen ion that is commonly found as a contaminant in wastewaters due to metal finishing, electroplating and coal coking. Cyanide in various forms is highly toxic, carcinogenic, and mutagenic. Control and remediation of cyanide–contaminated water and soil is therefore necessary. There are several methods for the treatment of CN^- rich effluents, such as alkaline chlorination, the sulfoxide/air process and the hydrogen peroxide process. Though these methods are well established, they suffer from serious shortcomings: (1) They are not able to degrade stable CN^- metal complexes; (2) They require expensive reagents, equipments, maintenance and royalty payments; (3) They tend to generate undesired by-products such as chlorinated compounds.

Bioremediation is seen as a most promising strategy to preduce CN^- contamination. So far, most attempts focus on CN^- degrading fungi and bacteria and try to to incorporate natural attenuation processes into planned and more efficient treatment procedures. Bacterial oxidation to CO_2 at shallow depths of disposal lagoons (compare the figure) is the primery operator, counting for about 90% of the total CN^- degradation. Furthermore, several abiotaic degradation pathways have been described, including evaporation, oxidation with atmorspheric O_2, cleavage by UV radiation, adsorption by mineral surfaces and precipitation processes. Yet, all these mechanisms accelerate natural decyanidation in tailings ponds only to a very limited amount. Furthermore, the final products like CNO^- or SCN^- are not necessarily environmentally-friendly. Furthermore, many of those processes produce stable intermediary products that last considerably longer under environmental conditions than the original CN^-.

Thus, a survey of the literature on CN^- based metal extraction and their CN^- rich waste products allows the following conclusions: (1) The conventional reporting of analytical data suffers from the omission of numerous CN^- complexes and compounds. (2) It is frequently assumed that free CN^- is degraded completely to CO_2 and various N compounds under natural conditions. However, in metal rich environments, very stable complexes may form and resist degradation for long periods of time. Thus, CN^- assumed to be "destroyed" or "not-present" might in fact still be present and potentially harmful. (3) At the moment, no universal applicable solution for CN^- related problems exists, though many chemical or biological techniques are available or under development. (4) CN^- usage is not to cease any time soon, nor is there an immediate need for a ban. However, research is needed for a less controversial and equally-effective alternative lixiviant.

Assessment of Aquifer Vulnerability to Contamination by Mining Activities in Santo Domingo, Nicaragua

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Since around 1860, mining for gold has taken place in the small town of Santo Domingo in the province of Chontales/Nicaragua. Mining activities have been carried out on different scales: artisanal, small-scale and industrial mining. Artisanal and small-scale miners have been using amalgamation with mercury (Hg) for extracting the gold from the ore. Unfortunately, no waste treatment of any kind can be carried out at this scale. Therefore, the miners are disposing the remnants of ore, still with high gold and Hg contents, directly into rivers and creeks. Industrial mining in Santo Domingo has been reactivated after three decades of inactivity but uses cyanide for gold extraction (compare the study by G. Kreitner in this volume). The current industrial ore extraction site is located very close to an old mine gallery that has been used as a water source for human consumption, the *Tunel Azul*. The likelihood of a contamination of drinking water has raised concern among the municipal authorities and the population of Santo Domingo.

In the frame of the midterm meeting of the Biorem project, the coordinators met with the new municipal authorities of Santo Domingo. During a fruitful mutual exchange, the mayor and the technical staff of the environmental department explained their concerns about the water resources, and requested academic support from the Biorem team in order to enable decisions based on scientific knowledge. Due to the obvious threat to the water supply of the population, Biorem included the new scope of water quality into the research aims. The responsibility for the assessment of aquifer vulnerability to contamination by mining activities was assumed by Igg-Cigeo. In more detail, the new activites by Igg-Cigeo aim to …

- … update the information of contamination in the streams and groundwater in the Santo Domingo region.

- … identify and characterize possible interactions between surface water and groundwater.

- … determine, if the water of the *Tunel Azul* is affected by mining activities or by any other sources of contamination.

- … assess the risk of future contamination of the aquifer.

- … determine the percent share ratio between surface water and groundwater at the *Tunel Azul*.

In an interdisciplinary approach, geological, geophysical and hydro-geochemical methods and analyses will be combined in order to accomplish these objectives. The geological data acquisition is virtually finished; the geophysical surveys and sampling for hydro-geochemical analysis will be carried out in the immediate future.

Impact of the heavy metals copper, zinc and cadmium on growth and development of the moss *Physcomitrella patens* Hedw.

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A large number of bryophytes inhabit extreme ecological niches and are therefore exposed to a variety of abiotic stress factors, including heavy metal pollution. Often, the combinationb of stresses at the natural site prevents a clear statement on the stressor-specific effect. On the other hand, many studies aim to localize metal deposition in specific cellular compartments without considering growth parameters.

Here, growth rates of the moss *Physcomitrella patens* Hedw. (Funariaceae) on solid heavy metal spiked media are reported over a period of five weeks. The effects of copper, zinc and cadmium are analyzed separately, linked to the anions chloride ($CdCl_2$: 5 µM, 1 µM, 0.1 µM; $ZnCl_2$: 5 mM, 1 mM, 100 µM; $CuCl_2$: 100 µM), sulphate ($ZnSO_4$ and $CuSO_4$: 1 mM, 100 µM) and EDTA ($ZnNa_2EDTA$ and $CuNa_2EDTA$: 100 mM, 10 mM, 1 mM, 100 µM), respectively. Even at such metal levels, most samples show an increase of biomass and *P. patens* proves a high tolerance. Furthermore, the results show a difference in growth rate depending on the offered metal anion with chloride showing the worst and EDTA the least harmful effect. Moreover, a significant tendency to form more filamentous protonemata and less leafy gametophytes is found on higher-concentrated substrates.

Therefore, the metal- and anionspecific effects reported here provide an important basis for the use of in vitro technique for studies on element toxicity.

BioRem – Database for Remediation of Heavy Metal Rich Habitats and Protection of their Biodiversity

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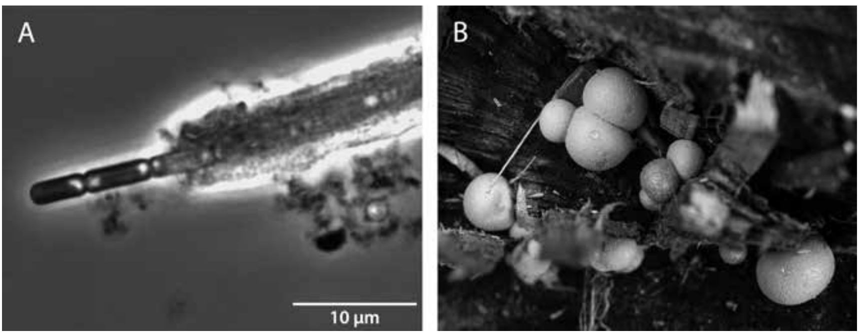
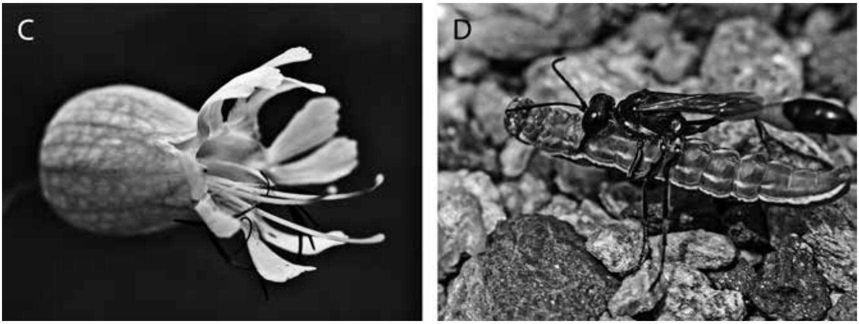
BioRem is an open access on-line database, which aims to document the biological and mineralogical diversity of terrestrial sites enriched in toxic metals and metalloids. All around the globe, they are the habitat of specialized metal tolerant organisms, ranging from microorganisms (A: *Phormidium* sp., Phormidiaceae) over protists (B: *Lycogala epidendron*; Lycogalaceae), fungi or plants (C: *Silene vulgaris*, Caryophyllaceae) to animals (D: *Ammophila pubescens*, Sphecidae). A comprehensive inventory of metal tolerant organisms together with an analysis of environmental conditions with a special focus on geological aspects, combined with research about the specific adaptations of metal tolerant organisms shall support the development of holistic models about the functioning of metal rich ecosystems, and lead to an improved understanding of interactions and adaptation strategies of metal tolerant organisms. Furthermore, the database enables the identification of plants and microorganisms suitable for remediation actions where protection of the population and the environment is needed.





Though this study fully supports the need of remediation measures, a second perspective is discussed as well: metal rich habitats, especially very old ones, host unique biocoenoses and therefore serve as reservoirs of biodiversity. The organisms and biocoenoses found there are the only sources to study metal tolerance and immoblisation *in situ*; they serve as natural examples for habitat remediation and deserve conservation in order to enable future studies. Thus, strategies must be developed to ensure the survival of strategies, where safety reasons make remediation – and therefore destruction – of specific sites necessary. Hence, BioRem contributes to the aim of the Göteborg 2010 target to halt loss of biodiversity

Finally, BioRem shall be a resource for education and for the dissemination of the present knowledge about the ecology of heavy metal rich sites and their organisms, and it shall provide tools for the evaluation of socio-economic strategies for either remediation or preservation of heavy metal habitats.

Amphibians at Metal and Metalloid Contaminated Habitats

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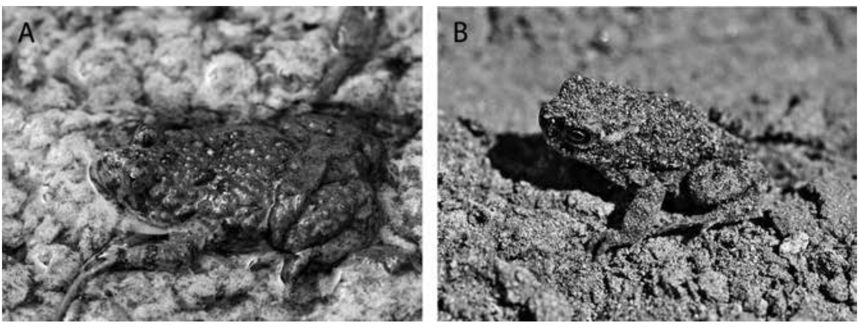
High concentrations of bioavailable metals and metalloids in waters or soils lead to the formation of distinct and usually impoverished biocoenoses, as these elements are toxic for most organisms. Amphibians are frequently believed to be especially sensitive due to their permeable skin and their likeliness to swallow particles of the substrate. Some authors consider metals and metalloids to be involved in the global decline of amphibians.

This study presents evidence for the presence of amphibians at metal and metalloid rich habitats in Central and Eastern Europe, including habitats naturally rich in metals or contaminated by mining activities. Dry habitats like rocky spoil heaps and sandy mine tailings were generally found to be devoid of amphibians. At moist habitats, especially creeks, puddles and ponds fed by drainage water, however, six species of amphibians were observed, i. e., *Bombina variegata*, *Rana ridibunda*, *Rana temporaria*, *Bufo viridis*, *Salamandra salamandra* and *Salamandra atra*. All six species were found in habitats superficially similar to their typically preferred habitats,



e. g. *Bombina variegata* in small puddles (A), *Bufo viridis* on sandy areas with a loose vegetation (B) etc.

Increased concentrations of copper, lead, arsenic, antimony and other elements, and a moderately acidic pH did not keep off amphibians. Extremely contaminated or highly acidic water bodies were devoid of amphibians though they may be present in the surrounding; thus, amphibians seem be able to tolerate moderate amounts of toxic elements but avoid extreme degrees of contamination. At least some amphibians seem to exhibit a limited tolerance against toxic metals and metalloids, possibly due to metallothioneins and other proteins for detoxification.

Mine Waste in Romania: Origins, Threats and Remediation

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Romania hosts a great variety of mineral deposits, which occupy a remarkable portion of its territory. According to the National Agency for Mineral Resources, these deposits contain ores of gold, silver, copper, lead, zinc, iron, manganese, uranium, molybdenum, tungsten, aluminium and others. Accordingly, mining has a long tradition in Romania and therefore a pronounced impact on the environment. Large areas are occupied by spoil heaps, mine waste dumps and ponds with drainage water. Even the uncontrolled release of mine drainage water is occasionally observed.

Until 1989, mining was one of the most important branches of industry in Romania. Afterwards, the Romanian mining industry declined continuously due to economic reasons and the need to comply with European and international environmental standards. During the first decade of the 21st century, the number of employees in the mining industry dropped from 70,000 to 2,500. In many mining facilities, activities are restricted to deconstruction, monitoring of environmental pollution and remediation measures. In 2008, 799 tailing ponds covered a total of 6,900 ha, and 109 mining dumps covered 2,140 ha, containing both ferrous and non-ferrous ores. 90% of all waste affected areas in Romania are covered by mine tailings and tailing ponds.

Mines and mine waste deposits are found in 14 of the 41 counties, mainly in the Western Carpathians. In Maramureş, 300 mine waste sites cover about 30,000 ha, i. e. more than 4.7% of the county (See figures A and B). These waste sites contain increased levels of copper, lead, zinc, cadmium, manganese and arsenic. The counties of Caraş-Severin, Hunedoara, Alba and Harghita are seriously affected as well. Most of this area is drained by rivers like Vişeu şi Iza, Someş, Mureş, which are tributaries of the Tisza river, which is a tributary of the Danube. Thus, metals released in the Western Carpathians may affect a significant portion of Europe.

Remediation activities include stabilization, and re-embankment, drainage and revegetation of the mine waste dumps and ponds; the recovery of certain elements is considered as well. For that, Territorial Environmental Agencies have some special programs and researches projects. For example Forest Research Institute in collaboration with Experimental Forestry Resort from Brasov in one the national research project "Energohalst", carry out laboratory and pilot experiments in order to reduce the costs and the time requirements.

At least five plant species have been identified, which seem to have a high potential for bioremediation, i. e. *Robinia pseudacacia* (Fabaceae), *Eleagnus angustifolia* (Eleagnaceae), *Hippophae rhamnoides* (Eleagnaceae), *Miscanthus × giganteus* (Poaceae) and *Phalaris arundinacea* (Poaceae).

There is still a long way to go for the Romanian mining industry in order to extract and process precious ores in a safe, environmentally friendly, sustainable and economically viable way, and many brownfield sites require remediation. The first steps, however, have been made, and significant progress can be observed both in the fields of applied research and practical implementation.

Two typical Romanian mine waste sites, both from Maramureş: (A) Tăuții des Sus Pond, a tailing pond next to the village Satul Nou that is considered as a significant danger for people and environment and (B) the Mălăini mine waste dump at Cavnik Valley where some revegetation massures already have taken place.

Geology of Nicaragua

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From the geological viewpoint, Nicaragua is a very diverse land in Central America, as it provides a linkage between the geologically older part of Central America in the north and the younger part in the south (Weyl 1980). To understand this, we have to take a look on the formation history of Central America (Rogers 2003). In the Late Jurassic (, North and South America became separated and started to drift apart. At the same time the Chortis Block (today's Honduras and El Salvador) detached from the southwest coast of Mexico. From the west approached the Farallon Palate, which pushed the Mezcalera Plate under the American plates. At the subduction zone of the two oceanic plates, a volcanic island chain arose, the Guerrero-Caribbean Arc, which consisted of Cuba, Jamaica and Siune Terrane (part of Nicaragua). In the Late Cretaceous the Mezcalera Plate disappeared completely and the southern part of the Guerrero-Caribbean Arc reached the hot spot of Galapagos, where a plateau of submarine volcanoes and volcanic islands, the Chorotega Block (today's Costa Rica) was formed. Meanwhile the Farallon plate drifts further into the proto-Caribbean opening and brings the rest of the Caribbean Arc to its today position. Thereby the Siune Terrane collided with the Chortis Block. At the end of the Late Cretaceous the Chorotega Block collided also with the Siune Terrane/Chortis Block. Until the Eocene the Caribbean part of the Farallon Plate comes to a hold and a new subduction zone gets established before the cost of the Chortis and Chorotega Blocks, which pushed them to the east to its today position.

Nicaragua can be classified into four physiographic units. The Central Highland is the largest unit and ranges from the northern border with Honduras southeastward to the Caribbean Sea. The basement is mainly formed by volcanic rocks and Ignimbrites from the Eocene to the Pliocene. Beside this, there are areas at the border to Honduras which consist of metamorphic and plutonic rocks from the Cretaceous or older (Hradecký 2011). From the Central Highland eastward runs the second unit, the Caribbean Coastal Plain. It consists of sediments of the Quaternary and the recent Alluvium. This area mostly belongs to the Siune Terrane. The southern part is presented by the Pacific Coastal Plain. This area is manly formed by sedimentary rocks from the Eocene to the Miocene and belongs to the younger Chorotega Block. The fourth unit is the Nicaraguan Depression, which runs from the border to Costa Rica to the northern Pacific Coast of Nicaragua and contains the two lakes and a chain of active and inactive volcanoes. So it consists of recent and quaternary volcanic rocks, pyroclastic and alluvial deposits.

Until now, the subduction zone of the Cocos Plate along the westcoast is active, resulting in active volcanism. Along the Nicaraguan Depression a continuous chain of volcanoes from the Golf of Fonseca to the Lake Nicaragua is found, including the Cerro Negro, which erupted six times between 1850 and 1971, or the Concepción, which spit lava in 1957. These volcanoes belong to the Central American Volcanic Arc extending from Mexico to Costa Rica. Here, earthquakes are generated in high depths through the subduction of the Cocos Plate and in depth less than 50km due to the volcanism and the faulting of the crust (Funk et al. 2009). One of these earthquakes destroyed ¾ of Managua in 1972 and caused 11.000 deaths and costs of around 500 Mio Dollar.

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Physical-Chemical and Biological Characterization of Soils and Sediments of Interest

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The second year of the Biorem project was focused on the investigation of the main sites, i. e., the spoil heap La Estrella and the uncontaminated reference site El Sardinillo in Santo Domingo, in order to characterize the physical-chemical and biological parameters of the soils and sediments of interest, to quantify the nature and extent of the contamination by metals and metalloids, and to determine the characteristics of the environmental setting around the sites of interest. Two soil/sediment samples were collected together with plant specimens at both sites and analyzed for 28 total extractable (aqua regia) and leachable (distilled water and $CaCl_2$ 0.01 M) metals and metalloids by ICP-OES.

Total extractable metals in soil were divided in three groups: (1) The major elements were found in the same concentrations at La Estrela and the reference site. (2) The minor elements Pb, Zn, Cu and V were found in higher concentrations than at the reference site. (3) The trace elements Ti, Ni, Sb, Ag and Au were found in higher concentrations compared with the reference site.b The water leachable metals were also divided in three groups: (1) The major elements Si, Na, Ca, K, Mn, Mg and Fe were found in the same concentrations at both sites. (2) The minor elements Ba and B were found in the same concentrations in both habitats but Pb and Cu showed higher concentrations at La Estrella. (3) The same levels of the trace elements Ti, As and Sb were found at both sites but concentrations of Se and Ag were increased at La Estrela, the same was true for Hg.

Nine additional soil/sediment samples were collected from various sites of interest including heaps, water-driven stone mills and reference sites in the two mining towns Santo Domingo and La Libertad-Chontales in order to estimate the autochthonous bioremediation potential of the soil/sediments. This was achieved by the isolation, identification, purification and quantification of fungal communities. *Fusarium* and *Aspergillus* (Trichocomaceae) proved to be the dominant genera.

Representative herbaceous plants were also identified at both sites. At El Sardinillo, *Solanum* sp. (Solanaceae) and *Hyptis obtusifolia* (Lamiaceae) dominated, whereas various Poaceae, *Thelypteris* sp. (Thelypteraceae) and *Cyperus* sp. (Cyperaceae) were found on the spoil heap La Estrela.

Furthermore, five whole plants that were always present at the sites of interest were analyzed for total extractable metals and metalloids by ICP-OES. Again, the total extractable metals were divided in three groups: (1) The major elements K Ca, Mg and Fe found in comparable concentrations in all plants, only *Cyperus* sp. exhibited increased levels of Fe and Al. (2) The minor and trace elements Ba, Zn and Ag were found in the same concentrations in all five plants. Cu and Ag were increased in *Cyperus* and in *Solanum*.

Higland plants under extreme conditions and their phytoremediation potential

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Climate change is causing an accelerated glacier retreat in the Andes Mountains of Perú. Furthermore, 95% of the global wastewater is released to the environment without any treatment and nearly 2.4 billion people lack adequate sanitation, and 1.1 billion people lack access to safe water. The government's responsibility is to ensure the quantity and quality of water for the population in a timely manner. In Perú, there are 730 mining liabilities, 20 of them are the national priority, of which five are in Ancash. In the Santa River basin, we found three major problems: progressive decrease in the amount of water (quantity), decreased water quality (chemical, physical and biological) and water availability is restricted to the rainy season. Water quality is losing by the presence of heavy metals from acid mine drainage (AMD) and acid rock drainage (ARD). However in these scenarios are emerging biological communities (plants and microorganisms) with potential use as bioindicators or in bioremediation. Previous evaluations have allowed us to identify 52 species with phytoremediation potential, as they are adapted to live in acidic waters with heavy metals: Poaceae: 30; Cyperaceae: 8; Juncaceae: 9; Plantaginaceae: 1; Brassicaceae: 1; Haloragaceae: 1; Scrophulariaceae: 2. In more detail, we evaluated four disturbed environments: Huancapetí (AMD), Mesapata (AMD; shown at the photograph by S. Sassmann), Quilcayhuanca (ARD) and Quebrada Honda (AMD-ARD). The most predominant species are *Calamagrostis ligulata*,

Distichia muscoides, *Juncus imbricatus*, *Juncus bufonius* and *Cyperus niger*. To assess the level of accumulation of heavy metals, plant samples were taken from the highlands above 3.500 m, during periods of drought and rain; they were digested with HNO_3 and H_2O_2 at 40 °C (AOAC Official Method 975.03 metals in plants); metal content was determined by ICP mass spectrometry (ICP- 200.7 - rev4.4 - EPA 1994), and field parameters (pH, conductivity) were determined with the multiparameter, model 34OI. *Calamagrostis ligulata* in Huancapetí wetland accumulates heavy metals such as Al (470 mg · kg^{-1}), As (434 mg · kg^{-1}), Fe (2.375 mg · kg^{-1}), Mn (2.311 mg · kg^{-1}), Zn (3.209 mg · kg^{-1}) and Si (459 mg · kg^{-1}). *Juncus imbricatus* in Mesapata wetland accumulates heavy metals such as Al (450 mg · kg^{-1}), As (545 mg · kg^{-1}), Fe (4.790 mg · kg^{-1}), Pb (211 mg · kg^{-1}), Mn (1.550 mg · kg^{-1}) and Zn (2.197 mg · kg^{-1}). *Cyperus sp.* in Quilcayhuanca wetland accumulates heavy metals such as Al (315 mg · kg^{-1}), As (8 mg · kg^{-1}), Fe (1.260 mg · kg^{-1}), Mn (200 mg · kg^{-1}), Zn (50 mg · kg^{-1}) and Si (870 mg · kg^{-1}). *Calamagrostis ligulata* in Quebrada Honda wetland accumulates heavy metal such as Al (1.975 mg · kg^{-1}), As (1.150 mg · kg^{-1}), Fe (25.750 mg · kg^{-1}), Mn (7.245 mg · kg^{-1}), Zn (1.172 mg · kg^{-1}) and Si (647 mg · kg^{-1}).

Sustainable alternative for management and bioremediation of the Santa River

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On its journey of 347 km from Conococha at 4,050 m, until zero meters in the Pacific Ocean, the Santa River incorporates various natural and anthropogenic contaminants that reduce the water quality, resulting in significant risks for both the environment and humans. The main pollutants of the waters of this river include:

- Domestic wastewaters that are discharged without any treatment as direct effluents from various cities of the Callejon de Huaylas.
- Suspended solid particles mainly due to erosion of the tributaries like the Tablachaca river (Pallasca province).
- The presence of heavy metals and metalloids as products of mining activities and glacial retreat.
- Serious organic pollution is confirmed by the presence of thermotolerant coliform bacteria that exceed 10^6 MPN · 100 ml^{-1} at Conococha and reach more than 10^9 MPN · 100 ml^{-1} in the Santa Valley.

Sediment pollution peaks at the bridges of Tablachaca and Mantas where the turbidity reaches 1,800 FNU and the total suspended solids reach 2,400 mg · l^{-1}. The heavy metal contamination starts from glaciers where reactive sulfide rocks react with oxygen and water and produce dissolved heavy metals by oxidation. The metal release from glacier forelands is supplemented by mining effluents and other sources that release contaminated water frequently without treatment.

We pay special attention to the behavior of heavy metals in the snowy Pastoruri where global warming and glacial retreat lead to weathering of rocks that react with oxygen and water, therefore producing sulfuric acid, which dissolves heavy metals contaminating the water and the environment. In spite of the extreme conditions at 5,000 meters, at a pH of 2.8, low oxygen tension and extreme UV radiation, we saw the emergence of a whole microbial and plant community that has adapeted to these extreme conditions (extremophiles). We have shown the presence of sulfate-reducing bacteria in the sediment that reduce the newly formed sulfates under anaerobic conditions, thus re-precipitating the dissolved metals. Together with other bacteria oxidizing and precipitating iron, manganese and aluminum under microaerophilic or aerobic conditions, recovery of the water can be observed. Preliminary tests show the decline of heavy metals such as Al, Zn, Fe, Mn, accompanied by a rise in pH from 2.8 to about 5.0, after passing through natural wetlands where microbial communities work in partnership with plants. 5.5 km from the headwater springs and streams, where high concentrations of Fe, Al, Mn, Zn are observed, the concentrations of these metals fall next to the detection limits due to the biological activity, thus restoring water quality. Thus, we can highlight the important role of these extremophiles with their potential to restore water quality by bioremediation. Our results also manifest the importance of high Andean wetlands not only as excellent water reserves but also recovery systems for water quality.

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